

Incidental effects of emotional valence in single word processing: An fMRI study

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Received 14 April 2005; revised 27 June 2005; accepted 28 June 2005
Available online 8 August 2005

The present study aimed at identifying the neural responses associated with the incidental processing of the emotional valence of single words using event-related functional magnetic resonance imaging (fMRI). Twenty right-handed participants performed a visual lexical decision task, discriminating between nouns and orthographically and phonologically legal nonwords. Positive, neutral and negative word categories were matched for frequency, number and frequency of orthographic neighbors, number of letters and imageability. Response times and accuracy data differed significantly between positive and neutral, and positive and negative words respectively, thus, replicating the findings of a pilot study. Words showed distributed, mainly left hemisphere activations, indicating involvement of a neural network responsible for semantic word knowledge. The neuroimaging data further revealed areas in left orbitofrontal gyrus and bilateral inferior frontal gyrus with greater activation to emotional than to neutral words. These brain regions are known to be involved in processing semantic and emotional information. Furthermore, distinct activations associated with positive words were observed in bilateral middle temporal and superior frontal gyrus, known to support semantic retrieval, and a distributed network, namely anterior and posterior cingulate gyrus, lingual gyrus and hippocampus when comparing positive and negative words. The latter areas were previously associated with explicit and not incidental processing of the emotional meaning of words and emotional memory retrieval. Thus, the results are discussed in relation to models of processing semantic and episodic emotional information.

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Keywords: Emotional valence; Positive, neutral, negative words; Lexical Decision Task; Semantic Memory; fMRI; Neuroimaging

Introduction

The last decade has produced many neuroimaging studies investigating the fundamental functions of memory and emotion.

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Most of these studies focused on effects of episodic memory during encoding and recognition of emotional contents. Both, recent event-related potential (ERP) studies and neuroimaging experiments revealed a number of cortical regions or electrophysiological correlates associated with the processing of the emotional valence of pictures (Anders et al., 2004; Lane et al., 1999; Smith et al., 2004; Taylor et al., 1998), sentences (Maratos et al., 2001; Maratos and Rugg, 2001) or words (Cato et al., 2004; Crosson et al., 1999; Dolcos et al., 2004; Hamann and Mao, 2002; Windmann and Kutas, 2001). For example, having subjects process verbal information during a word generation task, Cato et al. (2004) found activity in rostral frontal and retrosplenial cortical areas for both positive and negative stimuli using event-related fMRI design. The authors suggest that these findings correspond to the processing of emotional connotations as a semantic attribute.

Taken together, these studies show an enhanced processing of emotional information in both hemispheres involving the inferior frontal gyrus and a cortico-limbic circuit including the amygdala, the hippocampal formation and the posterior cingulate gyrus (LeDoux, 1995; for reviews, see: Dolan, 2002; Hamann, 2001; Wager et al., 2003). Beyond this functionality and connectivity of the explicit memory system for different stimulus types, relatively little is known about the cortical network responsible for emotional effects in word recognition. While most of the above mentioned studies investigated attentional processing of affective valence, the question occurs, whether emotional valence effects of verbal stimuli can be seen when the meaning of the experimental stimuli is processed incidentally?

Some researchers claimed that in situations where previously encoded information is subsequently processed without any conscious recollection subjects' performance is not affected by the emotional valence of words (Danion et al., 1995; Nugent and Mineka, 1994; Parrot et al., 2005). One prominent paradigm for investigating this issue is the lexical decision task (LDT). In the LDT, subjects categorize stimuli as words or nonwords. Although they do not have to explicitly process the meaning of the words, it can be shown that different semantic features influence reaction

time and accuracy measures (e.g., Azuma and van Orden, 1997; Binder et al., 2003). Using an “affective” LDT with positive, negative and neutral words, Siegle et al. (2002) did not find an effect of emotional valence, neither in normal, nor in dysphoric participants, thus supporting the findings of Danion et al. (1995). However, the generality of this result is questionable. For reasons of dissociating between depressed and nondepressed subjects, the authors used lists of only 10 words per emotional valence condition comprising verbs, nouns, and adjectives, without controlling for a variety of factors, such as word type, imageability or orthographic neighborhood size, known to systematically affect lexical decision performance (Binder et al., 2003; Gentner, 1981; Grainger and Jacobs, 1996; Jacobs and Grainger, 1994). In contrast, Windmann et al. (2002) reported an advantage for negative stimuli compared with neutral words in an LDT with subliminal stimulus presentation, suggesting influences of affective information at a prelexical processing stage. In accordance with these latter findings, different research groups revealed affective interference effects in word recognition using the LDT (Bradley et al., 1994; Challis and Krane, 1988; Matthews and Southall, 1991; Ruiz-Caballero and Moreno, 1992; Strauss, 1983; Williamson et al., 1991; Windmann and Kutas, 2001), but the direction of the effect is still controversial. The studies of Williamson et al. (1991) and Challis and Krane (1988) showed enhanced processing of emotional stimuli (irrespective of their valence) as compared to neutral stimuli, while in a meta-analysis of seven studies Siegle (1996; Unpublished Master’s Thesis, <http://www.pitt.edu/~gsiegle>) found significantly faster response latencies for positive compared with negative, and positive compared with neutral words in normal subjects (for a review on LDT, see Siegle et al., 2002).

Only a few neurocognitive studies reported incidental effects of emotional valence in single word processing. In an ERP study, Naumann et al. (1992) found increased P3 amplitudes associated with the emotional valence of adjectives using a structural processing task, but failed to replicate this finding with nouns (Naumann et al., 1997). Bernat et al. (2001) reported that emotional valence modulated ERPs as early as 100–400 ms after word onset, suggesting that unconscious processing has an early and more frontally distributed influence. This result was also found by Williamson et al. (1991) for ERP data when comparing psychopathic and non-psychopathic inmates with an affective LDT.

To summarize, these findings can be discussed in relation to the “affective primacy hypothesis” according to which an unattended memory system categorizes every stimulus as positive or negative (Murphy and Zajonc, 1993). This evaluation process may occur preconsciously at an early stage of perception (Anderson and Phelps, 2001; Bargh, 1992; Windmann et al., 2002; Williamson et al., 1991).

A recent block-design fMRI study by Canli et al. (2004) used an LDT to discriminate brain activation for neutral, happy, sad and threat-related words in depressed and normal subjects. They found a complex activation pattern spreading from parietal and superior temporal lobes to frontal regions suggesting different cognitive processes for depressed and control groups. However, Canli et al. (2004) only report “between groups” effects. It thus remains unclear which neural structures are associated with the unattended processing of the emotional valence of words in normal subjects. We addressed this issue in the present fMRI study.

The aim of this study was to identify brain regions supporting incidental effects of emotion on semantic memory when processing positive, neutral and negative words. An event-related fMRI design was employed to investigate trial by trial differences in brain

activation during an affective LDT. Assuming that incidental processing of emotional valence in word recognition is subserved by at least partially the same brain regions known to be involved in explicit emotional memory tasks, we expected to find several neural correlates in the following regions: the inferior and orbitofrontal gyrus, amygdala, hippocampus and posterior cingulate cortex (Cato et al., 2004; Dolcos et al., 2004).

Methods

Stimulus material

150 nouns consisting of 4 to 8 letters were drawn from a larger corpus of 2483 German words. For this corpus at least 20 subjects were asked to rate each word on a Likert scale (ranging from -3 to $+3$) for emotionality and imageability. Only words were selected which were homogeneously rated as positive or negative, respectively, by the majority of subjects (standard deviations on emotional valence ratings less than 1), and which belonged to three non-overlapping distributions for positive (valence scores $\geq +1.5$), negative (≤ -1.5), and neutral valence (between -0.5 and $+0.5$). Similar to previous studies, lists of 50 positive, 50 neutral and 50 negative words were chosen, matched for mean word frequency, number of letters and syllables, number and frequency of orthographic neighbors (word statistics derived from German CELEX database, Baayen et al., 1995), and imageability. The average valence ratings given to the selected 50 positive, 50 negative and 50 neutral words were $+1.94$, -1.97 and 0.04 respectively.¹

A set of 150 orthographically legal and pronounceable non-words was created either by changing one letter or as new compositum of legal German syllables. The 150 words and 150 nonwords were matched on mean number of letters, syllables and mean positional bigram frequency. (The complete list of stimuli is available upon request.)

Pilot study

A behavioral experiment was conducted as a pilot study to see whether the emotional valence manipulations affected response latencies and accuracy measures in a LDT. To produce comparable results, we have chosen the same design as in the subsequent event-related fMRI-study.

20 right-handed subjects (range 20–31 years, mean 24.1, 11 females), undergraduates from the Free University of Berlin participated for partial course credit. Test items were randomly assigned on a computer screen using Presentation™ software (Neurobehavioral Systems, <http://nbs.neuro-bs.com>) on an IBM compatible PC. The experiment started with the presentation of a fixation cross (+) in the center of the screen, and subjects were asked to fixate this stimulus when it was present. Trials began with the disappearance of the fixation cross and presentation of a single stimulus for 500 ms, followed by the reappearance of the fixation cross. Interstimulus interval was jittered between 2600 and 3000

¹ As a result of the complex matching procedure, negative stimuli yielded higher arousal scores compared with both, positive and neutral stimuli (the last two did not differ). To estimate the effects of arousal in the present study, SPMs were computed including mean arousal-ratings as a regressor variable. This analysis produced comparable results as reported in this paper.

ms (in accordance with the later fMRI-study). Subjects were instructed to respond as quickly and accurately as possible, pressing the left mouse button for “word” and the right mouse button for “nonword”. The mapping between fingers and mouse buttons was changed after half of the subjects. Response times and error rates from each participant were submitted to a one-way repeated measures analysis of variance (ANOVA) for both subjects (F_1) and items (F_2). Outliers more or less than two standard deviations apart from individual means were removed from the analysis. Thus, 4.8% of all observations were removed by this procedure. For mean response latencies and error rates, see Table 1.

Response latencies were faster for words than for nonwords in the subject [$F_1(1, 19) = 23.426, P < 0.001$], and the item analysis [$F_2(1, 298) = 204.885, P < 0.001$]. For the emotional valence conditions, analysis of the response time data revealed a significant main effect in both analyses [$F_1(2, 38) = 7.291, P < 0.001$; $F_2(2, 147) = 4.219, P = 0.017$] due to faster responses for positive compared with neutral words (Bonferroni corrected planned comparisons, $P = 0.023$) and compared with negative words ($P = 0.011$). Neutral and negative stimuli did not differ significantly in response latencies. The analysis of the error data showed a main effect of lexicality [$F_1(1, 19) = 7.807, P = 0.012$; $F_2(1, 298) = 13.801, P < 0.001$], with more errors to nonword stimuli. When comparing the emotional valence conditions, the ANOVA elicited a main effect of emotionality in the subject [$F_1(2, 38) = 4.137, P = 0.024$], and a trend towards significance in the item analysis [$F_2(2, 147) = 2.796, P = 0.064$]. This effect is mainly due to fewer errors in the positive valence condition compared with the neutral condition ($P = 0.016$). No other comparison revealed a significant result.

Consistent with many findings in previous LDT studies, words were responded to quicker and with fewer errors than nonwords (e.g., Binder et al., 2003; Fiebach et al., 2002; Grainger and Jacobs, 1996). Moreover, we found a main effect of emotional valence, indicating improved recognition of positive words, even when valence was incidental to the task. These results are in accordance with similar recent findings by Canli et al. (2004) and with theories assuming different processes for positive and negative stimuli (Bernat et al., 2001; Isen, 1985; 1987; Ashby et al., 1999).

fMRI-study

Subjects

22 right-handed young adults aged between 20 and 36 years (mean 26.3) from Bremen University were employed in the

study after having given written informed consent in accordance with guidelines set by the Bremen University ethics committee. Two participants' data were excluded from further analysis due to inadequate behavioral performance. Of the remaining 20 subjects, 12 were female. All were native German speaker with no history of neurological or psychiatric illness.

Procedure

A training trial of the experimental task consisting of four neutral words and four nonwords was first given outside the scanner. No mention was made of the different types of words employed in the experimental phase. The experiment started after a 15-min anatomical scan.

Stimuli in the fMRI task were presented using Presentation™ software on Windows 98 IBM-PC, which also recorded response time measures and accuracy data. An LCD projector (JVC G15E, XGA-resolution) was used to rear-project the stimuli onto a screen located near the subjects crone, visible via a mirror mounted on the head coil of the fMRI scanner, at a distance approximately 30 cm from the projection screen. Stimuli were presented in white uppercase Arial 24 font on a black background and subtended an average horizontal visual angle of 3°. Responses were given through a hand-held PC-mouse by button press with either the right index or middle finger.

The scanning session started with a short instruction and two dummy trials. The following 300 test trials were presented in random order for lexical decision. To synchronize acquisition timing between scanner and stimulus-PC, the start of the first trial was controlled by an external pulse from the scanner. Material and procedures were identical to those employed in the pilot study.

MRI data acquisition

Neuroimaging was performed with a 3T SIEMENS Magnetom Allegra™ scanner using a whole head, local gradient coil (SIEMENS Erlangen, Germany). High resolution T1 weighted anatomic reference images were acquired as a set of 160 contiguous sagittal slices ($1 \times 1 \times 1$ mm voxels, MPRAGE, TR 2.3 s, TE 4.38 ms, 256×256 , FA 8°). Functional imaging used a single shot echo planar sequence with following parameters: TE 30 ms, TR 2.5 s, 64×64 mosaic images with a FOV of 192 mm, FA 90°. One volume covering the whole brain consisted of 38 slices parallel to AC–PC plane with 3 mm slice thickness, and no interslice gap.

Image preprocessing

Image preprocessing and statistical analysis were performed using the SPM2 toolbox (Wellcome Dept. London, <http://www.fil.ion.ucl.ac.uk/spm/>). Functional images were slice time corrected for acquisition order and realigned to the first image in time series to correct for motion artefacts. The data were spatially normalized to standard stereotactic space using the implemented EPI template (based on the Montreal Neurological Institute (MNI) 305 brain average) and non-linear basis functions. Subsequently, the EPI volumes were spatially smoothed with an isotropic 8 mm (FWHM) Gaussian kernel to accommodate residual across-participant anatomical differences. The time series for each voxel were high-pass filtered to

Table 1
Lexical decision performance data

	Pilot study		fMRI study	
	Mean	SD	Mean	SD
<i>Response times (in ms)</i>				
Positive	696	115	789	140
Neutral	719	113	812	162
Negative	727	130	828	168
Nonwords	826	185	881	141
<i>Error rates (in %)</i>				
Positive	4.0	3.5	1.8	2.1
Neutral	6.9	4.2	4.7	4.5
Negative	6.2	5.9	3.6	2.8
Nonwords	9.5	7.0	3.8	2.3

a maximum of 128 s. The first two volumes were discarded to allow for T1 equilibration effects.

Statistical analysis of images

Voxel-wise fixed effects contrast images made by subtraction analyses were performed at the single subject level and random effects analyses (Holmes and Friston, 1998) were conducted at the group level to create SPM contrast maps. Data were modeled as five discrete event types: words from each of the three categories (positive, neutral, negative) for correctly discovered stimuli, correctly judged nonwords and a rest category including all misses and outliers. Principal contrasts were between those events that received correct responses. Regressors modeling events were convolved with a standard canonical hemodynamic response function (HRF) and their temporal derivative. Thus, linear contrasts (subtractions between modeled events) of parameter estimates were estimated for each subject. Initial statistic parametric maps (SPMs) were computed by an ANCOVA incorporating the canonical HRF, its derivative and gender as a covariate (using the ReML estimator and a nonsphericity correction). All reported analyses were based on one-tailed *t* tests derived from the canonical HRF alone (which carried all the effects obtained with the ANCOVA, see Smith et al., 2004), conducted with the significance level set at $P < 0.001$ (uncorrected) and an extent threshold of 4 contiguous voxels. For visualization, these group activation maps were overlaid on the MNI 305 brain average from SPM2 canonical image set.

Regions of interest (ROI) analysis was conducted using MarsBaR toolbox for SPM (<http://marsbar.sourceforge.net>). Significant clusters from group contrasts were taken back to the first (individual) level to derive percent signal change measures for the three affective conditions.

Results

Behavioral results

Response times and error rates from each participant were submitted to a one-way repeated measures ANOVA. 4.6% of all observations were removed following the outlier procedure.

Words and nonwords differed significantly in their response latencies in both subject analysis [$F_1(1,19) = 15.395$, $P = 0.001$] and item analysis [$F_2(1,298) = 77.300$, $P < 0.001$] due to faster responses for words. Additionally, there was a significant effect of emotional valence for subjects [$F_1(2,38) = 9.994$, $P < 0.001$], and items [$F_2(2,147) = 7.222$, $P = 0.001$]. Subsequently computed *t* tests (Bonferroni-corrected for multiple comparisons) revealed significant differences between positive and neutral ($P = 0.035$) and positive and negative words ($P = 0.003$, see Table 1). A main effect was found for emotional valence on the error rates for subject analysis [$F_1(1,38) = 4.936$, $P = 0.012$], and item analysis [$F_2(2,147) = 3.403$, $P = 0.036$], due to more errors in the neutral condition compared with the positive one ($P = 0.017$).

With longer reaction times in the fMRI study compared to the pilot study, these results fully replicate the pattern observed in the pilot study (Table 1). Thus, also in the behavioral fMRI data we found an advantage for positive words compared with negative or neutral words.

fMRI data

Words vs. nonwords

A number of brain areas showed greater activity in response to words than to nonwords. Significant effects were elicited in left middle and superior frontal gyrus (BA 8, 9), bilateral temporal lobe (BA 20, 22), bilateral angular gyrus (BA 39), medial frontal gyrus (BA 10, 25) and bilateral posterior cingulate gyrus and precuneus (BA 23, 31, see Fig. 1, Table 2). These areas correspond closely to those reported in other recent fMRI studies of lexical decision tasks indicating involvement of neural networks responsible for processing semantic word knowledge (Binder et al., 2003; Fiebach et al., 2002; Henson et al., 2002).

Nonword–word comparisons yielded more bilateral prefrontal activations with significant clusters in inferior and middle frontal gyrus (BA 45, 47) and medial frontal gyrus (BA 6, 8), as well as activated regions in left temporal lobe (middle temporal, superior temporal, BA 21, 22, and fusiform gyrus, BA 37) and right amygdala and hippocampus, as can be seen in Table 2.

Nonspecific valence effects

To compare the incidental processing of emotional words and neutral words, we collapsed positive and negative words to form a valence independent emotional condition. The resulting contrast identified significant clusters in left orbitofrontal gyrus (BA 11) and bilateral inferior frontal gyrus (BA 45) with greater activation to emotional than to neutral words (Fig. 2). The reverse contrast showed significantly greater hemodynamic responses to neutral words in the left medial frontal gyrus, right superior and middle frontal gyrus (BA 10) and the middle temporal gyrus (Table 3). To see whether the reported activations are due to valence-independent processing we masked these nonspecific valence contrasts exclusively by both, the positive–negative and the negative–positive contrast (at $P < 0.05$, uncorrected). No region reached the selected significance level, suggesting that the nonspecific valence effects are mainly carried by the valence-specific effects (see below).

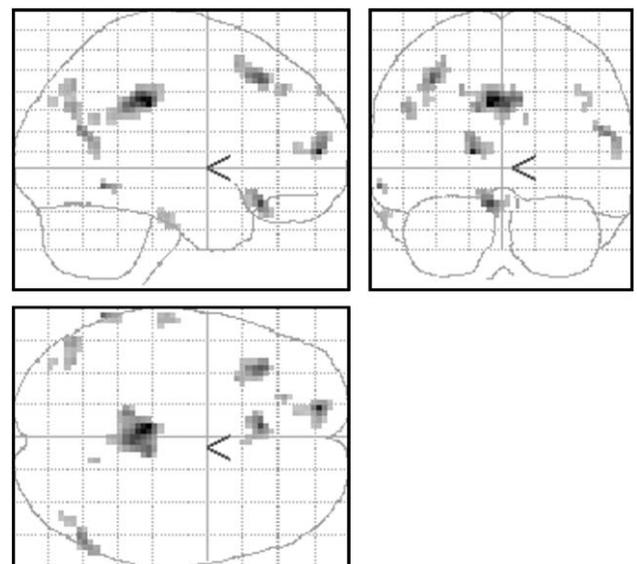


Fig. 1. Maximum intensity projections illustrating voxels common to word > nonword contrast (thresholded at $P < 0.001$, uncorrected).

Table 2
Regions of significant activation in the word–nonword contrast

Brain region	BA	Cluster size	<i>T</i>	<i>x</i>	<i>y</i>	<i>z</i>	
<i>Word > Nonword</i>							
L	Middle + superior frontal gyrus	BA 8/9	54	5.67	−36	27	45
L	Superior + medial frontal gyrus	BA 10	45	6.45	−15	57	9
L	Angular gyrus	BA 39	19	4.54	−48	−69	30
L	Inferior temporal gyrus	BA 20	13	4.17	−63	−21	−24
L	middle temporal gyrus	BA 21/37	10	5.36	−63	−54	−9
L	Precuneus	BA 19/39	8	4.37	−39	−69	42
L	Middle + superior frontal gyrus	BA 9	6	4.33	−21	39	42
L	Precuneus	BA 19	4	3.79	−39	−78	36
L	Superior frontal gyrus	BA 9	4	3.96	−12	57	39
B	Posterior cingulate gyrus/precuneus	BA 23/31	180	7.03	−6	−30	33
B	Medial frontal gyrus	BA 11/25	35	5.90	−6	27	−18
R	Middle + superior temporal gyrus	BA 22/39	29	5.06	54	−63	18
R	Angular gyrus	BA 39	9	3.94	42	−69	33
R	Posterior cingulate gyrus/precuneus	BA 31	4	4.10	12	−57	27
<i>Nonword > Word</i>							
L	Inferior frontal gyrus	BA 6/9/45	644	7.04	−42	27	0
L	Middle + superior temporal gyrus	BA 21/22	121	5.86	−60	−9	−6
L	Superior frontal gyrus	BA 6	95	5.90	−9	3	60
L	Fusiform gyrus	BA 37	8	4.39	−45	−51	−18
R	Inferior frontal gyrus	BA 47	48	5.92	33	27	−6
R	Inferior frontal gyrus	BA 45/46	36	4.56	51	24	21
R	Parahippocampal gyrus + amygdala	BA 34	17	4.91	24	−9	−21
R	Frontal lobe		9	4.86	27	15	15

x, *y*, *z* = coordinates according to MNI stereotactic space, BA = approximate Brodmann's area, L = left, B = bilateral, R = right, *T* = peak *T* value, cluster size in voxels, *P* < 0.001 (uncorrected).

Valence-specific emotion effects

Only small clusters were activated in the valence specific contrasts: Left orbito-frontal (BA 11) and superior frontal (BA 8) region and bilateral clusters in the middle temporal gyrus

(BA 46) were significantly more active for positive compared with neutral words, while only a right hemispheric prefrontal region in BA 10 was more active in the neutral vs. positive contrast (Table 3).

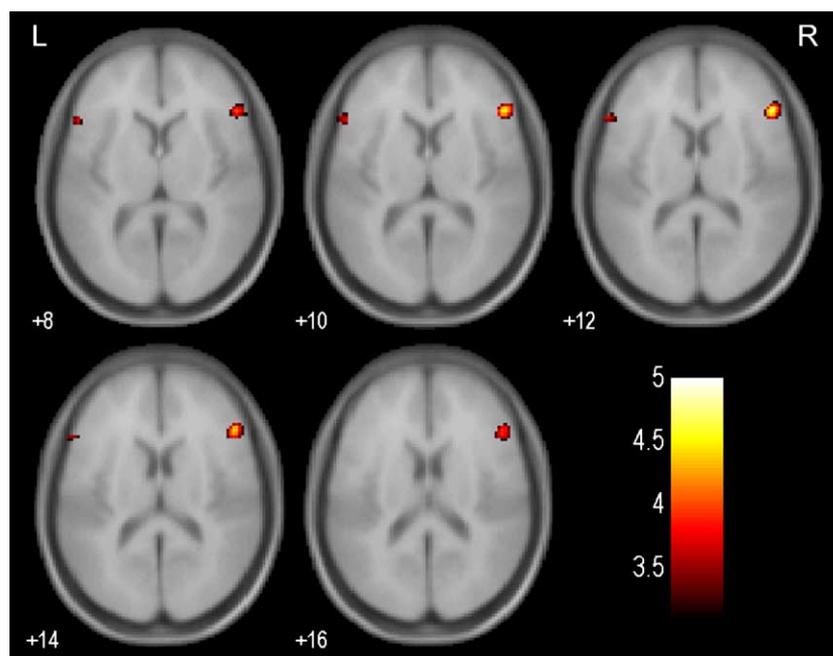


Fig. 2. Inferior frontal gyrus activity identified in the valence independent emotional > neutral contrast displayed on MNI 305 brain average (*P* < 0.001, uncorrected). The numbers at the left bottom corner indicate *z* coordinate in MNI space. The color bar indicates the *T* values. L = left, R = right.

Table 3
Regions showing significant signal changes to emotional valent words

Brain region	BA	Cluster size	<i>T</i>	<i>x</i>	<i>y</i>	<i>z</i>	
<i>Emotional > Neutral</i>							
L	Orbitofrontal gyrus	BA 11	7	4.72	−3	42	−24
L	Inferior frontal gyrus	BA 45	6	4.06	−54	21	9
R	Inferior frontal gyrus	BA 46	21	4.90	51	27	12
<i>Neutral > Emotional</i>							
L	Medial frontal gyrus	BA 42	14	4.79	−18	42	9
R	Superior + middle frontal gyrus	BA 10	9	5.13	33	63	0
R	Middle temporal gyrus		8	4.21	39	−45	6
<i>Negative > Neutral</i>							
R	Inferior frontal gyrus	BA 45/46	29	5.28	54	27	9
<i>Neutral > Negative</i>							
L	Posterior cingulate gyrus		31	5.07	−24	−54	15
L	Fusiform + parahippocampal gyrus	BA 20/36/37	26	4.56	−27	−33	−21
L	Parahippocampal gyrus	BA 34	7	4.60	−15	−3	−21
L	Anterior cingulate gyrus	BA 32	5	4.15	−18	42	9
R	Superior + medial frontal gyrus	BA 9/32	13	5.20	15	39	21
R	Superior + middle temporal gyrus	BA 22	12	4.53	39	−54	9
R	Medial frontal gyrus	BA 10	7	4.57	9	57	0
R	Posterior cingulate gyrus	BA 30	6	4.00	12	−57	3
R	Hippocampus		4	3.67	27	−21	−12
R	Posterior cingulate gyrus		4	3.82	27	−60	18
<i>Positive > Neutral</i>							
L	Orbitofrontal gyrus	BA 11	7	4.93	−3	42	−24
L	Middle temporal gyrus	BA 21	4	3.87	−45	6	−36
R	Superior + middle temporal gyrus	BA 38/21	11	5.61	48	6	−30
R	Superior frontal gyrus	BA 8	4	4.04	12	48	51
<i>Neutral > Positive</i>							
R	Middle frontal gyrus	BA 10	7	4.82	39	57	9
<i>Positive > Negative</i>							
L	Posterior cingulate gyrus	BA 31	20	6.34	−24	−63	18
B	Anterior cingulate gyrus	BA 32	13	4.47	0	39	−3
R	Lingual gyrus	BA 18/19/30	15	4.96	15	−54	0
R	Hippocampus		9	4.12	30	−21	−12

x, *y*, *z* = coordinates according to MNI stereotactic space, BA = approximate Brodmann's area, L = left, B = bilateral, R = right, *T* = peak *T* value, cluster size in voxels, *P* < 0.001 (uncorrected).

A right inferior frontal cluster survived the contrast between negative and neutral words (BA 45). The opposite contrast between neutral and negative stimuli with deactivations for the negative valence condition showed significant differences in the left-hemispheric parahippocampal gyrus (BA 34) spreading to the fusiform gyrus (BA 37) as well as left anterior (BA 32) and bilateral posterior cingulate gyrus (BA 30). Superior activations for neutral words (compared with negative ones) were also seen in a right-sided medial frontal region (BA 9, 10), middle temporal gyrus (BA 22) and the hippocampus (Table 3).

When directly comparing positive and negative conditions, positive words showed stronger responses in the left posterior cingulate gyrus (BA 31), bilateral anterior cingulate gyrus (BA 32), right-hemispheric lingual gyrus (BA 19) and right hippocampus (Fig. 3). Negative words revealed no activation focus with stronger hemodynamic response than positive words (Table 3).

Discussion

Behavioral measures

Common to most theories about processing words and pronounceable nonwords in a LDT is the idea that word stimuli also activate semantic nodes in a relational network. Thus, the subjects' responses can be facilitated or inhibited through the use of semantic information (e.g., Seidenberg and McClelland, 1989).

Our results clearly indicate an advantage for positive words compared with neutral or negative words in the LDT in response latencies and accuracy data for both the pilot study and the fMRI study. Given the minimal differences between the two experiments and the well-controlled characteristics of the stimulus material, the similarity of the obtained pattern of results in subject and item analyses produce a clear-cut picture. The LDT does not require emotionally valenced responses to be made, nor does it require that subjects (fully) identify the meaning of the words (Grainger and

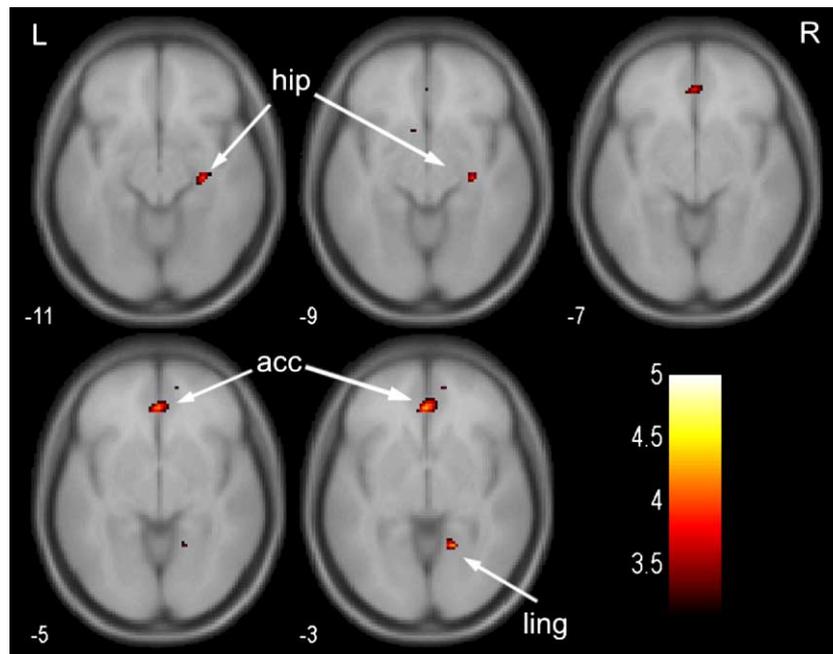


Fig. 3. Hippocampus (hip), anterior cingulate gyrus (acc) and lingual gyrus activity (ling) as identified in the positive > negative contrast ($P < 0.001$, uncorrected).

Jacobs, 1996). While dissociating between positive and negative emotional stimuli, our behavioral data strongly support the idea of an early evaluation process in word recognition. Thus, we could replicate earlier findings using the LDT (MacLeod et al., 1987; Ruiz-Caballero and Moreno, 1992; Strauss, 1983), and comparable differential effects between positive and negative words found in other studies of implicit memory, like word-stem-completion (Ruiz-Caballero and Gonzalez, 1994), priming (Bradley et al., 1994) or emotional stroop (Ehlers et al., 1988).

To account for this effect, one simple possibility is to assume that positively valenced stimuli generally and automatically facilitate word recognition, a view that is in accordance with a number of theories about emotion and memory. The associative network model of memory and emotion, for instance, claims, that emotional states can be represented as nodes in a semantic network (Bower, 1981). This flexibly handles the possibility of spreading activation in a semantic network, which accounts for the asymmetry between positive and negative affect (Isen, 1987). Isen (1985, 1987) proposed that this asymmetry between positive and negative material appears due to the different organization of the emotional material in memory, suggesting differently structured schemata or networks. According to this idea, positive material may be better elaborated and interconnected in the cognitive-emotional system than negative material (Ashby et al., 1999; Isen, 1985; Ruiz-Caballero and Gonzalez, 1994), while broader positive schemata should be more readily cued when the network activation increases. However, it is suggested that the influence of emotional “nodes” may be restricted to the retrieval of episodic (personally experienced) events (MacLeod et al., 1987; Ruiz-Caballero and Moreno, 1992).

Another possible account is the activation versus elaboration model (Graf and Mandler, 1984). According to this view, an automatic “integration” process involves the temporary strengthening of a representations’ internal organization. Thus, such a

representation will not be better recalled, but more readily produced when only some of its features have been fully processed, depending on the different cohesiveness of the representations’ internal structure (Isen, 1987; MacLeod and Mathews, 1991). Accordingly, a highly integrated positive representation will be easier to perceive than negative or neutral ones.

Still, it is puzzling that other studies failed to find such an asymmetry (Challis and Krane, 1988; Siegle et al., 2002; Williamson et al., 1991). However, these experiments differ in methodological and procedural aspects from our study and thus are not fully comparable (see Introduction). The question arises whether there are other factors than those controlled in our and previous studies.

fMRI data

One aim of this study was to examine effects of the emotional valence of words when a priori subjects do not have to pay attention to this dimension of the stimuli. Firstly, the activated brain regions indicate differences in the way the brain processes words and nonwords, allowing to conclude that blood oxygen level dependent (BOLD) responses to words may reflect the activation of semantic word knowledge as well as (to a lesser degree) the involvement of phonological and orthographic processes. Because nonwords were phonologically and orthographically legal and thus should produce partial activations of orthographic and phonological codes, activation differences may firstly be attributed to successful mapping of orthographic percepts onto word form representations (Fiebach et al., 2002). Moreover, the observed pattern including left hemispheric dorsal prefrontal and bilateral temporal activations (including angular and middle temporal gyrus) has previously been associated with semantic retrieval (Poldrack et al., 1999; Price, 2000; Price et al., 1997) and selection of competing alternatives in semantic knowledge (Thompson-

Schill et al., 1997). On the other hand, it is clear that the processes underlying a word vs. nonword decision differ in important respects (Grainger and Jacobs, 1996). This view is supported by the behavioral differences showing greater response latencies for nonwords, indicating that the rejection of a nonword in our study is more effortful than the recognition of a word. Higher retrieval effort has previously been associated with left inferior frontal activations (Buckner et al., 1998). Thus, the extended bilateral inferior frontal and the left medial frontal activations when processing nonwords likely are not only related to phonological processes (e.g., grapheme–phoneme mapping, Binder et al., 2003). Ventrolateral prefrontal activations have often been reported in studies involving verbal working memory tasks (e.g., response inhibition, D’Esposito et al., 2000; Jonides et al., 1998) and strategic control of lexical selection (Fiebach et al., 2002). Parahippocampal activations in the nonword condition are in accordance with recent findings showing that encoding of unfamiliar stimuli correlates with hippocampal activity (Henson et al., 2003).

Effects of emotional valence

A major finding of the current study is that emotional valence when processed incidentally in a word recognition task led to distinct prefrontal and middle temporal activations. The orbitofrontal and inferior frontal regions (IFG) are often reported in explicit memory on emotion (Dolcos et al., 2004; Smith et al., 2004) and IFG activations are more generally related to semantic memory functions (e.g., memory retrieval, Nyberg et al., 2003; Poldrack et al., 1999). An fMRI study by Cunningham et al. (2004) investigated implicit and explicit evaluation of emotional valence about socially relevant concepts and found similar activations in right inferior frontal and orbitofrontal cortex for automatic evaluation. The finding of orbitofrontal gyrus activation for positive stimuli is supported by recent experimental evidence concerning its role in the retrieval of positive contextual information or the appraisal of reward. They suggest that orbitofrontal cortex is engaged in the retrieval of memories that have been associated with positive emotional contexts (Damasio, 1996; Maratos et al., 2001; Rolls, 2000). In contrast, studies of emotional valence in explicit semantic memory tasks reported more superior frontopolar activations in BA 9, 10 (Cato et al., 2004; Crosson et al., 1999).

Although the negative-neutral subtraction contrast produced a right IFG activation and the positive-neutral contrast a left hemispheric orbitofrontal as well as bilateral middle temporal cluster, the observed pattern cannot be seen as support of the “valence hypothesis” (Canli et al., 1998; Davidson, 1995; see: Wager, 2003 for a meta-analysis). Because none of these regions survived the direct positive vs. negative comparison, it seems that both positive and negative stimuli are processed in both hemispheres leading only to significant BOLD responses when contrasted with neutral items (see Fig. 4). It is possible that the distinction between emotional valence and emotional intensity accounts for this result (Cunningham et al., 2004). While positive and negative items differed in their emotional valence, they were matched for absolute amount of emotional valence, contrary to neutral items, which are not affectively valent (intense) per se.

Further effects of positive words (compared with neutral words) were also evident in the middle temporal gyrus, a region previously reported in studies of semantic retrieval (e.g. Price, 2000; Price et

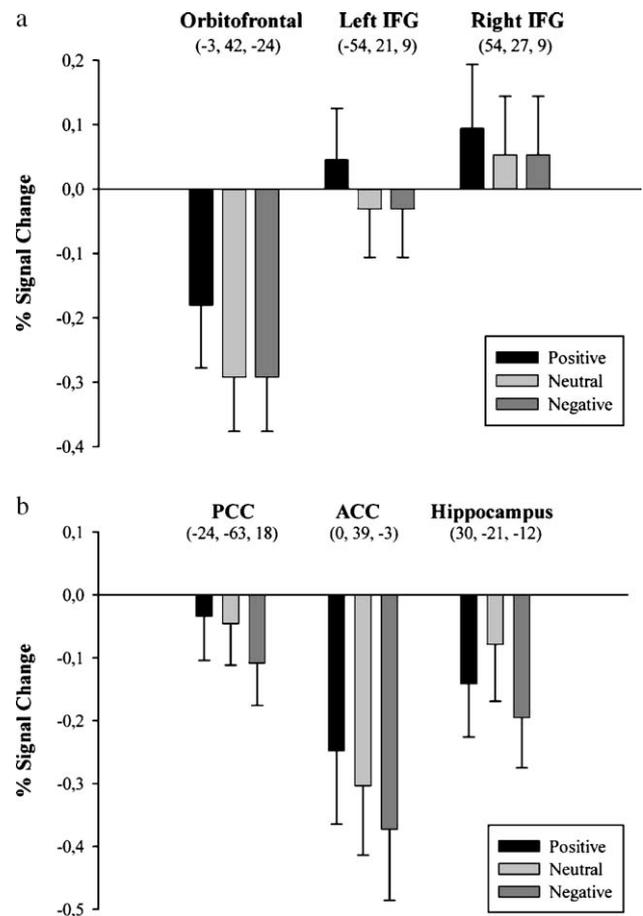


Fig. 4. Percent signal change and associated standard errors for positive, neutral and negative words at the peak of the hemodynamic response at regions indicated (IFG inferior frontal gyrus, ACC anterior cingulate gyrus, PCC posterior cingulate gyrus).

al., 1997). Since only positive words significantly increased the BOLD response of this region bilaterally, this might be due to the above mentioned more elaborated and interconnected positive schemata. However, this hypothesis needs to be investigated further, e.g., by manipulating the semantic cohesiveness of the experimental stimuli.

For the direct valence-specific contrast (positive over negative words), we identified several other regions which previous research has shown to support emotional processing, including anterior and posterior cingulate gyrus and hippocampus (see Fig. 3). Activity in posterior cingulate gyrus has been related to evaluation of an external stimulus with emotional salience (Cato et al., 2004; Maddock et al., 2003), and to episodic retrieval in general, suggesting increasing activity as an effect of emotional manipulation (Maddock, 1999; Maratos et al., 2001). Consistent literature findings suggest a crucial role of the posterior cingulate gyrus in interactions with the hippocampus formation in emotional memory retrieval (Dolcos et al., 2004; Smith et al., 2004). It is discussed that parahippocampal activation may not only be due to the retrieval process, but also to the (re)encoding process (Smith et al., 2004; Stark and Okada, 2003). The anterior cingulate gyrus is known to be involved in autonomic control, memory retrieval (Cabeza and Nyberg, 2000; Dehaene et al., 1994), conflict monitoring (Botvinick et al., 2004) and the mediation of motiva-

tional or affective responses (Barch et al., 1997; Devinski et al., 1995). Thus, one could argue that positive words trigger a higher amount of control processes, but this would be in contrast with the observed behavioral data pattern where positive stimuli produce shorter response latencies and fewer errors. Therefore, the anterior cingulate gyrus activation in this study more likely indexes its direct role in mediating different emotional processes including assignment of emotional valence to internal and external stimuli (Ashby et al., 1999; Devinski et al., 1995). This would be consistent with the close relationship of this region to the limbic structures of the brain.

Surprisingly, we did not observe amygdala activation in any of the emotional contrasts. Converging evidence indicated amygdala as an important interface between episodic memory and affect, possibly associating an affective state with a memory trace (Ashby et al., 1999; Damasio, 1996; Hamann and Mao, 2002; LeDoux, 1995; Siebert et al., 2003). Because most of the studies reported amygdala activation during encoding and retrieval of emotional pictures and words, its role in word recognition is almost unknown. When an emotionally arousing stimulus appears, it will first automatically activate right amygdala (Glascher and Adolphs, 2003; Wright et al., 2001). This is supposed to mediate a global, rapid and relatively automatic activation (Wright et al., 2001). Assuming that this amygdala activation holds true for single word processing, our failure to find amygdala activation might be due to the low temporal resolution of the fMRI. The other possibility is that the amygdala is not the only component of an implicit evaluation system, as suggested by a recent patient study (Phelps et al., 2003). The amygdala may be critical in automatically evaluating an affective stimulus, but other areas like inferior frontal or orbitofrontal gyrus may also subservise these automatic processes.

A recent model by Kensinger and Corkin (2004) describes the distinction between an arousal-dependent *amygdalar-hippocampal* and a valence-dependent *prefrontal cortex-hippocampal* network, supporting the idea of different neural pathways for valence and arousal. If performance in the LDT mainly depends on controlled encoding processes instead of arousal-mediated evaluation, then an amygdala involvement is not expected. Although we did not control the arousal dimension (see Footnote 1), it seems likely that the LTD does not depend as much on stimulus arousal as for example episodic memory tasks.

In conclusion, we found evidence of incidental processing of the emotional valence of word stimuli in both behavioral and functional neuroimaging data. Regions previously known to be associated with explicit emotional evaluation and emotional memory retrieval, as well as semantic retrieval per se, are also active when processing an affective word incidentally.

Acknowledgments

Thanks are due to Peter Erhard of the Center for Advanced Imaging, University of Bremen, for giving methodological support and to Lucia van Eimeren for editing the manuscript. During preparation of the manuscript, Lars Kuchinke was supported by the German Research Council (DFG, grant JA 823 /3-1 to Arthur M. Jacobs) and the research group “Neuroscience of Emotion” at the Hanse Institute for Advanced Study, Delmenhorst/ Bremen, Germany.

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