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Effects of Low-Spatial Frequency Components of Fearful Faces on Fusiform Cortex Activity

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Summary

Emotive faces elicit neural responses even when they are not consciously perceived [1, 2]. We used faces hybridized from spatial frequency-filtered individual stimuli [3] to study processing of facial emotion. Employing event-related functional magnetic resonance imaging (fMRI), we show enhanced fusiform cortex responses to hybrid faces containing fearful expressions when such emotional cues are present in the low-spatial frequency (LSF) range. Critically, this effect is independent of whether subjects use LSF or high-spatial frequency (HSF) information to make gender judgments on the hybridized faces. The magnitude of this fusiform enhancement predicts behavioral slowing in response times when participants report HSF information of the hybrid stimulus in the presence of fear in the unreported LSF components. Thus, emotional modulation of a face-responsive region of fusiform is driven by the low-frequency components of the stimulus, an effect independent of subjects' reported perception but evident in an incidental measure of behavioral performance.

Results and Discussion

We presented hybrid face stimuli [3, 4] (Figure 1A) to 13 healthy subjects who underwent functional magnetic resonance imaging (fMRI). Hybrids contained two individuals of opposite gender in high-spatial frequency (HSF) and low-spatial frequency (HSF) components. The parameters used for visual presentation allowed flexible use of HSF and LSF while subjects classified faces by gender. This experimental design (Figure 1B) enabled us to characterize brain responses to emotional components of the stimuli carried by LSF or HSF and the degree to which these responses were modulated by reporting information from one or the other spatial scale. Trials in which gender judgments are based on one spatial frequency (SF) band represent a relative neglect of the converse SF band for perceptual decision, although information from both SF ranges is always present. The validity of this approach is evident in the observation that all subjects denied seeing two faces within the stimuli, a fact consistent with previous observations that few subjects perceive the hybrid nature of these stimuli [3].

Work using SF-filtered stimuli indicates that fusiform cortex is generally more activated by HSF components of faces, although both amygdala and fusiform cortex show enhanced responses to fearful expressions driven by LSF [5]. We expected that this enhancement of amygdala and fusiform to LSF fear would be replicated in the current paradigm even when subjects reported HSF components and neglected LSF components in hybrid faces; this expectation is consistent with the hypothesis that emotive cues are often processed involuntarily within these regions [6], independent of attention [7] or awareness [1, 2] (although not always, see reference [8]). This is also consistent with the proposal that LSF information is processed rapidly and automatically to inform early object identification through top-down visual modulation [9, 10]. We also anticipated that implicit fear recognition, based on LSF, would be evident in behavioral performance.

Behavior

During scanning, subjects' reports were biased toward LSF (range: 50.2%–70%; mean: 60.5%). This confirms a flexible choice of SF cues, but it differs from previous results outside the scanner that suggested equal roles of LSF and HSF during gender judgments [3]. This may be explained by the different stimuli used (fearful faces from a different database) or other specific features of our fMRI protocol (e.g., presentation time, exact visual angle of the stimuli).

Reaction times (RTs) were analyzed by repeated measures ANOVA with SPSS (SPSS). There was a main effect of subjects' report, as gender judgments that were based on HSF were associated with slower RTs (LSF reported: 839 $\pm$ 48 ms; HSF reported: 931 $\pm$ 54 ms [means $\pm$ SEM]; $F(1,12) = 12.1$; $p < 0.01$). This appears consistent with the hypotheses that LSF information is processed faster and can lead to faster classification [9, 11, 12]. We explored the interaction between reported SF and LSF fear by testing for an RT change when reporting gender of the HSF faces in the presence of fear in LSF (see below). A nonsignificant trend to slower responses was evident ($F(1,12) = 2.1$; $p = 0.18$). No other main effect or interaction approached significance (all $p > 0.25$), indicating no slowing in response to fear in HSF.

Main Effect of LSF Fear

A main effect of fear in LSF compared to LSF neutral was found in right fusiform cortex (Figure 2). This effect was independent of the reported SF channel, as confirmed by a conjunction analysis across the simple effects of LSF fear (relative to neutral) when the LSF channel was reported and when the HSF channel was reported. This indicates that fear in LSF components

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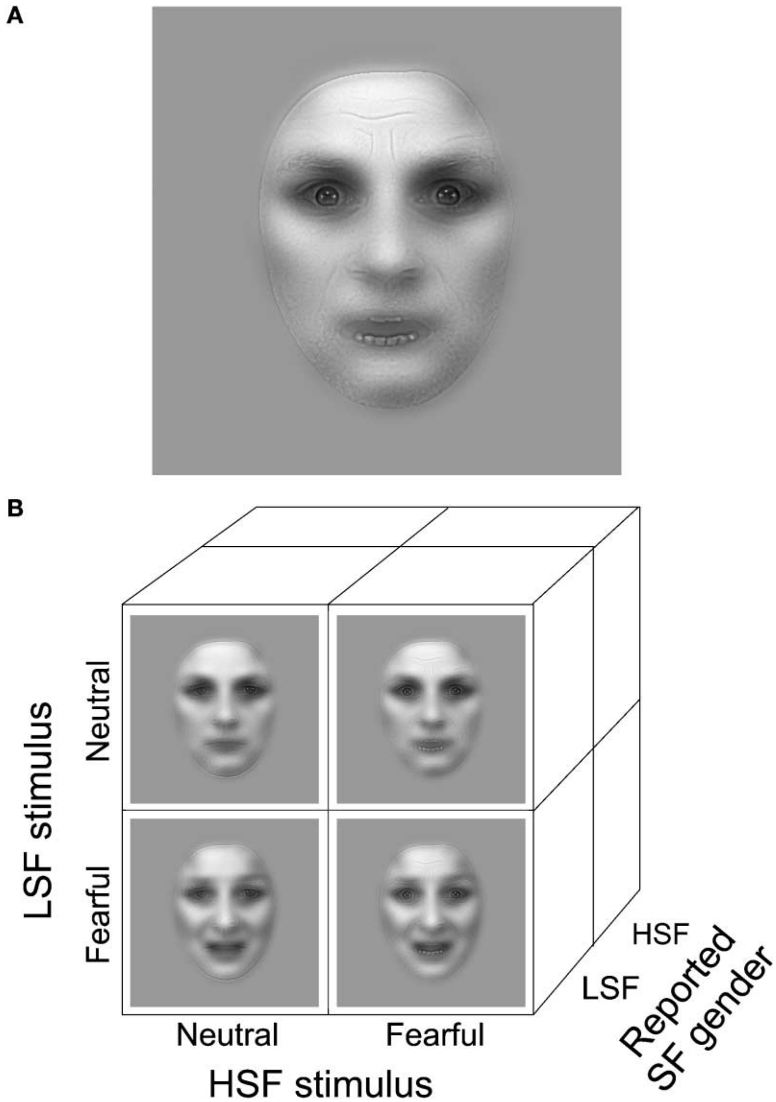

Figure 1. Example Stimuli and Experimental Design

(A) Six males and six females were selected from the KDEF database of faces (D. Lundqvist and J.-E. Litton, personal communication; photographic face set available from the Department of Neurosciences, Karolinska Hospital, Stockholm, Sweden). The example stimulus shows a neutral female at low spatial frequencies and a fearful male at high spatial frequencies. Perception is typically dominated by HSF cues when looking at such stimuli nontachistoscopically. To see the LSF, squint or increase the viewing distance. (B) Experimental design: all hybrids contained a male and a female face; subjects could report either the low or high SF by judging the gender of the face perceived during rapid presentations. At each SF, the face could be either fearful or neutral, resulting in a $2 \times 2 \times 2$ factorial design. A total of 288 stimuli were used (each of 12 stimuli crossed with 6 of the opposite gender, with 4 possible pairings of expressions: neutral/neutral, fearful/neutral, neutral/fearful, fearful/fearful).

caused greater activation in right fusiform cortex regardless of which SF channel subjects' report.

While behaviorally the overall reaction time interaction between LSF emotion and reported SF (Figure 3A) was nonsignificant (see above), a significant correlation was evident between the RT measure of this interaction for each subject and the magnitude of activation to LSF fear in right fusiform (Figure 3B) ($p < 0.05$). In other words, the degree to which a subject showed enhanced fusiform activity to LSF fear relative to LSF neutral predicted an RT cost during reporting of the HSF face in the presence of a neglected fearful face in LSF. This behavioral slowing might represent a distractor effect in which salient information in the stimulus array (the LSF fear component) tends to compete for attention and slows processing when attention is directed to a different component of the stimulus.

We additionally lookeded for responses in specific regions at reduced thresholds, based upon a priori hypotheses. Based on the proposal that a colliculopulvinar pathway transmits coarse visual information to the amygdala even under conditions in which conscious vision is suppressed [13–17] and upon previous findings [5], we predicted activation in amygdala, superior colliculus, and pulvinar to LSF fear in faces. Bilateral foci in amygdala/periamygdaloid cortex showed weak activation for the main effect of LSF fear (x, y, z = −18, −6, −33, Z = 1.78; x, y, z = 33, −6, −24, Z = 1.81), although not at the same coordinates as previous work (for comparison: x, y, z = −20, −10, −28 and x, y, z = 20, −10, −30 [5]). The former of our foci appears to be centered on perirhinal cortex but extends laterally and dorsally into ventral amygdala. The latter is in lateral right amygdala. In addition, lateral posteroinferior thalamus also exhibited a weak activation in the peak voxel found in our previous work (x, y, z = 9, −21, −9; Z = 1.67) [5]. As in the previous study, this activation extended broadly throughout posterior and lateral thalamus and into superior colliculus (x, y, z = 0, −30, −3; Z = 2.09).

The demonstration of fusiform responses to LSF fear extends previous findings concerning fusiform cortex sensitivity to facial emotion. It has repeatedly been shown that fusiform activation is greater in response to emotional compared to neutral faces [7, 18, 19]. Recent

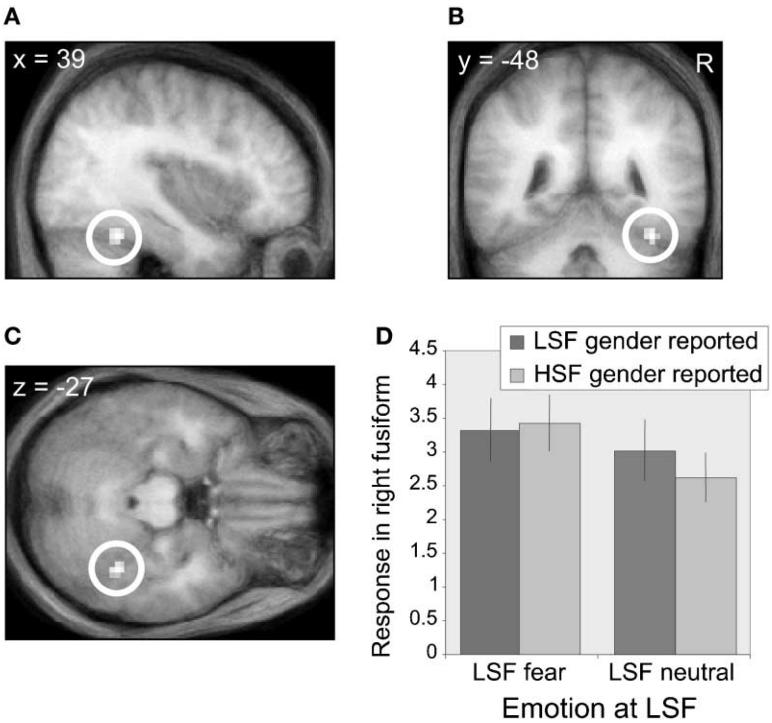

Figure 2. Fusiform Response to Fear in Low Spatial Frequencies

(A–C) Sagittal, coronal, and horizontal sections of SPMs showing response in right fusiform cortex in the contrast of main effect of LSF fear (LSF fear–LSF neutral). Peak at x, y, z = 39, −48, −27; Z = 4.33; $p < 0.05$ SVC. Activation displayed at $p < 0.001$ uncorrected on the mean structural image from the group of subjects.

(D) Parameter estimates from peak fusiform voxel showing response to LSF fear is greater than to LSF neutral independent of subjects' report (i.e., whether they report perceiving LSF or HSF stimulus).

findings indicate that despite greater responses in fusiform cortex to HSF components of faces (regardless of expression), fearful LSF faces activate this region more than neutral LSF faces. Conversely, fearful expressions in HSF do not activate fusiform more than neutral [5]. Our new data indicate that fusiform activity is modulated by fearful LSF components even when the LSF channel is not reported and subjects instead report gender traits from a concurrent HSF face.

Suggestions that fusiform modulation by emotionality is subserved by feedback from amygdala [6, 20, 21] imply that a fear-detecting process engaging the amygdala may modulate fusiform responses to a current stimulus. It has also been suggested that both amygdala and thalamic (pulvinar) responses are selectively tuned to extract LSF cues in faces [5]. Our findings indicate that emotionality in the LSF channel might influence concurrent perceptual processing within an HSF channel known to drive fusiform activity [5], even when subjects report facial information present in the HSF. Indeed, we found a corresponding behavioral effect in individual RT measures that indicated that the RT interaction between LSF emotion and reported SF was significantly correlated with the strength of differential activation (LSF fear > LSF neutral) in right fusiform. This suggests a coupling between the modulation of fusiform by emotion and the efficiency of perceptual processing of an HSF stimulus.

Although we confirmed the role of LSF fear in activating the amygdala [5], the strength of this effect was weak. One possible reason is that hybrid stimuli were all unusual relative to conventional and nonhybrid filtered faces, such that the amygdala activates even in our "neutral" condition, an explanation consistent with the view that the amygdala is involved in monitoring ambiguous stimuli [22, 23]. In support of this, the peak from the left periamygdaloid focus showed mean activity above baseline in all eight face conditions (i.e., including trials with neutral faces at both SF bands). Additionally, the amygdala is known to rapidly habituate [19, 24–26], and the current experiment was relatively long (18 min). Indeed, linear habituation effects with time in amygdala were evident (x, y, z = −21, 0, −33, Z = 2.37; x, y, z = −27, −6, −24, Z = 2.05). Although not at the same peaks as the main effects of LSF fear, these effects overlapped the activation in our previous study [5] and the left ventral amygdala activation evident for the time-independent effect.

Main Effect of HSF Fear

We also tested for a main effect of HSF fear, but we found no evidence for any effect of HSF fear in voxels activated by LSF fear (fusiform peak, Z = 1.00; posterolateral thalamus, Z = −0.94; left amygdala, Z = −1.25; right amygdala, Z = 0.09; all $p > 0.15$). This replicates a lack of significant responses to fearful expression conveyed by HSF cues in faces in these regions [5]. However, significant responses to HSF fear occurred in posterior cingulate (x, y, z = 15, −36, 39; Z = 4.02), motor cortex (x, y, z = 42, 0, 36; Z = 3.75), medial prefrontal cortex (x, y, z = 9, 63, 30; Z = 3.63), and lateral orbitofrontal cortex (x, y, z = 45, 35, −21; Z = 3.53).

Interaction of LSF Emotion and Reported SF

Finally, we looked for differential effects of LSF fear when the gender of the LSF face was reported as compared to reporting the HSF face gender. An interaction between LSF emotion and reported SF was observed in right orbitofrontal cortex (OFC) (Figure 4A). This interaction reflected greater activation to fearful expressions

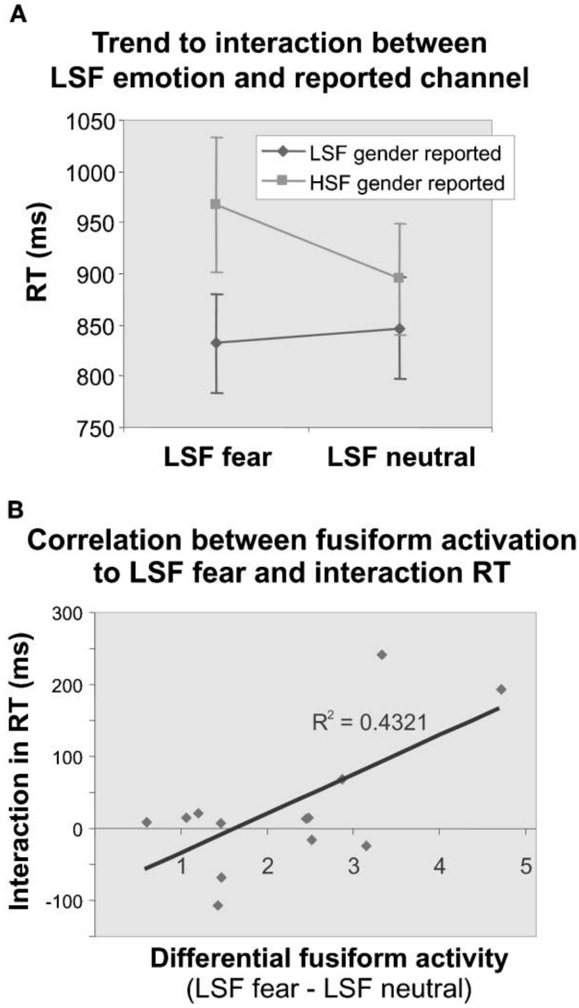

Figure 3. Behavioral Effect of Fear in LSF

(A) Relation between fear in LSF and subjects' report suggesting a trend to slower RTs when fear is present in LSF and the subject reports an HSF stimulus.

(B) Significant correlation between fusiform activity to main effect of LSF fear and behavioral interaction between report and LSF fear in reaction times ($p < 0.05$). This indicates that greater fusiform activity to LSF fear stimuli relates to a behavioral slowing when responding to the HSF components of the stimulus.

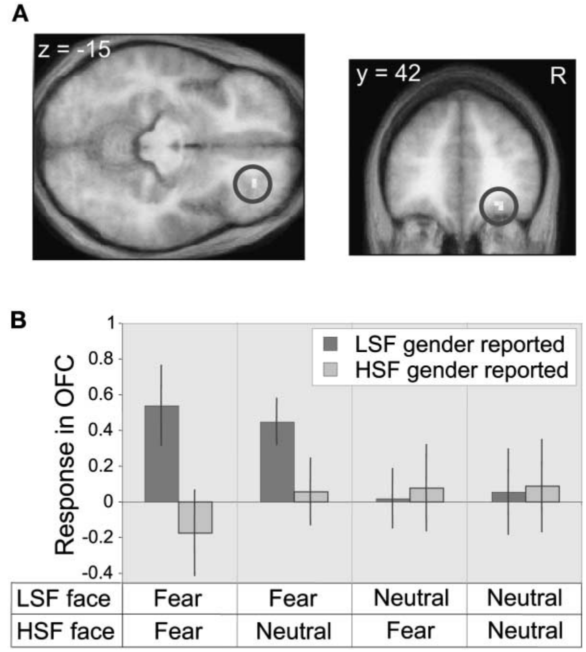

Figure 4. Orbitofrontal Cortex Shows an Interaction between Report and LSF Fear

(A) SPM showing response in right orbitofrontal cortex in the interaction between LSF fear and behavioral report. Peak at x, y, z = 24, 42, −15; Z = 3.41; $p < 0.001$ uncorrected. The display is shown as in Figure 2A.

(B) Parameter estimates from peak voxel in orbitofrontal cortex showing response to LSF fear is greater than to LSF neutral only when subjects report LSF components of the stimulus. (Simple effect of LSF fear when LSF reported, Z = 3.43; simple effect of LSF fear when HSF fear reported, Z = −0.82).

in LSF only when subjects report the gender of the face in this channel (Figure 4B; simple effect of LSF fear when LSF reported, Z = 3.43; simple effect of LSF fear when HSF fear reported, Z = −0.82. This effect was independent of the expression in the concurrent HSF face. Thus, in contrast to fusiform, where effects of LSF fear were independent of subjects' report, right OFC exhibited an interaction between LSF fear and explicit report. This finding accords with the view that sectors of ventral prefrontal cortex are involved in conscious, deliberative, emotional processing [27]. We speculate that processing of LSF fear stimuli may cause a downstream effect in OFC only if the LSF stimulus is perceived. This interpretation converges with fMRI findings from a patient with parietal neglect [28], in which a similar peak in right OFC showed an enhanced response to consciously perceived, as opposed to neglected, fearful faces. Additionally, human electrophysiological studies have identified an early (~120 ms) frontal ERP component that distinguishes fearful from neutral faces [29] but is abolished when spatial attention is diverted from the fearful face [30]. This parallels our finding of orbitofrontal responses to LSF fear stimuli only when the LSF is the reported frequency band. Further, these data extend previous studies showing differential emotional responses during explicit/attentive versus implicit/incidental processing of facial emotion, where such differences arose during different tasks [8, 18, 31–33]. Here, only subjective report of the stimulus varied, while both task and stimulus remained the same.

In conclusion, using hybrid stimuli, we demonstrate that emotional facial information contained within LSF influences fusiform responses independently of whether the gender corresponding to those spatial frequencies is reported or not. The magnitude of this modulation predicts behavioral slowing when reporting the gender of a concurrent HSF face in the hybrid, as a function of the (independently manipulated and task irrelevant) emotion present in LSF. These results reveal distinct processing of information involuntarily extracted from a stimulus that signals fear compared to that extracted from the same stimulus for an explicit perceptual decision. In contrast to such effects in fusiform, and concordant with neurophysiological data of attention-dependent frontal responses to fearful faces [28, 30], OFC responds to LSF fear cues in faces only when LSF is reported. These data confirm that emotional responses may occur partly independent of explicit visual processing of HSF within temporal cortical regions that are critical in face perception, whereas frontal responses may specifically reflect the conscious emotional percept.

Experimental Procedures

Stimuli

Hybrid stimuli were generated according to the method outlined in [12]. Briefly, a face of one gender was low-pass filtered at 6 cycles per face (cpf; approximately 1.5 cycles per degree [cpd] in the scanner) and combined with a high-pass-filtered (24 cpf/6 cpd) face of the opposite gender. These cutoffs are similar to those of previous studies [3, 5]. Faces at each SF could be either fearful or neutral, but they were always of opposite gender (Figure 1).

Subjects

Fourteen subjects (eight females) took part in the study, which was approved by the local ethics committee. Data from one female subject were excluded due to excessive head movement. No subject reported perceiving hybrid stimuli in debriefing. All 13 included subjects (age range: 22–44; mean: 30 years) were right-handed, healthy, and had normal or corrected-to-normal vision.

Experimental Task

Subjects made gender discriminations on hybrid faces presented for 90 ms. This duration was chosen after pilot experiments with our stimuli, and visual presentation apparatus suggested that such a presentation time ensured an equal likelihood of reporting HSF versus LSF stimuli within cross-gender face hybrids, as reported by reference [3]. Stimulus onset asynchrony was 3 s. In addition to the 288 stimuli, 62 null events were included; the total session length was approximately 18 min. Following the main experimental session, while still in the scanner, subjects made gender discriminations on the same individual faces presented in either high or low frequencies, filtered with the same parameters as the component frequencies used in hybrid faces. Gender judgments from this session served to interpret the subjects' classification responses from the hybrid sessions (see the Supplemental Data available with this article online).

fMRI Data Collection and Analysis

See the Supplemental Data for details of fMRI scanning and data analysis. Briefly, 435 volumes (TR $= 2.5$ s) weighted for BOLD contrast were acquired in each subject. Following realignment [34], slice-timing correction, normalization and smoothing, data were analyzed in a general linear model [35] with SPM2b (Wellcome Department of Imaging Neuroscience; http://www.fil.ion.ucl.ac.uk/spm) by using a random effects approach. Eight event types of interest (Figure 1B) were modeled for each subject along with four event types for ambiguous trials (see the Supplemental Data) and linear contrasts of parameter estimates corresponding to the main effects and interactions computed. One-sample T tests were then used to calculate the consistency of these experimental effects across participants. A threshold of $p < 0.001$ uncorrected for multiple comparisons with an extent threshold of 100 mm^3 (>4 contiguous voxels) was used to define activations. In regions predicted a priori (fusiform cortex), we report results that survive a correction for multiple comparisons across a small volume of interest [36].

Supplemental Data

Supplemental Data including details of the fMRI approach and data analysis are available at http://www.current-biology.com/cgi/content/full/13/20/1824/DC1/.

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References

1. Morris, J.S., Ohman, A., and Dolan, R.J. (1998). Conscious and unconscious emotional learning in the human amygdala. Nature *393*, 467–470.
2. Whalen, P.J., Rauch, S.L., Etcoff, N.L., McInerney, S.C., Lee, M.B., and Jenike, M.A. (1998). Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. J. Neurosci. *18*, 411–418.
3. Schyns, P.G., and Oliva, A. (1999). Dr. Angry and Mr. Smile: when categorization flexibly modifies the perception of faces in rapid visual presentations. Cognition *69*, 243–265.
4. Morrison, D.J., and Schyns, P.G. (2001). Usage of spatial scales for the categorization of faces, objects, and scenes. Psychon. Bull. Rev. *8*, 454–469.
5. Vuilleumier, P., Armony, J.L., Driver, J., and Dolan, R.J. (2003). Distinct spatial frequency sensitivities for processing faces and emotional expressions. Nat. Neurosci. *6*, 624–631.
6. Dolan, R.J. (2002). Emotion, cognition and behaviour. Science *298*, 1191–1194.
7. Vuilleumier, P., Armony, J.L., Driver, J., and Dolan, R.J. (2001). Effects of attention and emotion on face processing in the human brain: an event-related fMRI study. Neuron *30*, 829–841.
8. Pessoa, L., McKenna, M., Gutierrez, E., and Ungerleider, L.G. (2002). Neural processing of emotional faces requires attention. Proc. Natl. Acad. Sci. USA *99*, 11458–11463.
9. Bar, M. (2003). A cortical mechanism for triggering top-down facilitation in visual object recognition. J. Cogn. Neurosci. *15*, 600–609.
10. Bullier, J. (2001). Integrated model of visual processing. Brain Res. Brain Res. Rev. *36*, 96–107.
11. Goffaux, V., Gauthier, I., and Rossion, B. (2003). Spatial scale contribution to early visual differences between face and object processing. Brain Res. Cogn. Brain Res. *16*, 416–424.
12. Schyns, P.G., and Oliva, A. (1994). From blobs to boundary edges: evidence for time- and spatial-scale-dependent scene recognition. Psychol. Sci. *5*, 195–200.
13. Sahraie, A., Weiskrantz, L., Trevethan, C.T., Cruce, R., and Murray, A.D. (2002). Psychophysical and pupillometric study of spatial channels of visual processing in blindsight. Exp. Brain Res. *143*, 249–256.
14. Dodds, C., Machado, L., Rafal, R., and Ro, T. (2002). A temporal/nasal asymmetry for blindsight in a localisation task: evidence for extrageniculate mediation. Neuroreport *13*, 655–658.
15. Rafal, R., Smith, J., Krantz, J., Cohen, A., and Brennan, C. (1990). Extrageniculate vision in hemianopic humans: saccade inhibition by signals in the blind field. Science *250*, 118–121.
16. Morris, J.S., Ohman, A., and Dolan, R.J. (1999). A subcortical pathway to the right amygdala mediating "unseen" fear. Proc. Natl. Acad. Sci. USA *96*, 1680–1685.
17. Morris, J.S., DeGelder, B., Weiskrantz, L., and Dolan, R.J. (2001). Differential extrageniculostriate and amygdala responses to presentation of emotional faces in a cortically blind field. Brain *124*, 1241–1252.
18. Winston, J.S., O'Doherty, J., and Dolan, R.J. (2003). Common and distinct neural responses during direct and incidental processing of multiple facial emotions. Neuroimage *20*, 84–97.
19. Breiter, H.C., Etcoff, N.L., Whalen, P.J., Kennedy, W.A., Rauch, S.L., Buckner, R.L., Strauss, M.M., Hyman, S.E., and Rosen,

B.R. (1996). Response and habituation of the human amygdala during visual processing of facial expression. Neuron *17*, 875–887.
20. Morris, J.S., Friston, K.J., Buchel, C., Frith, C.D., Young, A.W., Calder, A.J., and Dolan, R.J. (1998). A neuromodulatory role for the human amygdala in processing emotional facial expressions. Brain *121*, 47–57.
21. Rotshtein, P., Malach, R., Hadar, U., Graif, M., and Hendler, T. (2001). Feeling or features: different sensitivity to emotion in high-order visual cortex and amygdala. Neuron *32*, 747–757.
22. Davis, M., and Whalen, P.J. (2001). The amygdala: vigilance and emotion. Mol. Psychiatry *6*, 13–34.
23. Whalen, P.J. (1998). Fear, vigilance, and ambiguity: initial neuroimaging studies of the human amydgala. Curr. Dir. Psychol. Sci. *7*, 177–188.
24. Buchel, C., Morris, J., Dolan, R.J., and Friston, K.J. (1998). Brain systems mediating aversive conditioning: an event-related fMRI study. Neuron *20*, 947–957.
25. Phillips, M.L., Medford, N., Young, A.W., Williams, L., Williams, S.C., Bullmore, E.T., Gray, J.A., and Brammer, M.J. (2001). Time courses of left and right amygdalar responses to fearful facial expressions. Hum. Brain Mapp. *12*, 193–202.
26. Wright, C.I., Fischer, H., Whalen, P.J., McInerney, S.C., Shin, L.M., and Rauch, S.L. (2001). Differential prefrontal cortex and amygdala habituation to repeatedly presented emotional stimuli. Neuroreport *12*, 379–383.
27. Damasio, A.R. (1994). Descartes' Error: Emotion, Reason and the Human Brain (New York: G.P. Putnam's Sons).
28. Vuilleumier, P., Armony, J.L., Clarke, K., Husain, M., Driver, J., and Dolan, R.J. (2002). Neural response to emotional faces with and without awareness: event-related fMRI in a parietal patient with visual extinction and spatial neglect. Neuropsychologia *40*, 2156–2166.
29. Eimer, M., and Holmes, A. (2002). An ERP study on the time course of emotional face processing. Neuroreport *13*, 427–431.
30. Holmes, A., Vuilleumier, P., and Eimer, M. (2003). The processing of emotional facial expression is gated by spatial attention: evidence from event-related brain potentials. Brain Res. Cogn. Brain Res. *16*, 174–184.
31. Critchley, H., Daly, E., Phillips, M., Brammer, M., Bullmore, E., Williams, S., Van Amelsvoort, T., Robertson, D., David, A., and Murphy, D. (2000). Explicit and implicit neural mechanisms for processing of social information from facial expressions: a functional magnetic resonance imaging study. Hum. Brain Mapp. *9*, 93–105.
32. Gorno-Tempini, M.L., Pradelli, S., Serafini, M., Pagnoni, G., Baraldi, P., Porro, C., Nicoletti, R., Umita, C., and Nichelli, P. (2001). Explicit and incidental facial expression processing: an fMRI study. Neuroimage *14*, 465–473.
33. Narumoto, J., Okada, T., Sadato, N., Fukui, K., and Yonekura, Y. (2001). Attention to emotion modulates fMRI activity in human right superior temporal sulcus. Brain Res. Cogn. Brain Res. *12*, 225–231.
34. Friston, K., Ashburner, J., Frith, C.D., Poline, J.-B., Heather, J.D., and Frackowiak, R.S.J. (1995). Spatial registration and normalization of images. Hum. Brain Mapp. *2*, 165–189.
35. Friston, K., Holmes, A.P., Worsley, K., Poline, J.-B., Frith, C., and Frackowiak, R.S.J. (1995). Statistical parametric maps in functional imaging: a general linear approach. Hum. Brain Mapp. *2*, 189–210.
36. Worsley, K., Marrett, S., Neelin, P., Vandal, A.C., Friston, K.J., and Evans, A.C. (1996). A unified statistical approach for determining significant signals in images of cerebral activation. Hum. Brain Mapp. *4*, 58–73.