

Threat as a Feature in Visual Semantic Object Memory

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Abstract: Threatening stimuli have been found to modulate visual processes related to perception and attention. The present functional magnetic resonance imaging (fMRI) study investigated whether threat modulates visual object recognition of man-made and naturally occurring categories of stimuli. Compared with nonthreatening pictures, threatening pictures of real items elicited larger fMRI BOLD signal changes in medial visual cortices extending inferiorly into the temporo-occipital (TO) “what” pathways. This region elicited greater signal changes for threatening items compared to nonthreatening from both the natural-occurring and man-made stimulus supraordinate categories, demonstrating a featural component to these visual processing areas. Two additional loci of signal changes within more lateral inferior TO areas (bilateral BA18 and 19 as well as the right ventral temporal lobe) were detected for a category–feature interaction, with stronger responses to man-made (category) threatening (feature) stimuli than to natural threats. The findings are discussed in terms of visual recognition of processing efficiently or rapidly groups of items that confer an advantage for survival. *Hum Brain Mapp* 00:000–000, 2012. © 2012 Wiley Periodicals, Inc.

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INTRODUCTION

The neural systems representing objects in the human brain appear to be organized to encode objects by the category or categories of which they are members. In the lexical-semantic system, there is evidence from both lesion studies [Damasio and Tranel, 1993] and functional imaging data for spatially distinct regions that are differentially responsive to items that belong to the categories of animals, fruits and vegetables, plants, and tools [Damasio et al., 1996; Martin et al., 1996]. Other studies have explored if the reported categorical organization was actually secondary to other factors such as familiarity of the items in the categories. Alternative approaches to account for a presumed categorical organization have also been advanced, such as the sensory and/or functional characteristics of the items as opposed to their category membership [Chieffi et al., 1989], or the visual perceptual features of the items [Mechelli et al., 2007; Sartori et al., 1993]. Integrated models of lexical-semantic and multimodal organization of object representation suggesting that there is a category–feature interaction [Hart and Kraut, 2007; Hart and Gordon, 1992] have also been proposed.

Similar lines of investigation have been undertaken in the visual object recognition system. The ventral temporal lobes have been found by functional magnetic resonance imaging (fMRI) to include clustered brain regions which are characterized by high category–selectivity for faces [fusiform face area, FFA, Kanwisher et al., 1997], places and scenes [parahippocampal place area, PPA, Epstein and Kanwisher, 1998], and bodies [extrastriate body area, EBA, Downing, et al., 2001 but see Haxby et al., 2001; O’Toole et al., 2005]. Other accounts posit the interaction of accumulated perceptual, featural characteristics of the objects, with categorical designation as part of the visual object recognition process [Mack and Palmeri, 2011]. Two major classes of visual object recognition models—canonical [Riesenhuber and Poggio, 2000; Serre et al., 2007] and exemplar-based models [e.g., Kruschke, 1992; Nosofsky, 1986; Nosofsky and Kruschke, 1992]—both assume initial stages of visual perceptual feature processing proceed from a basic perceptual through to more complex featural levels, with eventual integration with categorical membership. As basic perceptual features are essential components in object recognition, these models also implicitly assume that information about more complex features is engaged in the visual object recognition process.

Studies in the auditory system have identified other features of an object that play an integral role in object recognition. Functional MRI studies in the nonverbal sound domain have found spatially distinct regions in the right superior temporal gyrus that respond selectively to animal sounds, with another region that responds to what subjects perceive as threatening items [Kraut et al., 2006]. Threat as a feature has been proposed as a semantic, meaningful abstraction of perceptual characteristics (barking and lips curled exposing teeth) with previous or primitive knowl-

edge that these abstractions are associated with harm. Motivated by the finding that threat plays an essential role in the auditory object recognition system, we questioned whether an emotionally laden feature such as threat interacts with visually responsive cortical regions that are engaged during visual object recognition. Such stimuli elicit increased cortical activity in tasks focusing on visual perceptual systems [see reviews by Phelps and LeDoux, 2005; Phelps, 2006] and attention [Bradley et al., 2003]. To address how processing of similar stimuli affects cortical regions that are active during object recognition, we used an fMRI-based paradigm of deciding if a stimulus was a real object/item as contrasted to a not real one as an assessment of visual object recognition. The stimuli consisted of pictures of threatening and nonthreatening objects chosen from a variety of categories (animals, fruit and vegetables, weapons, etc.) and visually scrambled versions of the same stimuli. Although the subjects were not explicitly instructed to evaluate either the threat valence or the category membership of the stimuli, we hypothesized that threatening stimuli would result in distinct activation patterns in visual cortices, which would vary across individual categories.

METHODS

Subjects

We tested 18 right-handed participants (8 men) between the ages of 20 and 40 years (mean = 26.5 years) who had no neurological or psychiatric impairments. All the subjects had either normal or corrected-to-normal vision.

Stimuli

We used 90 colored pictures chosen from the International Affective Picture Set (IAPS) set of normed pictures as well as 22 additional pictures selected for the categories of combat scenes ($N = 16$) and weapons ($N = 6$). Each picture was then modified to create a corresponding meaningless visual stimulus (visually scrambled versions) by randomizing the phase information and recombining it with the original picture’s magnitude information [Haxby et al., 2002].

The real pictures comprised eight groups of items from six different categories, as follows:

- 1a. Animals – threatening ($N = 16$)
- 1b. Animals – nonthreatening ($N = 16$)
- 2a. Nature scenes – threatening ($N = 8$)
- 2b. Nature scenes – nonthreatening ($N = 8$)
- 3a. Combat – threatening ($N = 16$)
- 3b. Pleasant situations – nonthreatening ($N = 16$)
4. Weapons – threatening ($N = 16$)
5. Food – nonthreatening ($N = 16$).

The threatening stimuli were derived from two groupings on the pleasantness scale (IAPS scales), one clustered

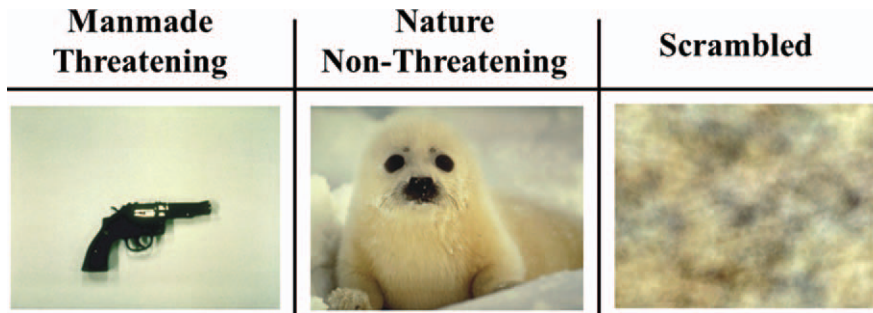


Figure 1.

Sample visual stimuli for threatening, nonthreatening, “real” items’, and a corresponding visual “scrambled” item.

at the pleasant end and the other at the unpleasant end of the scale. From the two groups, the researchers (T.F. and J.H.) evaluated the threat content of pictures in the IAPS picture set, using the IAPS ratings of unpleasantness as a guide and selected threatening and nonthreatening stimuli based on consensus. Additional pictures depicting weapons and combat scenes were added to the set based on consensus.

The resultant threatening stimulus groups consisted of animals, nature, weapons, and combat, whereas the nonthreatening stimulus groups consisted of animals and nature from the same categories of items as the threatening stimuli. As a contrast to the combat situations, we used pictures of scenes of pleasant situations. The combat scenarios consist predominantly of weapons/equipment in combat theaters. These groups were examples of the

higher level categories of natural items (e.g., animals, nature) and man-made ones (e.g., weapons, combat). The group of food was chosen as a nonthreatening comparison to the threatening category of weapons, as both classes of items are manipulable objects but differ in threat valence. (See Fig. 1 for examples of stimuli.)

To further confirm that the stimuli were subjectively perceived as threatening or nonthreatening to the study participants, we asked them, after the fMRI task, to rate each picture for pleasantness, arousal, and threat on a Likert scale (range of 1–5). The average pleasantness rating for threatening stimuli was 1.8 (sd = 0.78) and 4.1 for nonthreatening (sd = 0.4), and the average threat rating was 3.6 for threatening stimuli (sd = 1.11) and 1.1 for nonthreatening (sd = 0.18) (see Table I). Comparison of threatening to nonthreatening

TABLE I. Stimuli ratings for threatening, arousal, and pleasantness

Stimuli	Threatening ratings	Arousal ratings	Pleasantness ratings
Threatening animals	3.49 (1.07)	3.38 (0.42)	2.25 (1.12)
Nonthreatening animals	1.21 (0.28)	3.04 (0.39)	4.07 (0.51)
ANOVA comparing threatening to nonthreatening animals	$F(1,30) = 68.56, P < 0.0001$	$F(1,30) = 5.685, P = 0.02$	
Threatening nature scenes	3.21 (0.85)	2.98 (0.22)	2.12 (0.89)
Nonthreatening nature scenes	1.17 (0.15)	3.02 (0.30)	4.15 (0.42)
ANOVA comparing threatening to nonthreatening nature scenes	$F(1,14) = 44.84, P < 0.0001$	$F(1,14) = 0.086, P = 0.7738$	
Weapons	3.92 (0.65)	3.31 (0.51)	1.51 (0.30)
Food	1.03 (0.04)	3.13 (0.28)	3.82 (0.24)
ANOVA comparing weapons to food	$F(1,30) = 321.40, P < 0.0001$	$F(1,30) = 1.593, P = 0.2166$	
War situations	3.47 (0.4)	3.12 (0.16)	1.62 (0.38)
People in pleasant situations	1.04 (0.05)	3.20 (0.48)	4.30 (0.27)
ANOVA comparing war to people in pleasant situations	$F(1,32) = 570.928, P < 0.0001$	$F(1,32) = 0.597, P = 0.4454$	
Threatening natural items	3.40 (0.99)	3.25 (0.41)	2.20 (1.04)
Threatening artifactual items	3.68 (0.58)	3.20 (0.38)	1.57 (0.35)
ANOVA comparing threatening natural to threatening artifactual items	$F(1,56) = 1.894, P = 0.1743$	$F(1,56) = 0.032, P = 0.6794$	
Threatening items	3.58 (1.11)	3.23 (0.39)	1.84 (0.78)
Nonthreatening items	1.11 (0.18)	3.11 (0.38)	4.07 (0.40)

Averaged ratings and standard deviations (sd) from subjects of unscrambled stimuli grouped by category. Ratings assessed on a Likert scale of 1–5 for threat, arousal, and pleasantness. These ratings were subjected to a series of one-way between-subjects analyses of variance as noted.

stimuli (animals, nature scenes, war vs. pleasant situations, weapons vs. fruit and vegetables) showed no significant differences between arousal ratings (except animals) and all showed significant differences between threat ratings [analysis of variance (ANOVA), P 's < 0.0001]. Threatening items from the superordinate category of natural items were not significantly different in threat and arousal ratings compared with threatening man-made items (weapons, combat situations).

Further assessment of the ratings with principal components analysis (PCA) of the covariance matrix (varimax rotation; all eigenvalues >1.0) revealed an arousal dimension (i.e., for all arousal ratings normalized loadings [r] > 0.77) and a threatening dimension ($r_{\text{war}} = 0.98$, $r_{\text{weapons}} = 0.98$, $r_{\text{threatening_animals}} = 0.60$, and $r_{\text{threatening_weather}} = 0.59$ for the threatening ratings). Thus, PCA of the ratings supported the a priori classification of the stimuli as threatening and provides evidence against arousal being a confounding feature of threat for these images.

We performed a discriminant correspondence analysis (DCA) on the pictures of the real items to verify that the imaging results were not attributable to the visual perceptual characteristics of the stimuli (e.g., arousing colors or shapes, sharp contrasts, etc.) [DCA, see Abdi, 2007a]. We used DCA to classify each stimulus image as a member of one of eight a priori-defined categories (i.e., 1–5 as described above). Previous studies have shown that the low-level visual similarity structure of the stimuli could predict the spatial pattern of fMRI signal changes when subjects performed stimulus categorization tasks [Abdi, 2007b; O'Toole et al., 2005]. The generalization performance of the DCA classifier was only marginally better than chance (with eight categories, chance being 12.5%, and the classifier being 16.8%). This analysis shows that the semantic features corresponding to our experimental categories were not identifiable via low-level visual characteristics (e.g., red color of blood, sharp white pointed teeth, etc.) of the stimulus pictures themselves. This analysis also demonstrates that visual patterns based on perceptually arousing or salient contrasts are not inherent in the stimuli and are unlikely to account for the differences in BOLD response.

Behavioral Procedures

The 224 pictures of real and nonreal “scrambled” items were pseudorandomized and presented individually using a Neuroscan system (Compumedics). The images were displayed from an LCD projector onto a translucent screen placed near the subjects' feet and viewed using a mirror system mounted on the head coil. Using an event related design, each stimulus was presented for 2,700 ms with an average interstimulus interval of 5,800 ms that was pseudorandomized and jittered (3,100–8,200 ms).

Subjects were instructed to use a button box placed in their right hand to indicate whether they perceived an item to be real (an item they recognized) or nonreal (not a

picture of an item they recognized). An index finger button push indicated a perceived real item, whereas a middle finger button push indicated a perceived nonreal item.

fMRI Procedures

Functional MRI data were acquired on a 3.0 T Siemens Trio TIM MRI scanner, using a 12-channel head coil. The data were acquired in the axial plane, using an EPI sequence with a TR of 2 s, a TE of 25 ms, and a flip angle of 90°. Slice thickness was 3.2 mm, with no gap, and slices collected in an interleaved fashion. Field of view was 24 cm, with a 64 × 64 acquisition matrix. There were four series of stimulus administration, with the average length of a series being 8 min 8 s (range, 7:55–8:18 s) and the total time of the experiment 32 min 33 s. During interstimulus intervals, a small cross was displayed in the center of the screen as a visual fixation point.

ANALYSIS

Image analyses were performed using SPM5. Each individual's data were slice-time corrected for an interleaved foot-to-head acquisition, motion corrected, spatially smoothed (8 mm FWHM Gaussian kernel), temporal filtered (high-pass = 0.008 Hz) to remove low-frequency signal drift, and normalized into a standardized Talairach template. Signal changes were modeled as delta functions temporally coincident with the onset of each stimulus and convolved with a canonical hemodynamic response function. Sixteen regressor models were constructed, representing each of the real and nonreal categories. Voxel-wise regression analyses were calculated by regressing the BOLD time-series data on the 16 regressors to obtain signal change estimates for each category. Nuisance regressors were included to control for motion. Contrasts were then constructed to detect signal change differences in the responses between (1) real and nonreal items, (2) threatening and nonthreatening items, (3) threatening items and their corresponding scrambled versions, and (4) nonthreatening items and their corresponding scrambled versions. Results from these subject-level analyses were used as the basis for group-level random effects analyses.

The amygdalae were defined, a priori, as regions of interest (ROIs) given their generally accepted role in processing stimuli with prominent emotional or fearful/threatening valence. Amygdalar anatomical ROIs were delineated using the WFU PickAtlas [Maldjian et al., 2003].

Using SPM, a 2 × 2 repeated measures ANOVA was performed as a group-level omnibus test to identify main effects and interaction effects for the manipulated features (threat vs. nonthreat) and categories (natural vs. man-made items). To correct for familywise Type I errors, the results were cluster-thresholded based on Monte-Carlo simulations (AlphaSim software; Ward, 2000) so that surviving clusters were significant with a familywise $\alpha = 0.05$ and a voxel-level $\alpha = 0.005$. Clusters of 153 voxels were

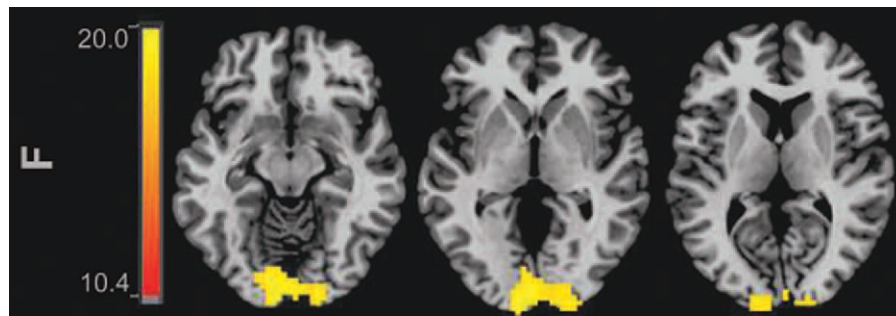


Figure 2.

Threat Feature Main Effect. Foci of signal change detected for the main effect of threat using whole-brain 2 (Threatening vs. Nonthreatening) \times 2 (Man-Made vs. Natural) ANOVA. Color-scaling is based on F-values for the main effect, with the voxel-wise $F_{\text{minimum}}(1,17) = 10.4, P < 0.005$, and the brain-wise cluster

$k = 153$, with $P < 0.05$. The direction of the difference (Threatening $>$ Nonthreatening) is reported in more detail in the text. Data are displayed on the axial view of a template brain with the right side of the figure corresponding to the right side of the brain.

considered significant with familywise $\alpha = 0.05$, based on the simulations (1,000 iterations for a dataset having 25,579 $3.5 \text{ mm} \times 3.5 \text{ mm} \times 4 \text{ mm}$ voxels, smoothness = 8 mm FWHM, cluster = pairs of voxels having a connectivity radius $< 6.37 \text{ mm}$). For the amygdalar ROIs, a lower voxel-level $\alpha = 0.05$ was used without a cluster threshold. Coordinates for peak statistics with the significant clusters are reported in millimeters in the “LPI” format, where coordinates left (L) of the midsagittal plane, posterior (P) to a vertical plane passing through the anterior commissure, and inferior (I) to a horizontal plane passing through the anterior and posterior commissures are negative.

RESULTS

Behavioral Data Results

The mean accuracy for identifying both real and scrambled images was 86%. In addition, the subjects achieved 85% and 87% accuracy respectively in the threatening and nonthreatening subsets of the real images. A 2 (Real) \times 2 (Threatening) ANOVA revealed that these differences were not significant for real vs. scrambled items ($F = 0.28, P > 0.60$), but were significant for threatening vs. nonthreatening items ($F = 8.47, P < 0.01$). The interaction was not significant ($F = 4.06, P > 0.05$). Thus, subjects were slightly more accurate at judging the nonthreatening subsets of images as being real than at judging the threatening subsets of images.

The mean RTs for correct responses were 1,046 ms for real threatening, 969 ms for scrambled threatening, 1,093 ms for real nonthreatening, and 926 ms for scrambled nonthreatening stimuli. The differences were significant for real vs. scrambled items ($F = 29.72, P < 0.0001$), but not significant for threatening vs. nonthreatening items ($F = 0.04, P > 0.84$) or the interaction ($F = 1.74, P > 0.20$). Thus, RTs to determine that the veridical stimuli were “real” was predictably longer ($M = 1,070 \text{ ms}, \text{sd} = 296 \text{ ms}$) than the time to determine that scrambled stimuli

were not real ($M = 947 \text{ ms}, \text{sd} = 271 \text{ ms}$). An ANOVA comparing RTs of threatening natural items and threatening man-made items showed a significant effect ($P = 0.0042$). Threatening natural item RTs were significantly longer than threatening man-made ($P = 0.0015$). The mean RTs for correct threatening natural items were 724 ms ($\text{sd} = 223 \text{ ms}$) and threatening man-made were 682 ms ($\text{sd} = 226 \text{ ms}$).

fMRI Analyses Results

The voxel-wise 2 (feature: threat vs. nonthreat) \times 2 (category: naturally occurring items vs. artifacts) ANOVAs revealed a significant main effect of threat (Fig. 2) within BA 17, 18, and 19 (the peak $F(1,17) = 25.47, P < 0.005$, and LPI coordinates = $-7, -100, 0 \text{ mm}$, and $k = 422$ voxels). Within these regions, voxels responded more strongly to threatening stimuli ($M = 0.58\%, \text{sd} = 0.29\%$) than to nonthreatening stimuli ($M = 0.38\%, \text{sd} = 0.28\%$) (Fig. 3). There

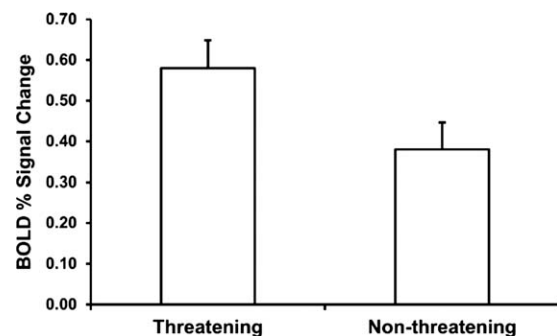


Figure 3.

Threat Feature Main Effect from Peak Voxel. Illustration of the main effect of threat from the whole-brain 2 (Threatening vs. Nonthreatening) \times 2 (Man-Made vs. Natural) ANOVA. Data are from the voxel (LPI coordinates = $-7, -100, 0 \text{ mm}$) having the highest F-value ($F(1,17) = 25.47, P < 0.005$) within the significant cluster. Errors bars represent SEM.

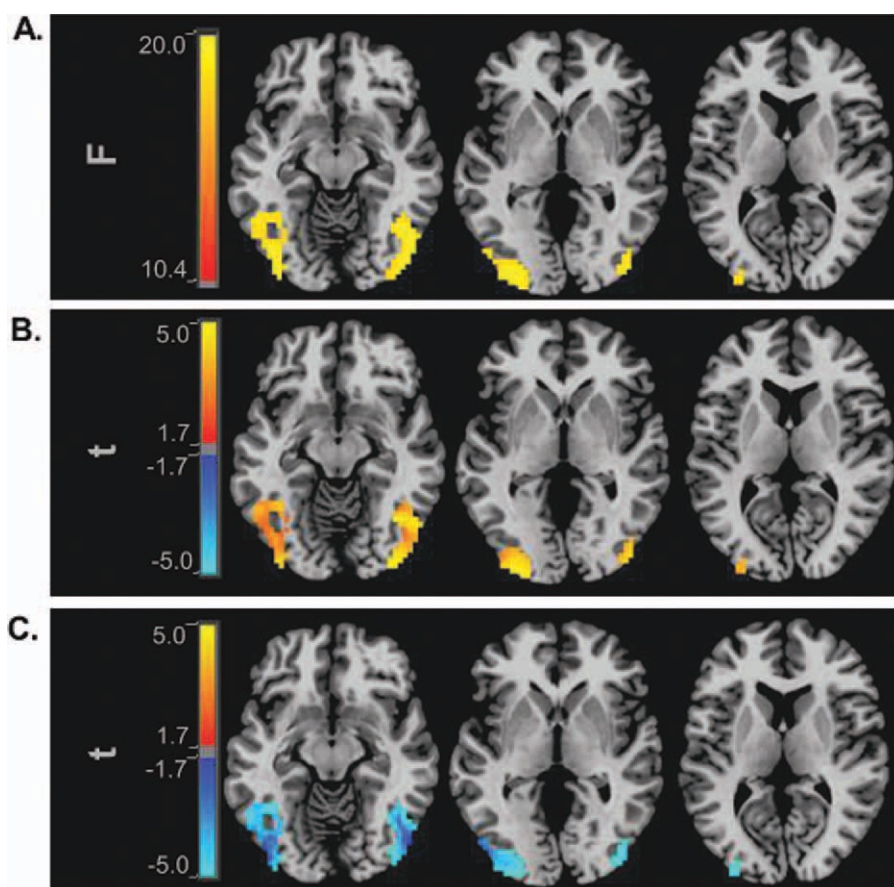


Figure 4.

Category-Feature Interaction Effects. **A.** Foci of signal change detected using whole-brain 2 (Threatening vs. Nonthreatening) \times 2 (Man-Made vs. Natural) ANOVA. Color-scaling is based on F-values for the interaction effect, with the voxel-wise $F_{\text{minimum}}(1,17) = 10.4$, $P < 0.005$, and the brain-wise cluster $k = 153$, with $P < 0.05$. **B.** Contrasts comparing man-made to natural threatening stimuli within the interaction ROIs depicted in **A.** **C.** Contrasts comparing man-made to natural nonthreatening

stimuli within the interaction ROIs depicted in **A.** For **B & C**, color-scaling is based on the t-values for the contrasts, with red-to-yellow indicating higher percent signal change for man-made versus natural and blue-to-cyan indicating higher percent signal change for natural compared with man-made and with the voxel-wise $|t_{\text{minimum}}| = 1.7$, $P < 0.05$. Data are displayed on the axial view of a template brain with the right side of the figure corresponding to the right side of the brain.

also were significant Feature \times Category interaction effects (Fig. 4), but significant effects of category alone were not found.

The Feature \times Category interaction effects occurred bilaterally further along the ventral visual stream than the main effect of threat (Fig. 4). Significant clusters extended bilaterally from BA 18/19 along inferior temporal cortex (left interaction effect peak $F(1,17) = 29.84$, $P < 0.005$, and LPI coordinates = $-42, -90, -7$ mm, and $k = 226$ voxels, and the right interaction effect peak $F(1,17) = 27.04$, $P < 0.005$, and LPI coordinates = $45, -62, -10$ mm, and $k = 178$ voxels; Fig. 4A). For both clusters, significantly greater signal change was observed for threatening man-made stimuli ($M = 0.15\%$, $sd = 0.15\%$) than for threatening natural stimuli ($M = 0.06\%$, $sd = 0.14\%$), peak $t(17) = 5.14$, P

< 0.05 (Figs. 4B and 5). However, for both clusters, significantly greater signal change was observed for natural nonthreatening stimuli ($M = 0.14\%$, $sd = 0.15\%$) than for man-made nonthreatening stimuli ($M = 0.02\%$, $sd = 0.14\%$), peak $t(17) = -4.76$, $P < 0.05$ (Figs. 4C and 5).

A significant main effect of threat was present in the right and left amygdala (left peak $F(1,17) = 8.70$, $P < 0.05$, and LPI coordinates = $-31, 3, -29$ mm, and $k = 7$ voxels, and the right peak $F(1,17) = 5.61$, $P < 0.05$, and LPI coordinates = $28, 0, -29$ mm, and $k = 2$ voxels. For both right and left amygdala, voxels responded more strongly to threatening stimuli (left $M = 0.07\%$, $sd = 0.09\%$; right $M = 0.05\%$, $sd = 0.07\%$) than to nonthreatening stimuli (left $M = 0.02\%$, $sd = 0.10\%$; right $M = -0.0005\%$, $sd = 0.08\%$).

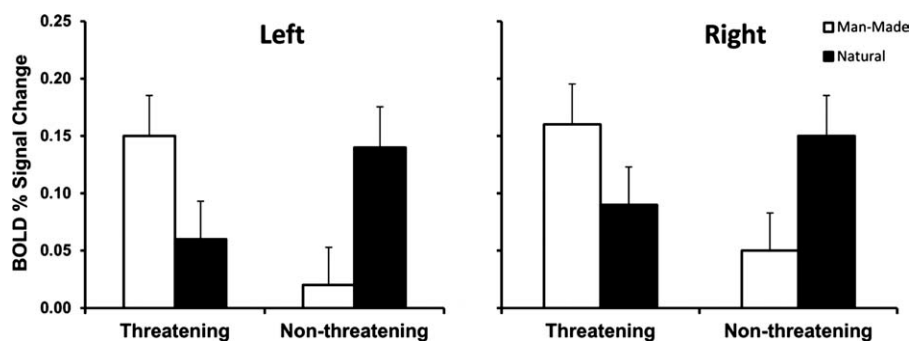


Figure 5.

Category–Feature Interaction Effects. Illustration of the Category \times Feature interaction effects from the whole-brain 2 (threatening vs. nonthreatening) \times 2 (Man-Made vs. Natural) ANOVA. Data are from the voxels (LPI coordinates Left = -42 ,

-90 , -7 mm, and Right = 45 , -62 , -10 mm) having the highest F-values ($F_{\text{left}}(1,17) = 29.84$, $P < 0.005$, and $F_{\text{right}}(1,17) = 27.04$, $P < 0.005$) within the significant cluster. Error bars represent SEM.

DISCUSSION

We found foci of increased BOLD signal changes within early nonprimary visual cortices for threatening stimuli. Within one of these regions, the increased BOLD signal changes for threatening items was present across multiple categories, providing evidence for feature-specific processing in visual object recognition across those categories [Hanson et al., 2004; Hart and Gordon, 1992; Kraut et al., 2006; Mechelli et al., 2007; Sartori et al., 1993]. We also detected a category–featural interaction in two more laterally and ventrally located regions, as evidenced by significantly greater signal changes elicited by man-made threatening items than by natural threatening stimuli. These findings provide evidence for both a feature-specific and a category–feature interactive organization in visual object recognition for the feature of threat, and interactions between the category of man-made items and the feature of threat [Hanson et al., 2004; Hart and Gordon, 1992; Kraut et al., 2006; Mechelli et al., 2007; Sartori et al., 1993].

The selective threat-responsive region in visual recognition is consistent with theories that it is advantageous to process efficiently or rapidly groups of items of evolutionary significance [Caramazza and Shelton, 1998] and/or those that would confer an advantage for survival [Hart and Gordon, 1992; Hart and Kraut, 2007; Lamme et al., 1998]. The greater signal changes with man-made threatening compared with naturally occurring threatening items suggest that responses to stimuli that most people identify as threats to survival (e.g., weapons) increase visual region responsivity more than stimuli that might in the past have more frequently represented threats (wild animals). This presumably reflects the experiences, or at least the fears, of the predominantly urban-dwelling populations from which our subject cohort is derived. Thus, these findings more strongly support the Neural Hybrid Model [Hart and Kraut, 2007] where survival as opposed to evolutionary significance confers a predominant advantage in visual

object recognition. Regions associated with threatening stimuli across all categories are located medially near primary visual cortices. The additional region selective for threatening man-made items is located more laterally and toward the inferior temporal regions of “what” pathway. These localizations have two implications: (1) brain regions that process features are localized closer to primary visual cortices, whereas category processing is more distally localized in visual semantic object processing stream and (2) processing of categories of items that are of more recent origin in humankind’s life experience are encoded further away from primary sensory cortices than is the processing of more “primitive” groupings.

The presence of the featural organization for threatening stimuli in both the nonverbal sound auditory and now visual object recognition is most consistent with an organization based on survival [Hart and Kraut, 2007], as these stimuli initiate a sensorimotor (flight/fight) response, and thus merit efficient processing as a salient stimulus in the environment [Bar et al., 2006; Vuilleumier et al., 2003]. The close proximity between regions that perform the early stages of visual perceptual processing and regions that perform higher order operations (e.g., threatening stimuli) facilitates efficient and rapid processing of dangerous stimuli. The importance of fear and survival-motivated activation is further substantiated by the signal changes detected in the amygdalae for threatening stimuli, and that were not detected for the nonthreatening stimuli in this study. In addition, with regards to facilitation of rapid processing of visual stimuli more generally, Bar et al. (2006) found magnetoencephalographic and fMRI evidence that there is a rapid feed-forward of coarse low spatial frequency data from early visual regions to orbitofrontal cortex. This is presumed to engage other regions to provide an early estimate of object identity and may then help optimize the speed, accuracy or both of subsequent more refined semantic processing in ventral temporal cortices and determination of object identity. Thus, although the signal changes

we have detected are close to primary visual cortex, there is a high probability that these changes reflect modulatory inputs from anatomically relatively distant regions, likely more rostral in either the amygdalae or frontal lobes.

The amygdalae almost certainly modulate the threat-related responses we detected, given the well-documented influence of the amygdalae on responses in perceptual systems [see reviews by Phelps and LeDoux, 2005; Phelps, 2006]. Previous studies indicate that stimuli of greater emotional valence increased signal changes in visual cortices for pictures [Kosslyn et al., 1996; Lane et al., 1997] and facial expressions [Morris et al., 1998; Vuilleumier et al., 2004], even when the stimuli are imagined [Kosslyn et al., 1996]. The anatomic substrates for these amygdalo-occipital (TO) interconnections in humans are likely homologous to those of old world (macaque) monkeys [Amaral et al., 2003]. Investigations into processing facial expressions that convey a sense of fear [Vuilleumier et al., 2003] have found evidence for differential activity in a subcortical (retino-tecto-pulvinar) pathway that on analysis of coarse visual features may provide early input to the amygdalae, and thus involved in early transmission to the visual system for stimuli with a fearful emotional valence.

Analyzing the interaction between the feature threat and categories of items in visual object recognition motivates the evaluation of the potential roles played by primitive perceptual features and attention. We chose our stimuli and data analyses to mitigate the effects of low-level featural or perceptual differences. (i.e., color, simple shapes, etc.) on the signal changes we detected. The DCA analysis of the stimuli to detect such fundamental differences between our threatening and nonthreatening stimuli revealed no such distinctions [Abdi, 2007a,b]. In addition, our analyses did not identify significant signal changes in the regions in question when comparing threatening stimuli to their scrambles, which further argues against purely perceptual characteristics causing the signal changes noted [Sabatinelli et al., 2011]. Attention has been reported to modulate visual cortical signal changes elicited by viewing pictures [Bradley et al., 2003]. Further, the emotional valence of attentional cues can influence early visual perceptual processes such as luminance contrast sensitivity [Phelps et al., 2006], and previous studies have demonstrated attentionally facilitated extraction of the orientation of objects occurring even in primary visual cortex [Haynes and Rees, 2005; Kamitani et al., 2005] or association cortices for emotional processes in general [Lane et al., 1997]. Studies have also suggested that on viewing emotionally laden stimuli, attentional processes influence dorsal prefrontal or dorsal parietal modulation of visual cortical responses [Peers et al., 2005]. All these important findings notwithstanding, the fMRI findings in the present study do demonstrate significant activation mostly in the primary and secondary visual cortices and demonstrate no statistically significant signal change in dorsal prefrontal or parietal attentional regions that would be

analogous to what has been found in the attention studies cited above.

Our analyses demonstrate that the regions with significant signal changes appear to respond strongly to threatening stimuli rather than to emotional stimuli in general. The PCA of the ratings of the stimuli for both arousal and threat supported the a priori classification of the stimuli as threatening and provided evidence against arousal being a confounding feature of threat for these stimuli. Thus, the activation pattern seen does not appear to be secondary to emotional responses in general or to an arousal response attributable to the stimuli [Gerdes et al., 2010].

These findings have significant implications for disease states such as Post-Traumatic Stress Disorder, traumatic brain injury, phobias, anxiety disorders, and other clinical states with overresponsiveness to threatening stimuli. In several of these conditions, electrophysiological studies have found objective evidence of hyperarousal to unattended, threatening visual stimuli [Stanford et al., 2001]. Such data suggest that there is acquired, enhanced and dysfunctional activation in memory subsystems associated with processing the feature threat. Further investigations of the threat-responsive areas in these patients would help determine whether there are any differences from comparable healthy control subjects and whether these different activation patterns have diagnostic and/or therapeutic implications.

CONCLUSIONS

In addition to the categorical organization for which supporting data have been previously reported in visual object recognition, the present study demonstrates greater BOLD signal changes for threatening stimuli in the visual association cortices extending into the TO “what” pathways. Threatening items across all categories elicited signal changes in multiple foci throughout early nonprimary visual cortices, providing evidence for a featural organization of items in visual object recognition. In the more lateral inferior TO regions on both sides, we found foci of signal change that are driven by threatening man-made items, indicating that these BOLD responses reflect the interaction between both the category (man-made) and feature (threatening) designations of the stimuli, which is consistent with optimization of detecting objects relevant to survival. The combination of findings indicates that at least as regards the feature threat, the visual semantic object recognition system is organized in a way that comprises both feature-selective and category-feature interactions. Whether other features share these organizational attributes remains to be determined.

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REFERENCES

- Abdi H (2007a): Discriminant correspondence analysis. In: Salkind NJ, editor. *Encyclopedia of Measurement and Statistics*. Thousand Oaks, CA: Sage. pp 270–275.
- Abdi H (2007b): Metric multidimensional scaling. In: Salkind NJ, editor. *Encyclopedia of Measurement and Statistics*. Thousand Oaks, CA: Sage. pp 598–605.
- Amaral DG, Behnia H, Kelly JL (2003): Topographic organization of projections from the amygdala to the visual cortex in the macaque monkey. *Neuroscience* 118:1099.
- Anderson AK, Phelps EA (2001): Lesions of the human amygdala impair enhanced perception of emotionally salient events. *Nature* 411:305–309.
- Anderson AK (2005): Affective influences on the attentional dynamics supporting awareness. *J Exp Psychol Gen* 134:258–281.
- Azizian A, Polich J (2007): Evidence for attentional gradient in the serial position memory curve from event-related potentials. *J Cogn Neurosci* 19:2071–2081.
- Bar M, Kassam KS, Ghuman AS, Boshyan J, Schmid AM, Dale AM, Hämäläinen MS, Marinkovic K, Schacter DL, Rosen BR, Halgren E (2006): Top-down facilitation of visual recognition. *Proc Natl Acad Sci* 103:449–454.
- Bradley MM, Sabatinelli D, Lang PJ, Fitzsimmons JR, King W, Desai P (2003): Activation of the visual cortex in motivated attention. *Behav Neurosci* 117:369–380.
- Brett M, Johnsrude IS, Owen AM (2002): The problem of functional localization in the human brain. *Nat Rev Neurosci* 3:243–249.
- Caramazza A, Shelton JR (1998): Domain-specific knowledge systems in the brain: The animate–inanimate distinction. *J Cogn Neurosci* 10:1–34.
- Carretié L, Mercado F, Tapia M, Hinojosa JA (2001): Emotion, attention, and the ‘negativity bias’, studied through event-related potentials. *Int J Psychophysiol* 41:75–85.
- Chieffi S, Carlomagno S, Silveri MC, Gainotti G (1989): The influence of semantic and perceptual factors on lexical comprehension in aphasic and right brain-damaged patients. *Cortex* 25:591–598.
- Damasio AR, Tranel D (1993): Nouns and verbs are retrieved with differently distributed neural systems. *Proc Natl Acad Sci* 90:4957–4956.
- Damasio H, Grabowski TJ, Tranel D, Hichwa RD, Damasio AR (1996): A neural basis for lexical search. *Nature* 380:499–505.
- Davis M, Whalen PJ (2001): The amygdala: vigilance and emotion. *Mol Psychiatry*, 6:13–34.
- Dolcos F, Abeza R (2002): Event-related potentials of emotional memory: Encoding pleasant, unpleasant, and neutral pictures. *Cogn Affect Behav Neurosci* 2:252–263.
- Downing PE, Jiang Y, Shuman M, Kanwisher N (2001): A cortical area selective for visual processing of the human body. *Science* 293:2470.
- Ecker C, Reynaud E, Williams SC, Brammer MJ (2007): Detecting functional nodes in large-scale cortical networks with functional magnetic resonance imaging: A principal component analysis of the human visual system. *Hum Brain Mapp* 28:817–834.
- Epstein R, Kanwisher N (1998): A cortical representation of the local visual environment. *Nature* 392:598–601.
- Ferree TC (2006): Spherical splines and average referencing in scalp EEG. *Brain Topogr* 19:43–52.
- Ferree TC, Brier MR, Hart J, Jr, Kraut MA (2009): Space-time-frequency analysis of EEG data using within-subject statistical tests followed by sequential PCA. *Neuroimage* 45:109–121.
- Fink GR, Halligan PW, Marshall JC, Frith CD, Frackowiak RS, Dolan RJ (1997): Neural mechanisms involved in the processing of global and local aspects of hierarchically organized visual stimuli. *Brain* 120(Pt 10):1779–1791.
- Fortin A, Ptito A, Faubert J, Ptito M (2002): Cortical areas mediating stereopsis in the human brain: A PET study. *Neuroreport* 13:895–898.
- Gerdes A, Wieser M, Mühlberger A, Weyers P, Alpers G, Plichta M, Breuer F, Pauli P (2010): Brain activations to emotional pictures are differentially associated with valence and arousal ratings. *Front Hum Neurosci* 28:175.
- Hanson SJ, Matsuka T, Haxby JV (2004): Combinatorial codes in ventral temporal lobe for object recognition: Haxby (2001) revisited: Is there a “face” area? *NeuroImage* 23:156–166.
- Hart J, Jr, Anand R, Zoccoli S, Maguire M, Gamino J, Tillman G, King R, Kraut M (2007): Neural substrates of semantic memory. *J Int Neuropsychol Soc* 13:865–880.
- Hart J, Gordon B (1992): Neural subsystems for object knowledge. *Nature* 359:60–64.
- Hart J, Jr, Kraut MA (2007): Neural hybrid model of semantic object memory (version 1.1). In: Hart J, Jr, Kraut MA, editors. *Neural Basis of Semantic Memory*. New York: Cambridge University Press. pp 331–360.
- Haxby JV, Gobbini MI, Furey ML, Ishai A, Schouten JL, Pietrini P (2001): Distributed and overlapping representations of faces and objects in ventral temporal cortex. *Science* 293:2425.
- Haxby JV, Hoffman EA, Gobbini MI (2002): Human neural systems for face recognition and social communication. *Biol Psychiatry* 51:59.
- Haynes J, Rees G (2005): Predicting the orientation of invisible stimuli from activity in human primary visual cortex. *Nat Neurosci* 8:686–691.
- Horn JL (1965): A rationale and test for the number of factors in factor analysis. *Psychometrika* 30:179–185.
- Junghöfer M, Elbert T, Tucker DM, Braun C (1999): The polar average reference effect: A bias in estimating the head surface integral in EEG recording. *Clin Neurophysiol* 110:1149–1155.
- Junghöfer M (2000): Statistical control of artifacts in dense array EEG/MEG studies. *Psychophysiology* 37:523–532.
- Kamitani Y, Tong F (2005): Decoding the visual and subjective contents of the human brain. *Nat Neurosci* 8:679–685.
- Kanwisher N, McDermott J, Chun MM (1997): The fusiform face area: a module in human extrastriate cortex specialized for face perception. *J Neurosci* 17:4302–4311.
- Karns CM, Knight RT (2009): Intermodal auditory, visual, and tactile attention modulates early stages of neural processing. *J Cogn Neurosci* 21:669–683.
- Kawasaki H, Adolphs R, Kaufman O, Damasio H, Damasio AR, Granner M, Bakken H, Hori T, Howard M (2001): Single-neuron responses to emotional visual stimuli recorded in human ventral prefrontal cortex. *Nat Neurosci* 4:15.
- Kosslyn SM, Shin LM, Thompson WL, McNally RJ, Rauch SL, Pitman RK, Alpert N (1996): Neural effects of visualizing and perceiving aversive stimuli: A PET investigation. *Neuroreport* 7:1569–1576.
- Kraut M, Pitcock J, Calhoun V, Li J, Freeman T, Hart J (2006): Neuroanatomic organization of sound memory in humans. *J Cogn Neurosci* 18:1877–1888.
- Lamme VA, Supèr H, Spekreijse H (1998): Feedforward, horizontal, and feedback processing in the visual cortex. *Curr Opin Neurobiol* 8:529–535.

- Lane RD, Reiman EM, Bradley MM, Lang PJ, Ahern GL, Davidson RJ, Schwartz G (1997): Neuroanatomical correlates of pleasant and unpleasant emotion. *Neuropsychologia* 35:1437–1444.
- Luck SJ, Woodman GF, Vogel EK (2000): Event-related potential studies of attention. *Trends Cogn Sci*, 4:432–440.
- Makeig S, Westerfield M, Jung T, Enghoff S, Townsend J, Courchesne E, et al. (2002): Dynamic brain sources of visual evoked responses. *Science* 295:690.
- Maldjian JA, Laurienti PJ, Burdette JB, Kraft RA (2003): An automated method for neuroanatomic and cytoarchitectonic atlas-based interrogation of fMRI data sets. *Neuroimage* 19:1233–1239.
- Mangun GR, Hopfinger JB, Kussmaul CL, Fletcher EM, Heinze H (1997): Covariations in ERP and PET measures of spatial selective attention in human extrastriate visual cortex. *Hum Brain Mapp* 5:273–279.
- Maratos EJ, Rugg MD (2001): Electrophysiological correlates of the retrieval of emotional and non-emotional context. *J Cogn Neurosci* 13:877–891.
- Maratos FA, Mogg K, Bradley BP, Rippon G, Senior C (2009): Coarse threat images reveal theta oscillations in the amygdala: A magnetoencephalography study. *Cogn Affect Behav Neurosci* 9:133–143.
- Martin A, Wiggs CL, Ungerleider LG, Haxby JV (1996): Neural correlates of category-specific knowledge. *Nature* 379:649–645.
- Mechelli A, Josephs O, Lambon Ralph M, McClelland J, Price C (2007): Dissociating stimulus-driven semantic and phonological effect during reading and naming. *Hum Brain Mapp* 28:205–217.
- Morris JS, Friston KJ, Büchel C, Frith CD, Young AW, Calder AJ, Dolan RJ (1998): A neuromodulatory role for the human amygdala in processing emotional facial expressions. *Brain* 121:47.
- Morris JS, Ohman A, Dolan RJ (1999): A subcortical pathway to the right amygdala mediating “unseen” fear. *Proc Natl Acad Sci USA* 96:1680–1685.
- Nunez PL (1981): *Electric Fields of the Brain*. New York: Oxford University Press.
- Olofsson JK, Nordin S, Sequeira H, Polich J (2008): Affective picture processing: An integrative review of ERP findings. *Biol Psychol* 77:247–265.
- O’Toole AJ, Jiang F, Abdi H, Haxby JV (2005): Partially distributed representations of objects and faces in ventral temporal cortex. *J Cogn Neurosci* 17:580–590.
- Paller KA, McCarthy G, Wood CC (1988): ERPs predictive of subsequent recall and recognition performance. *Biol Psychol* 26:269–276.
- Palmeri TJ, Gauthier I (2004): Visual object understanding. *Nat Rev Neurosci* 5:291–213.
- Pape H-C, Driesang RB, Heinbockel T, Laxmi TR, Meis S, Seidenbecher T, Szinyei C, Frey U, Stork O (2001): Cellular processes in the amygdala: gates to emotional memory? *Zoology (Jena)* 104:232–240.
- Peers PV, Ludwig CJH, Rorden C, Cusack R, Bonfiglioli C, Bundesen C, Driver J, Antoun N, Duncan J (2005): Attentional functions of parietal and frontal cortex. *Cereb Cortex* 15:1469–1484.
- Perrin F, Pernier J, Bertrand O, Echallier JF (1989): Spherical splines for scalp potential and current density mapping. *Electroencephalogr Clin Neurophysiol* 72:184–187.
- Phelps EA (2006): Emotion and cognition: Insights from studies of the human amygdala. *Annu Rev Psychol* 57:27.
- Phelps EA, LeDoux JE (2005): Contributions of the amygdala to emotion processing: From animal models to human behavior. *Neuron* 48:175–187.
- Phelps EA, Ling S, Carrasco M (2006): Emotion facilitates perception and potentiates the perceptual benefits of attention. *Psychol Sci* 17:292–299.
- Reddy L, Kanwisher N (2006): Coding of visual objects in the ventral stream. *Curr Opin Neurobiol* 16:408–414.
- Reddy L, Kanwisher N (2007): Category selectivity in the ventral visual pathway confers robustness to clutter and diverted attention. *Curr Biol* 17:2067–2072.
- Ritchey M, Dolcos F, Cabeza R (2008): Role of amygdala connectivity in the persistence of emotional memories over time: An event-related fMRI investigation. *Cereb Cortex* 18:2494–2504.
- Sabatinelli D, Fortune E, Li Q, Siddiqui A, Krafft C, Oliver W, Beck S, Jeffries J (2011): Emotional perception: meta-analyses of face and natural scene processing. *Neuroimage* 54:2524–2533.
- Sartori G, Gnoato F, Mariani I, Prioni S, Lombardi L (2007): Semantic relevance, domain specificity and the sensory/functional theory of category-specificity. *Neuropsychologia* 45:966–976.
- Sartori G, Job R, Miozzo M, Zago S, Marchiori G (1993): Category-specific form-knowledge deficit in a patient with herpes simplex virus encephalitis. *J Clin Exp Neuropsychol* 15:280–299.
- Seidenbecher T, Laxmi TR, Stork O, Pape H-C (2003): Amygdalar and hippocampal theta rhythm synchronization during fear memory retrieval. *Science* 301:846–850.
- Schupp HT, Stockburger J, Codispoti M, Junghöfer M, Weike AI, Hamm AO (2007): Selective visual attention to emotion. *J Neurosci* 27:1082–1089.
- Sitnikova T, West WC, Kuperberg GR, Holcomb PJ (2006): The neural organization of semantic memory: Electrophysiological activity suggests feature-based segregation. *Biol Psychol* 71:326–340.
- Stanford MS, Vasterling JJ, Mathias CW, Constans JL, Houston RJ (2001): Impact of threat relevance on P3 event-related potentials in combat-related post-traumatic stress disorder. *Psychiatry Res* 102:125–137.
- Tallon-Baudry C, Bertrand O, Delpuech C, Pernier J (1997): Oscillatory γ -band (30–70 Hz) activity induced by a visual search task in humans. *J Neurosci* 17:722–734.
- Treisman AM, Gelade G (1980): A feature-integration theory of attention. *Cogn Psychol* 12:97–136.
- Ullman S (2007): Object recognition and segmentation by a fragment-based hierarchy. *Trends Cogn Sci* 11:58–64.
- Vaina LM, Solomon J, Chowdhury S, Sinha P, Belliveau JW (2001): Functional neuroanatomy of biological motion perception in humans. *Proc Natl Acad Sci USA* 98:11656.
- Vuilleumier P, Armony JL, Driver J, Dolan RJ (2003): Distinct spatial frequency sensitivities for processing faces and emotional expressions. *Nat Neurosci* 6:624–631.
- Vuilleumier P, Richardson MP, Armony JL, Driver J, Dolan RJ (2004): Distant influences of amygdala lesion on visual cortical activation during emotional face processing. *Nat Neurosci* 7:1271–1278.
- Welch P (1967): The use of fast Fourier transform for the estimation of power spectra: A method based on time averaging over short, modified periodograms. *IEEE Trans Audio Electroacoustics* 15:70–73.
- Whalen PJ (1998): Fear, vigilance, and ambiguity: Initial neuroimaging studies of the human amygdala. *Curr Directions Psychol Sci* 7:177–188.
- Wierenga CE, Perlstein WM, Benjamin M, Leonard CM, Rothi LG, Conway T, Cato M, Gopinath K, Briggs R, Crosson B (2009): Neural substrates of object identification: Functional magnetic resonance imaging evidence that category and visual attribute contribute to semantic knowledge. *J Int Neuropsychol Soc* 15:169–181.
- Wolfe J (1998): Visual search. In: Pashler H, editor. *Attention*. London, UK: University College London Press. pp 13–73.