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Dissociation of event-related potentials indexing arousal and semantic cohesion during emotional word encoding

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Abstract

Event-related potential (ERP) studies have shown that emotional stimuli elicit greater amplitude late positive-polarity potentials (LPPs) than neutral stimuli. This effect has been attributed to arousal, but emotional stimuli are also more semantically coherent than uncategorized neutral stimuli. ERPs were recorded during encoding of positive, negative, uncategorized neutral, and categorized neutral words. Differences in LPP amplitude elicited by emotional versus uncategorized neutral stimuli were evident from 450 to 1000 ms. From 450 to 700 ms, LPP effects at midline and right hemisphere frontal electrodes indexed arousal, whereas LPP effects at left hemisphere centro-parietal electrodes indexed semantic cohesion. This dissociation helps specify the processes underlying emotional stimulus encoding, and suggests the need to control for semantic cohesion in emotional information processing studies.

Keywords: Affect; Amygdala; Categorization; Emotion; Evoked potentials; P300

1. Introduction

Emotional stimulus encoding has been well-studied using event-related potential (ERP) methodology. These investigations have consistently shown that, relative to neutral stimuli, emotional stimuli elicit late positive-polarity potentials (LPPs) of increased amplitude (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Diedrich, Naumann, Maier, & Becker, 1997; Dolcos & Cabeza, 2002; Johnston, Miller, & Burleson, 1986; Naumann, Bartussek, Diedrich, & Laufer, 1992; Palomba, Angrilli, & Mini, 1997; Schupp et al., 2000; Schupp, Cuthbert et al., 2004; Schupp, Ohman et al., 2004). Emotional ERP effects generally encompass the P3 and/or a subsequent slow-wave (SW) and are broadly distributed, having been observed over frontal, central, and parietal scalp regions.

It has been suggested that increased LPPs reflect increased attentional resources devoted to emotionally arousing stimuli (Cuthbert et al., 2000; Schupp et al., 2000; Schupp, Cuthbert et al., 2004; Schupp, Ohman et al., 2004). This argument is based on cognitive studies that show an association between increased perceptual processing of stimuli (after initial identification) and increased LPPs (Ritter & Ruchkin, 1992). It is proposed that emotional stimuli (e.g., pictures of opposite sex nudes or dangerous animals) are particularly salient to humans because they are closely tied to reproduction and survival (i.e., they are evolutionarily significant stimuli). Because of this salience, emotional stimuli elicit activity in the brain's appetitive and defensive motivational systems (Lang, Bradley, & Cuthbert, 1998) and tend to recruit attentional resources and sustained attentional processing, which, in turn, leads to increased amplitude LPPs. This hypothesis receives support from the fact that highly arousing emotional stimuli, which are presumably especially motivationally significant, elicit LPPs of greater amplitude than less arousing emotional stimuli (Cuthbert et al., 2000; Schupp et al., 2000; Schupp, Junghofer, Weike, & Hamm, 2003).

Another factor that may contribute to the amplitude difference in LPPs elicited by emotional and neutral stimuli is *semantic cohesion.* A group of neutral items (e.g., the

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words *rug*, *theory*, and *folder*) is likely to possess lower inter-item associativity than a group of emotional items (e.g., the negative words *violence*, *anger*, and *threat*) and are thus less semantically cohesive. Numerous studies have shown that ERPs are sensitive to semantic factors during stimulus encoding. For example, studies of semantic priming have demonstrated that primed words (compared with unprimed words) elicit increased positivities during relatively late latency intervals (e.g., peaking between 550 and 650 ms in Bentin, McCarthy, & Wood, 1985). In addition, the amplitude of the N400 component elicited by individual words is inversely related to the ease with which those words are integrated into an existing semantic context (Kutas & Besson, 1999; Kutas & Hillyard, 1980; Kutas & Schmitt, 2003; Kutas & Van Petten, 1994). Typically, these studies have used non-emotional stimuli and have highlighted the semantic relationships between stimuli to a greater degree than have studies of emotional item encoding. Nonetheless, the results suggest that the increased semantic cohesion possessed by groups of emotional stimuli (relative to neutral stimuli) may contribute to increased amplitude LPPs, perhaps in concert with reductions in N400 amplitude.

Recent ERP studies (Maratos, Allan, & Rugg, 2000; McNeely, Dywan, & Segalowitz, 2004; Windmann & Kutas, 2001) have investigated the role played by semantic cohesion during *recognition memory testing* for emotional and neutral stimuli, with somewhat mixed results (see Section 4). The primary goal of the present study was to determine whether semantic cohesion contributes to the amplitude difference in LPPs elicited by emotional and neutral items during *initial encoding*. To achieve this aim, the scalp electroencephalogram was recorded while participants encoded four classes of words. Three of the word classes are commonly used in emotion research: positive, negative, and uncategorized neutral. These stimuli were specifically chosen so that the emotional words would be both more arousing and more semantically coherent than the uncategorized neutral words. The novel aspect of the study design involves the inclusion of a fourth stimulus class—categorized neutral words—which were organized around a "school" theme. These categorized neutral stimuli were selected to be equivalent to the uncategorized neutral stimuli with respect to arousal and valence, but equivalent to the positive and negative stimuli with respect to semantic cohesion. "School-related" stimuli were selected for the categorized neutral class because "school" constitutes a relatively broad semantic category whose exemplars could be matched to emotional stimuli with respect to word frequency, imageability, and semantic cohesion. We expected that it would be difficult to achieve such matching with other typical semantic categories—e.g., fruits, animals, or furniture—because those categories would tend to be too narrow or too imageable in comparison to the emotional stimuli (but see McNeely et al., 2004). Because semantic cohesion effects are likely to be more robust with lexical (versus pictorial) stimuli, we used words for this initial investigation.

There are two main assumptions inherent in the experimental design. First, ERPs that distinguish both emotional stimulus classes from the categorized neutral stimulus class (school-related words) should reflect arousal-related processes (because the emotional and categorized neutral stimuli have been equated for semantic cohesion). Based on the emotional ERP literature, we expected arousal-related ERP effects to be broadly distributed, to onset at about 300–400 ms post-stimulus, and to last for several hundred milliseconds (Cuthbert et al., 2000; Dolcos & Cabeza, 2002; Schupp et al., 2000).

Second, ERPs that distinguish categorized neutral stimuli from uncategorized neutral stimuli should reflect processes related to semantic cohesion. Because semantic cohesion has not been directly investigated in previous neuroscientific studies of emotional stimulus encoding, the precise timing and spatial location of ERP effects related to semantic cohesion was difficult to predict. However, given that hemispheric lateralization of activity in semantic-perceptual networks varies by stimulus type, we predicted that semantic cohesion effects would be lateralized to the left hemisphere since words were used as stimuli. With respect to timing, previous ERP research on word encoding indicates that ERP components are not modulated by contextual influences until approximately 260 ms post-stimulus (Halgren, 1990). Furthermore, the duration of other ERP components known to be sensitive to the context in which lexical stimuli are presented (e.g., the N400) is inversely related to the ease with which the stimuli can be integrated into the context. Because we used relatively broad contexts, we predicted that LPPs sensitive to semantic cohesion would be evident over left hemisphere sites in approximately the 260–700 ms time window. This prediction is in line with ERP studies of semantic priming, which have identified increased amplitude LPPs for target words (in semantically related prime-target pairs) in similar time ranges (Bentin et al., 1985). Dissociating the influences of arousal and semantic cohesion during encoding will help characterize the mechanisms underlying emotional advantages in stimulus processing, with potential implications for understanding how emotional content benefits other cognitive functions, such as memory.

2. Method

2.1. Participants

Twenty-one healthy right-handed participants (12 females, 9 males) with a mean age of 23 ($SD = 4.29$) participated in the experiment. Data from six participants were excluded from the analysis. One of these did not follow instructions, one ended the experiment prematurely because of illness, and one's data could not be analyzed because of technical difficulties. Data from three other participants were excluded because more than ~25% of their trials were rejected due to physiological artifacts (eye blinks, eye movements, muscle activity). The remaining fifteen participants (9 females, 6 males) had a mean age of 22 ($SD = 3.41$). Participants were screened by phone and written questionnaire for history of neurological and psychiatric illness, drug abuse, and psychotropic medication use. All participants provided written informed consent for a protocol approved by the Duke University Institutional Review Board and were either paid ($30) or received class credit for their participation.

2.2. Materials

Stimuli consisted of 384 words (see Appendix A). Ninety-seven were emotionally positive (e.g., "miracle"), 93 were emotionally negative (e.g., "anxiety"), 97 were school-related (e.g., "tutor"), and 97 were uncategorized neutral words (e.g., "panel"). Words were selected from the Affective Norms for English Words (ANEW) list (Bradley & Lang, 1999) and supplemented with additional words drawn from a list developed by the authors.

Words were chosen on the basis of properties related to arousal, valence, imageability, and semantic cohesion. Arousal and valence ratings were obtained from the ANEW database and additional pilot testing with undergraduate students and community residents at Duke University. Ratings were made using nine-point scales for both arousal (1 = *completely calm*, 9 = *completely aroused*) and valence (1 = *completely unpleasant*, 9 = *completely pleasant*). Mean arousal and valence ratings are provided in Table 1. A one-way ANOVA comparing arousal ratings revealed a main effect of Word Type, $F(3,380) = 152.90$, $p < .001$. Follow-up t tests revealed significant differences in arousal ratings between emotional words and both neutral word classes (all ps < .05) but no within-class differences—i.e., both classes of emotional words and both classes of neutral words were matched for arousal (all ps > .05). A one-way ANOVA comparing valence ratings revealed a main effect of Word Type, $F(3,380) = 645.92$, $p < .001$. Follow-up t tests indicated significant valence differences between negative and positive words, and between both classes of emotional words and the two classes of neutral words (all ps < .05). The two classes of neutral words did not differ significantly from each other ($p > .05$).

Word frequency estimates were obtained from Kucera and Francis (1967). A one-way ANOVA on word frequency failed to reveal differences related to Word Type, $F < 1$. In additional pilot testing, undergraduates at Duke University were presented with the stimulus lists and asked to use a 9-point scale to assess the ease with which each word could be imagined (1 = *hard to picture*, 9 = *easy to picture*). A one-way ANOVA comparing the imageability of the words did not reveal differences due to Word Type, $F(3,380) = 1.22$, $p = .30$.

The semantic cohesion of each of the four word lists was determined by submitting the lists to Latent Semantic Analysis (LSA; http://lsa.colorado.edu) (Landauer, Foltz, & Laham, 1998; Windmann & Kutas, 2001). LSA is a mathematical technique that extracts ratings of semantic similarity from bodies of text. Research has shown a close correspondence between judgments of similarity made by LSA and human participants (Landauer & Dumais, 1997). LSA yielded an average within-list semantic similarity estimate (±SEM) of 0.044 (.002) for positive words, 0.046 (.002) for negative words, 0.053 (.004) for school-related words, and 0.018 (.001) for uncategorized neutral words. A one-way ANOVA revealed a significant difference due to Word Type, $F(3,380) = 37.15$, $p < .001$. Follow-up t tests indicated that the semantic similarity estimates for positive, negative, and school-related words all differed significantly from the estimate for uncategorized neutral words (all ps < .05). No other between category comparison revealed a significant difference (all ps > .05). Thus, the positive, negative, and school-related lists had a statistically indistinguishable degree of within-list semantic similarity, which was greater than that of the uncategorized neutral list.

To summarize, all words were matched for frequency and imageability. Positive and negative words were equated for arousal, as were uncategorized neutral and school-related words. Positive and negative words were more arousing than the uncategorized neutral and school words. The uncategorized neutral and school-related words were matched for valence, which was significantly different from the valence of the positive and negative words. Finally, positive, negative, and school-related word lists were matched for semantic cohesion; these three lists were more semantically coherent than the list of uncategorized neutral words.

Lists of each class of word stimuli were divided in half, and two master lists were formed, each containing negative, positive, school-related, and uncategorized neutral words. The order of words within each list was pseudo-randomized. Each participant was presented with one of the two

Table 1
Mean (*SD*) stimulus properties, participant ratings, and reaction times (RT) by stimulus category

	Positive	Negative	School	Neutral
Frequency	15.40 (8.04)	15.44 (32.25)	17.70 (19.53)	17.03 (17.18)
Imageability	5.01 (2.11)	5.33 (0.93)	5.46 (1.56)	5.27 (1.87)
Normative valence	7.49 (0.57)	2.37 (0.89)	5.14 (1.00)	5.30 (0.69)
Normative arousal	5.96 (0.72)	5.99 (0.92)	3.97 (0.90)	3.81(1.22)
Participant arousal	2.65 (0.52)	2.58 (0.59)	1.93 (0.43)	1.70 (0.40)
Participant RT	681 (170)	712 (205)	711 (197)	702 (180)

Note. Frequency scores obtained from Kucera and Francis (1967). Imageability and normative arousal and valence ratings reflect scores on 9-pt scales, whereas participant arousal ratings reflect scores on a 4-pt scale.

lists, and the list presented was alternated on a participant-by-participant basis. The words were presented in nine runs of 20 and one run of 12; two run orders were used and alternated on a participant-by-participant basis. Words were centrally presented in white typeface on a black background—the font used was Times New Roman and the font size was 24. Participants were seated 57 cm from the screen and stimuli were centrally presented; consequently, stimuli subtended approximately 15 degrees of visual angle in the horizontal plane.

2.3. Procedure

The experiment was conducted on a PC using Presentation software (Neurobehavioral Systems, Inc., San Francisco, CA). Each session consisted of a practice run and 10 study runs. Individual trials consisted of a word (1500 ms duration) followed by an arousal rating screen (2000 ms duration), and a 1500 ms inter-stimulus interval separated the arousal rating screen from the next word. The arousal rating screen consisted of the digits 1, 2, 3, and 4, presented horizontally. Both the words and the digits used for arousal rating were presented directly below a centrally presented fixation cross, which was present on screen throughout each run. Participants were instructed to rate each word for arousal based on the initial emotional response it elicited using the 4-point scale (1 = *unarousing*, 2 = *slightly arousing*, 3 = *moderately arousing*, 4 = *very arousing*). Participants used a game pad to make their arousal ratings, and were instructed to wait until the arousal rating screen appeared before responding. All participants used both hands to make responses, but the mapping of response buttons was counterbalanced between participants to minimize lateralized ERP differences due to response button mapping. Participants used one hand to make low arousal ratings and the other hand to make high arousal ratings; the left/right mapping of the low/high arousal rating buttons was crossed between participants. Participants were instructed to remain still and avoid blinking during word presentation.

2.4. ERP recordings

The EEG was recorded from 64 electrodes in a custom elastic cap (Electro-Cap International, Inc., Eaton, OH) and referenced to the right mastoid during recording. Electrode impedances were maintained below 2 kΩ for the mastoids, below 10 kΩ for the facial electrodes, and below 5 kΩ for all the remaining electrodes. Horizontal eye movements were monitored by two electrodes at the outer canthi of the eyes, and vertical eye movements and eye blinks were detected by two electrodes placed below the orbital ridge of each eye. The 64 channels were recorded with a bandpass filter of 0.01 to 100 Hz and a gain of 1000. The raw signal was continuously digitized with a sampling rate of 500 Hz. Recordings took place in an electrically shielded, sound-attenuated chamber.

Because we recorded from 64 electrode sites, the nomenclature used here is based on the International 10–20 system (Jasper, 1958) but with additional information that reflects the increased spatial coverage. Electrodes are identified by 10–20 positions, modified with letters or symbols denoting the following: a = slightly anterior placement relative to the original 10–20 position, p = slightly posterior placement, i = inferior placement, s = superior placement, m = slightly medial placement, and ' = placement within 1 cm of 10–20 position.

2.5. ERP data reduction

Artifact rejection was performed off-line by discarding epochs of the EEG that revealed eye movements, eye blinks, excessive muscle-related potentials, drifts, or amplifier blocking. The mean percentage of trials dropped from analysis due to artifacts for the final set of participants was 13%. Averages were calculated for the different stimulus types from 400 ms before to 1200 ms after stimulus onset. The averages were digitally low-pass filtered at 60 Hz. After averaging, all channels were re-referenced to the algebraic average of the two mastoid electrodes. The ERP averages for individual participants were then combined into group averages across all participants.

2.6. ERP data analysis

ERPs elicited by each word type were plotted to allow visual inspection of emotional LPP effects expected based on previous literature (Schupp et al., 2000). Next, a series of difference waves was created in order to identify ERP effects indexing arousal and semantic cohesion. Preliminary analyses did not reveal significant differences due to emotional valence, and the primary goal of this experiment was to distinguish between ERPs sensitive to arousal and semantic cohesion. Therefore, ERPs elicited by negative and positive stimuli were averaged together to create a single "Emotional" category.

A difference wave was created by subtracting ERPs elicited by uncategorized neutral stimuli from those elicited by emotional stimuli. This comparison should reveal differences due to both arousal and semantic cohesion. Since this comparison is frequently performed in investigations of emotional ERP effects, it is hereafter referred to as the *standard emotion subtraction*. A second difference wave was then created by subtracting ERPs elicited by school-related (categorized neutral) stimuli from those elicited by emotional stimuli. Because the emotional and school-related stimuli were equated for semantic cohesion, this "Emotional minus School" comparison should only reveal differences due to arousal and is hereafter referred to as the *arousal subtraction*. Finally, a third difference wave was created by subtracting the "Emotional minus School" difference wave from the "Emotional minus Uncategorized Neutral" difference wave. This final difference wave is exactly equal to the difference wave that would be created by subtracting ERPs elicited by uncategorized neutral words from ERPs elicited by school-related words, and should isolate any ERPs that index semantic cohesion. Hence we refer to this difference of difference waves as the *semantic cohesion effect*.

A data-driven analytic approach was used to characterize the spatiotemporal distribution of ERP effects revealed by the difference waves and select groups of electrodes for statistical analysis. First, topographic voltage maps (Perrin, Pernier, Bertrand, & Echallier, 1989) for each of the three difference waves (standard emotion subtraction, arousal subtraction, semantic cohesion effect) were plotted for two time intervals (450–700 ms and 700–1000 ms) that covered the extent of the LPP. Second, separate ANOVAs were computed for every electrode site with Word Type as a repeated factor for each comparison of interest. The comparisons are referred to as the *standard emotion comparison* ("Emotional versus Uncategorized Neutral"), *arousal comparison* ("Emotional versus School"), and *semantic cohesion effect* ("School versus Uncategorized Neutral"), respectively. ANOVAs were conducted on mean amplitude data, relative to a 200 ms pre-stimulus baseline, for the 450–700 and 700–1000 ms time windows. Resulting *F*-values were then plotted using spherical spline interpolation (Perrin et al., 1989), resulting in two *F*-maps for each comparison of interest (Hopf & Mangun, 2000). The purpose of computing *F*-maps was to confirm the reliability of the topographic analyses and to identify groups of electrodes where effects of arousal and semantic cohesion were maximal. For the degrees of freedom in this experiment (1,14), an *F* of 4.60 corresponds to an alpha of .05. Therefore, for each comparison we plotted *F*-values which equaled or exceeded this value. Finally, the *F*-maps were used to guide selection of groups of electrodes for use in region-of-interest (ROI) analyses. These analyses compared mean amplitude ERPs (relative to a 200 ms baseline) elicited by emotional, school-related, and uncategorized neutral words in the 450–700 and 700–1000 ms time windows. Electrode sites used for ROI analyses were chosen so as to encompass regions where amplitude differences were maximal in the standard emotion subtraction, which reveals ERP effects related to both arousal and semantic cohesion. The same ROIs were then used to interrogate the arousal and semantic cohesion effects separately. This data-driven approach allowed us to conservatively estimate the contributions made by arousal and semantic cohesion to LPPs elicited during emotional stimulus encoding.

3. Results

3.1. ERP Results

The following ranges (minimum–maximum) indicate the number of stimuli contributing to the ERPs, as a function of Word Type, after artifact rejection: negative (30–45), positive (31–47), uncategorized neutral (34–47), school-related (34–48). Late positive potentials were evident in the group averaged ERP waveforms elicited by each word type and had an onset time of approximately 450 ms post-stimulus (Fig. 1). As expected, emotional stimuli elicited increased amplitude LPPs relative to both types of neutral stimuli. This effect of emotion on LPP amplitude appeared broadly distributed and extended to about 1000 ms post-stimulus at most electrode sites. Furthermore, visual inspection of the data suggested that emotional and school-related words elicited increased LPPs relative to uncategorized neutral stimuli from approximately 450–700 ms at left hemisphere parietal electrodes (see electrode P3a, Fig. 1).

3.1.1. Topographical analyses

Fig. 2a shows topographical maps of the standard emotion subtraction in the 450–700 and 700–1000 ms time windows. From 450 to 700 ms, amplitude differences (Emotional > Neutral) are evident over midline and bilateral frontal sites as well as midline and left hemisphere central and parietal sites. From 700 to 1000 ms, differences over frontal sites were shifted more toward the midline and right hemisphere, and differences over central and parietal sites were no longer prominent.

Fig. 2b displays similar topographical maps of the arousal subtraction. From 450 to 700 ms, amplitude differences are evident primarily over midline and right hemisphere frontal and central sites, with differential activity apparent over some anterior parietal electrodes in the right hemisphere. From 700 to 1000 ms, amplitude differences were smaller with a less focal distribution.

Finally, the difference wave and topographical map illustrating the semantic cohesion effect are presented in Fig. 2c. From 450 to 700 ms, amplitude differences are observed primarily over parietal electrodes in the left hemisphere. No consistent amplitude differences were evident in the 700–1000 ms window.

3.1.2. F-maps and region-of-interest (ROI) analyses

The *F*-maps generally confirmed the results of the topographical analyses. Fig. 3a shows *F*-maps generated from comparisons of ERPs elicited by emotional and uncategorized neutral words. In the 450–700 ms window, statistically robust differences in the standard emotion comparison are evident over midline and bilateral frontal electrode sites, as well as left hemisphere (and some midline) central and parietal sites. From 700 to 1000 ms, the only prominent activity is located over midline and right hemisphere frontal sites. These results are consistent with the topographical analyses, as well as with previous ERP investigations of emotional stimulus processing (e.g., Dolcos & Cabeza, 2002). Fig. 3b displays the *F*-map generated from comparisons of ERPs elicited by emotional and school-related words in the 450–700 ms time window. The *F*-map indicates that reliable differences in amplitude reflecting the arousal comparison are found only over right hemisphere frontal sites. The *F*-map for this comparison from 700 to 1000 ms is not presented because no statistically reliable effects were identified in this time window. Collectively, these results constrain the

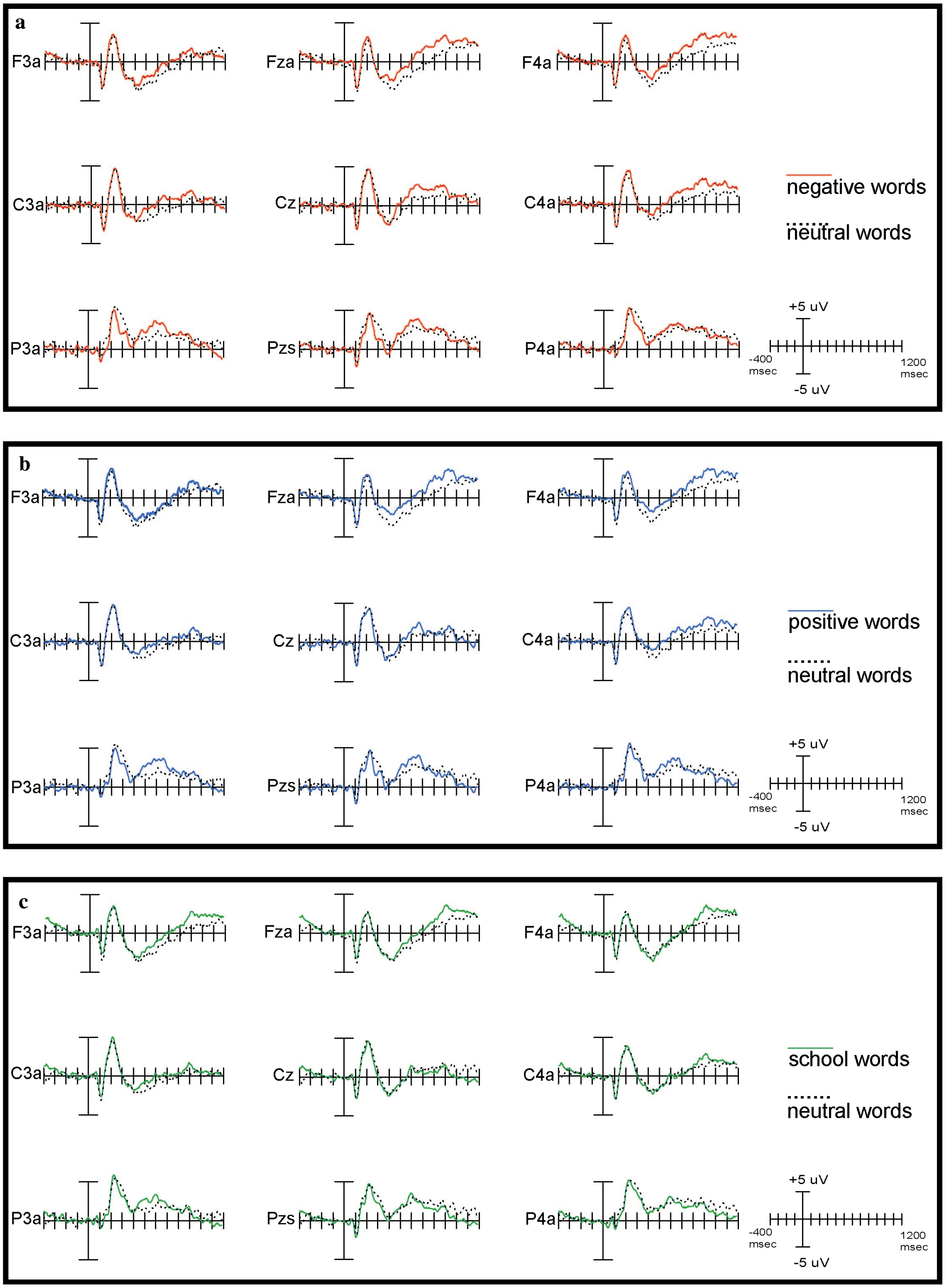

Fig. 1. Group averaged waveforms showing divergence of ERPs elicited by categorized words from those elicited by uncategorized words. Nine representative electrode sites are shown. (a) Responses elicited by negative words (solid red line) and uncategorized neutral words (dotted black line). (b) Responses elicited by positive words (solid blue line) and uncategorized neutral words (dotted black line). (c) Responses elicited by school-related (categorized neutral) words (solid green line) and uncategorized neutral words (dotted black line).

results from the topographical voltage analysis, where amplitude differences were more broadly distributed and temporally sustained. Fig. 3c displays the *F*-map generated from comparison of ERPs elicited by school-related and uncategorized neutral words in the 450–700 ms time window. The results of this analysis are consistent with the topographical map, and reveal that the semantic cohesion effect is localized to left hemisphere parietal electrodes. No reliable amplitude differences were evident in the 700–1000 ms time window.

ROI analyses were carried out on electrode sites where the topographic and *F*-map analyses of the standard

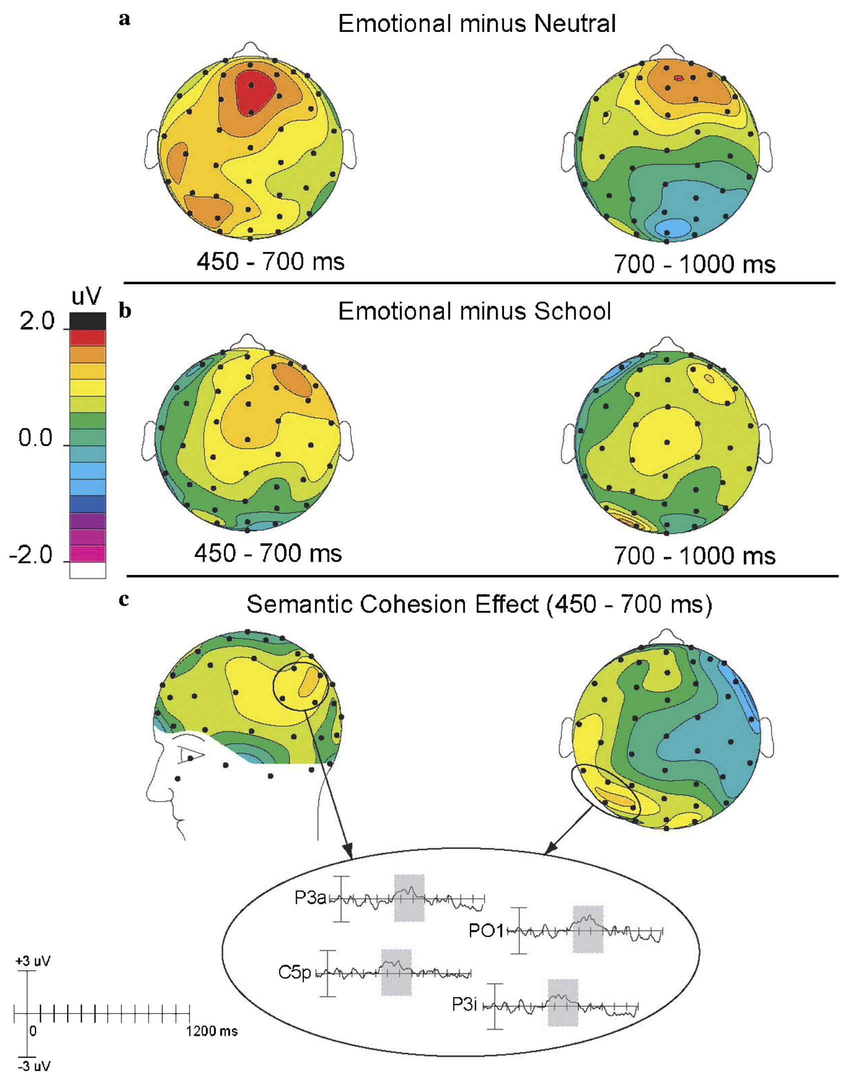

Fig. 2. Group averaged difference wave topographical voltage maps from 450–700 to 700–1000 ms. (a) *Standard emotion subtraction*. Topography was generated using a difference wave created by subtracting ERPs elicited by uncategorized neutral words from those elicited by Emotional words. (b) *Arousal subtraction*. Topography was generated using a difference wave generated by subtracting ERPs elicited by school-related (categorized neutral) words from those elicited by emotional words. This subtraction isolates arousal effects. (c) *Semantic cohesion effect*. Effects of semantic cohesion were revealed by subtracting the *arousal* difference wave from the *standard emotion* difference wave (which is also equal to the difference between the school-related (categorized neutral) words minus the uncategorized neutral words). Waveforms are from four electrodes where the semantic cohesion effect was maximal. The effect is evident from 450 to 700 ms (time window shaded in gray).

emotion comparison revealed maximal effects. Two ROIs were drawn, each using 12 electrodes (Fig. 4). One ROI covered primarily midline and right hemisphere frontal electrodes (F3s, FC1, Fza, Fzp, Cza, Fp2m, F4a, F4s, FC2, F8a, F4i, C4a), while the other ROI covered primarily centro-parietal left hemisphere electrodes (F3i, F7p, C3a, C3′, C5a, C5p, T3′, T35i, P3i, P3a, PO1, Pzi). Analyses were first conducted for the 450–700 ms time window. A repeated-measures ANOVA on mean amplitude data with factors Word Type (emotional, school-related, uncategorized neutral) and ROI (frontal, left centro-parietal) revealed a significant interaction, $F(2,28) = 3.48$, $p < .05$ (Greenhouse-Geisser corrected). Follow-up ANOVAs with Word Type as a repeated measures factor were then conducted at each ROI separately.

For the frontal ROI, the standard emotion comparison was significant, $F(1,14) = 11.02$, $p < .01$, due to the amplitude difference in LPPs elicited by emotional words ($M = .41\,\mu V$, $SD = 4.0$) versus uncategorized neutral words ($M = -.97\,\mu V$, $SD = 3.98$). The arousal comparison was also significant, $F(1,14) = 5.42$, $p < .04$, again due to larger amplitude LPPs elicited by the emotional words relative to the school-related words ($M = -.77\,\mu V$, $SD = 4.79$). However, the semantic cohesion effect was not significant, $F < 1$. These results indicate that activity over frontal electrode sites from 450 to 700 ms was sensitive to arousal, not semantic cohesion.

For the centro-parietal left hemisphere ROI, the standard emotion comparison was significant, $F(1,14) = 15.21$, $p < .01$, due to the amplitude difference in LPPs elicited by emotional words ($M = 2.01\,\mu V$, $SD = 3.28$) versus uncategorized neutral words ($M = .96\,\mu V$, $SD = 3.24$). By contrast, the arousal comparison was not significant, $F < 1$, because school words elic-

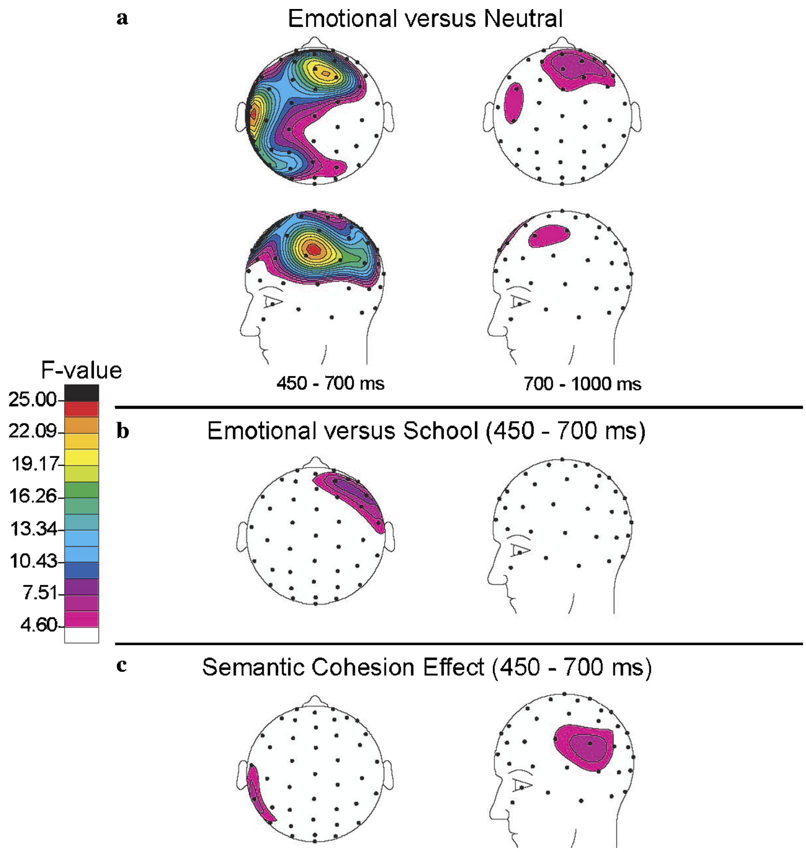

Fig. 3. *F*-maps displaying *F*-values generated from repeated-measures ANOVAs on mean amplitude data. Only *F*-values greater than or equal to 4.60 are presented. (a) *Standard emotion comparison*. Topography of *F*-values for comparison of emotional and uncategorized neutral words from 450–700 to 700–1000 ms time windows. (b) *Arousal comparison*. Topography of *F*-values for comparison of emotional and school-related (categorized neutral) words from 450 to 700 ms. This comparison reveals effects of arousal. (c) *Semantic cohesion effect*. Topography of *F*-values for comparison of school-related and uncategorized neutral words from 450 to 700 ms. This comparison reveals the semantic cohesion effect, localized primarily over left hemisphere parietal electrodes.

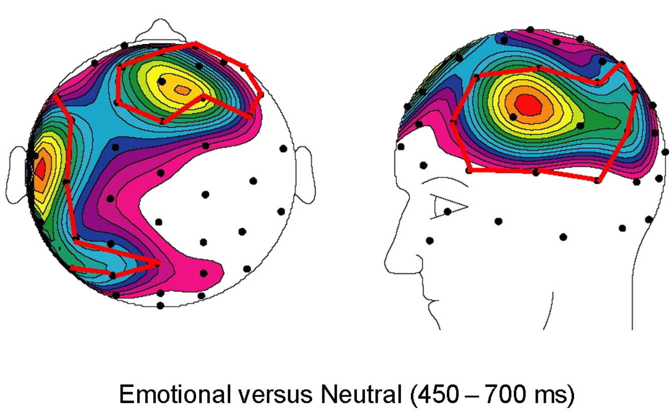

Fig. 4. Depiction of electrodes used in ROI analyses. Two ROIs (solid red lines) were generated based on the topographical voltage maps and the *F*-maps, and drawn around regions of maximum amplitude difference in the standard emotion comparison (emotional versus uncategorized neutral) from 450 to 700 ms. Each ROI was comprised of 12 electrodes. One ROI included primarily midline and right hemisphere frontal electrodes, the other included primarily centro-parietal left hemisphere electrodes.

ited LPPs of similar amplitude ($M = 1.79\,\mu V$, $SD = 3.62$) to those elicited by emotional words. Finally, the semantic cohesion effect was significant, $F(1,14) = 5.20$, $p < .04$. These results indicate that activity over left hemisphere centro-parietal electrode sites from 450 to 700 ms was sensitive to semantic cohesion, not arousal.

A repeated-measures ANOVA was next conducted on mean amplitude data in the 700–1000 ms time window, again with factors Word Type and ROI. The interaction was marginally significant, $F(2,28) = 2.66$, $p < .09$ (Greenhouse-Geisser corrected), and follow-up ANOVAs with Word Type as a repeated measures factor were again conducted at each ROI. For the frontal ROI, the standard emotion comparison was significant, $F(1,14) = 5.60$, $p < .03$, due to the amplitude difference in LPPs elicited by emotional words ($M = 2.99\,\mu V$, $SD = 3.16$) versus uncategorized neutral words ($M = 1.59\,\mu V$, $SD = 3.15$). The arousal comparison was not significant, $F(1,14) = 1.73$, although emotional words elicited LPPs of greater amplitude than school words ($M = 2.31\,\mu V$, $SD = 3.61$). Finally, the semantic cohesion effect was not significant, $F(1,14) = 1.16$, $p = .30$. For the left hemisphere centro-parietal ROI, none of the three comparisons were significant (all Fs < 1.05).

3.1.3. N400

The ERP results revealed that semantically coherent stimuli elicited increased LPPs from 450 to 700 ms over centro-parietal left hemisphere electrode sites. However, it is possible that these effects are simply a consequence of differences in N400 amplitude. The N400 is a negative-going waveform that is elicited by individual words and that is larger for words that are not well-integrated into an existing semantic context (Kutas & Besson, 1999; Kutas & Schmitt, 2003; Kutas & Van Petten, 1994). Because the uncategorized neutral words were not closely related to one another, they could have elicited a larger N400 than the other stimuli. This might lead to an apparent reduction in LPP amplitude for uncategorized neutral words relative to the three sets of semantically coherent stimuli.

To test this hypothesis, we conducted a repeated-measures ANOVA with Word Type (negative, neutral, positive, and school) as a factor. The ANOVA was conducted on mean amplitude data from 350 to 450 ms, where the N400 deflection appeared maximal (Fig. 1), at four electrode sites where the semantic cohesion effect was maximal—C5p, P3a, P3i, PO1 (semantic cohesion effect at these sites is plotted in Fig. 2c). This analysis failed to reveal a significant effect of Word Type, $F < 1$, indicating that effects of semantic cohesion on LPP amplitude do not appear to be related to differences in N400 amplitude.

3.2. Behavioral results

Participants' mean arousal ratings are summarized in Table 1. A repeated-measures ANOVA examining arousal ratings revealed a significant effect of Word Type, $F(3,42) = 32.14$, $p < .001$. Post hoc, Bonferroni-corrected contrasts showed no significant differences in arousal ratings between the two classes of emotional words ($p = .61$), and both classes of emotional words were rated as significantly more arousing than both classes of neutral words (all ps $< .01$). However, the school-related words were rated as more arousing than the uncategorized neutral words, $F(1,14) = 34.58$, $p < .001$. Mean reaction times to make arousal ratings, upon presentation of the arousal rating screen, are presented for each word type in Table 1. A repeated-measures ANOVA examining reaction times failed to yield a significant effect of Word Type, $F(3,42) = 1.69, p = .18$.

Because there was some discrepancy between normative and participant arousal ratings for the school-related words, additional ERP analyses were conducted according to the arousal ratings provided by each participant.

3.3. ERP re-analysis based on participants' arousal ratings

Participants rated the school words as more arousing than the uncategorized neutral words, although these classes were equated for arousal based on normative ratings (Table 1). To rule out any potential over-estimation of the ERP effects indexing semantic cohesion, the ERP data were re-analyzed according to participants' own arousal ratings. A subset of school-related words was selected for each participant so that his or her arousal ratings of school-related and uncategorized neutral words were equated. This was achieved by discarding the five school-related words rated as most arousing from each participant's data set. A repeated-measures ANOVA examining arousal ratings on this restricted dataset revealed a significant effect of Word Type, $F(3,42) = 36.68$, $p < .0001$. Post hoc, Bonferroni-corrected contrasts confirmed that both classes of emotional words were rated as more arousing than the restricted set of school-related words (ps $< .05$), but the contrast comparing arousal ratings for the uncategorized neutral and school-related words was no longer significant, $p = .24$. Restricting analyses to this subset of school-related words reduced the original data set by 11%, and the number of stimuli used to form an ERP from this subset of school words ranged from 31 to 43 across participants.

The ROI analyses of mean amplitude data were re-computed using the subset of school words rated by participants as low-arousing. For the 450–700 ms time window, the comparison with emotional words was significant at the frontal ROI, $F(1,14) = 4.95$, $p < .04$, due to larger amplitude LPPs elicited by emotional relative to low-arousing school words ($M = -.83\,\mu V$, $SD = 4.92$). The comparison with uncategorized neutral words was not significant, $F < 1$. Analysis at the left hemisphere centro-parietal ROI revealed that the comparison with emotional words was not significant, $F < 1$, due to the fact that LPPs elicited by the emotional and low-arousing school words ($M = 1.77\,\mu V$, $SD = 3.83$) were similar in amplitude. By contrast, the semantic cohesion effect was evident, $F(1,14) = 4.34$, $p < .056$, due to the fact that low-arousing school words elicited LPPs of greater amplitude than uncategorized neutral words. In summary, for the 450–700 ms time window results were identical when either the full set of school words or the subset of school words rated as low-arousing by participants was used. Both sets of analyses lead to the conclusion that midline and right hemisphere frontal electrodes indexed arousal while left hemisphere centro-parietal electrodes indexed semantic cohesion.

For the 700–1000 ms time window, analysis at the frontal ROI revealed that the comparison with emotional words was not significant, $F(1,14) = 1.60$, $p = .23$, although the low-arousing school words elicited LPPs of smaller amplitude ($M = 2.32\,\mu V$, $SD = 3.68$) than the emotional words. Comparison with the uncategorized neutral words also failed to reveal a significant difference, $F(1,14) = 1.26$, $p = .28$. Neither comparison was significant at the left hemisphere centro-parietal ROI (both Fs < 1), confirming the primary analysis.

4. Discussion

The results of this experiment indicate that arousal and semantic cohesion make dissociable contributions to LPPs elicited by emotional words. The standard emotion subtraction compared ERPs elicited by emotional and uncategorized neutral stimuli. This comparison revealed that emotional stimuli elicited ERPs of greater amplitude over frontal, central, and parietal scalp regions. Topographical voltage maps and *F*-maps showed that from 450 to 700 ms, these differences were primarily evident over two regions: midline and bilateral frontal sites, and midline and left hemisphere centro-parietal sites. From 700 to 1000 ms, differences at frontal electrodes were apparent over midline and right hemisphere frontal sites, and differences over centro-parietal sites were no longer prominent. The arousal subtraction compared ERPs elicited by emotional and categorized neutral (school-related) words. The combination of topographical voltage maps and *F*-maps revealed that from 450 to 700 ms, emotional stimuli reliably elicited increased amplitude LPPs primarily over frontal electrodes in the right hemisphere. The voltage topographies suggested that smaller amplitude differences, broadly distributed over central scalp regions, were present from 700 to 1000 ms, but these were not reliable as tested by the *F*-maps. Finally, a direct comparison of the two subtractions revealed the semantic cohesion effect: a left-lateralized, positive difference over centro-parietal electrodes from 450 to 700 ms post-stimulus (note again that this effect is identical to that obtained by taking the direct difference between ERPs elicited by school words and uncategorized neutral words). This effect was evident in both the topographic voltage maps and the *F*-maps, and reflects the fact that semantically coherent stimuli (both emotional and school-related words) elicited LPPs of greater amplitude than uncategorized neutral stimuli.

Accordingly, the ROI analyses revealed a clear dissociation in the 450–700 ms time window. At the frontal ROI, amplitude differences between emotional stimuli and both classes of neutral stimuli were significant, indicating sensitivity to arousal. By contrast, at the left hemisphere centro-parietal ROI the semantic cohesion effect was significant, but the arousal comparison was not.

4.1. Relationship to previous emotional ERP studies

The findings reported here contribute to a growing literature on ERPs elicited by emotional stimuli. Consistent with several previous investigations (Cuthbert et al., 2000; Dolcos & Cabeza, 2002; Johnston et al., 1986; Naumann et al., 1992), increased LPPs were elicited by emotional relative to uncategorized neutral stimuli. If only the standard emotion subtraction had been performed, all of these amplitude differences would have been attributed to emotional arousal. However, by including categorized neutral stimuli in the design we were able to demonstrate that while some of the LPP effects observed were attributable to arousal differences, others reflected processes indexing semantic cohesion. These results suggest that the contribution of arousal to emotional ERP effects using lexical stimuli may be more limited than had previously been envisaged.

Interestingly, arousal effects were observed over midline and right hemisphere electrode sites. This is consistent with models that accord the right hemisphere a special role in emotional information processing (Borod, 1992; Borod, Andelman, Obler, Tweedy, & Welkowitz, 1992). By contrast, semantic cohesion effects were left-lateralized. A similar hemispheric lateralization of emotional and linguistic ERP effects has been noted in a previous study using lexical stimuli. Ortigue et al. (Ortigue et al., 2004) presented emotionally arousing and neutral words, as well as non-words, to participants in a go/no-go lexical decision task. Stimuli were presented in word/non-word and non-word/non-word pairs, and the participants' task was to make speeded button presses when words were detected. During an early epoch (100–140 ms), a unique pattern of electrical activity was detected for emotional words presented in the right visual field. Source modeling of this activity revealed a bilateral occipital pattern of activity, with a right hemisphere current density maximum. All other stimulus/visual hemifield conditions elicited a pattern of activity with a left hemisphere current density maximum. The authors concluded that the data supported a model of stimulus processing that included left hemispheric specialization for language processing and right hemispheric specialization for emotional processing. While there are significant differences in task and relevant ERP components between the study performed by Ortigue et al. and the present one, the apparent devotion of linguistic and emotional processing resources to the left and right hemispheres, respectively, is similar.

We did not observe obvious differences in ERP amplitude due to emotional valence. This is in contrast to some previous work that has noted increased amplitude LPPs for negative relative to positive words (Bernat, Bunce, & Shevrin, 2001), but is in line with previous research that found equivalent P300 amplitudes for positive and negative words (Naumann et al., 1992). The reason for these discrepancies in the literature is unclear. One possibility is that because the task used here focused participants' attention on emotional arousal, ERP differences indexing valence were obscured. Another possibility is that common emotional words are not salient enough to give rise to robust valence effects.

4.2. Relationship to ERP studies of memory

By demonstrating that neural systems involved in emotional stimulus encoding are sensitive to both arousal and semantic cohesion, this report complements a recent fMRI experiment (Kensinger & Corkin, 2004) and multiple patient studies (Phelps et al., 1998; Phelps, LaBar, & Spencer, 1997) that reached similar conclusions in studies of explicit memory. A future step will be to specify the contributions made by arousal and semantic cohesion to electrophysiological indices of memory recorded during encoding of emotional items. Multiple ERP studies using the subsequent memory paradigm and lexical stimuli have shown that successful encoding is characterized by increased LPPs for subsequently remembered (versus forgotten) items, with some studies showing the effect lateralized to the left hemisphere (Friedman, 1990; Friedman & Johnson, 2000; Friedman & Trott, 2000; Neville, Kutas, Chesney, & Schmidt, 1986; Paller, Kutas, & Mayes, 1987; Paller & Wagner, 2002; Rugg, 1995a). This "difference due to memory," or *Dm effect* (Paller et al., 1987), can onset as early as 300 ms and often persists for several hundred milliseconds. A recent ERP study using the subsequent memory paradigm identified a Dm effect that was larger for emotional pictures relative to neutral pictures (Dolcos & Cabeza, 2002). This emotional modulation of the Dm effect was evident over centro-parietal electrodes during the 400–600 ms time window. The functional processes underlying this modulation are unclear, but the centro-parietal locus and similar timing relative to the semantic cohesion effect identified here suggest that semantic processes may contribute to emotional modulation of the Dm effect.

Semantic cohesion has already been investigated in ERP studies of recognition memory for lexical stimuli, with mixed results. A consistent finding in studies of recognition memory is the "old/new" effect, which refers to the fact that stimuli correctly judged "old" (hits) elicit increased amplitude positive potentials relative to stimuli correctly judged "new" (correct rejections) (for reviews, see Rugg, 1995b; Rugg & Allan, 2000). In a recent study, Maratos et al. (2000) found significant old/new effects at left parietal sites from 500–800 ms for both negative and neutral words, but the effect was larger for neutral words due to increased amplitude LPPs elicited by new negative words. This difference was interpreted as reflecting semantic cohesion processes, and the authors suggested that new negative words were capable of eliciting "spurious" episodic memories because of their close association with old negative words (an argument supported by the fact that new negative words elicited significantly more false alarms than new neutral words). However, McNeely et al. (2004) failed to find significant effects of semantic cohesion on ERPs elicited during recognition memory. They compared recognition memory for negative words and animal-related words (a semantically coherent group of non-emotional stimuli) and did not find evidence for either increased false alarms or significantly increased LPPs in response to the animal-related words. Consequently, they argued that emotional salience, rather than semantic cohesion, drives false recollection in studies of recognition memory for emotional items (see also Windmann & Kutas, 2001).

Additional experiments will be necessary to resolve the issues raised by these studies. However, the current results provide some support for Maratos et al. (2000) by showing that semantically coherent stimuli, whether emotional or not, can give rise to LPPs of increased amplitude relative to uncategorized neutral stimuli. A critical factor may be the choice of stimuli used to form the categorized neutral group. A relatively broad category such as "school" allows the investigator to balance the neutral and emotional stimuli for factors such as imageability. However, broader stimulus classes of this type may also elicit a wider range of arousal responses than narrower categories (e.g., types of furniture), possibly leading to unintended arousal effects on the ERPs. In this study, the standard deviation of participants' arousal ratings for school-related words (0.43) was very similar to that for uncategorized neutral words (0.40) and smaller than that for either negative (0.59) or positive (0.52) words, arguing against such a confound. Nonetheless, future studies could systematically vary the categorized neutral class in order to more precisely identify the spatiotemporal characteristics of semantic cohesion ERP effects.

Finally, it should be noted that ERP studies using nonverbal stimuli to limit the influence of semantic cohesion have nonetheless identified emotional modulations of memory. For example, Johansson, Mecklinger, and Treese (2004) recorded ERPs to positive, negative, and neutral faces during recognition testing. An early (380–500 ms) midfrontal "old/new" effect thought to reflect familiarity-based recognition judgments was also sensitive to emotional arousal (either positive or negative), while a later (500–700 ms) parietal effect thought to reflect recollection-based judgments was elicited only by negative faces. Furthermore, in a companion behavioral study correctly recollected negative faces elicited more "remember" judgments than either positive or neutral faces. Collectively, these results demonstrate that even when semantic cohesion is controlled negative stimuli can facilitate recollection-based memory performance while emotional stimuli in general may induce an arousal-based recognition bias (e.g., Windmann & Kutas, 2001).

4.3. Implications for emotional memory more broadly

The importance of this general issue extends beyond the ERP literature. Many studies have established that explicit memory for emotional items is better than for neutral items (Cahill & McGaugh, 1995; Hamann, 2001; Phelps et al., 1997), and the functional processes that underlie this effect are currently a topic of great interest. Experiments with both humans (Cahill et al., 1996; Canli, Zhao, Brewer, Gabrieli, & Cahill, 2000; Dolcos, LaBar, & Cabeza, 2004; Hamann, Ely, Grafton, & Kilts, 1999; LaBar & Phelps, 1998; Richardson, Strange, & Dolan, 2004) and non-human animals (McGaugh, 2000; McGaugh, Cahill, & Roozendaal, 1996) indicate that emotional arousal can facilitate subsequent memory via interactions between the amygdala and hippocampal memory system. However, some emotional memory effects are independent of arousal and the amygdala. For example, amygdala-lesioned patients display normal recall advantages for low-arousing emotional words as compared to neutral words, as well as for neutral words encoded in emotional (versus neutral) contexts (Phelps et al., 1998; Phelps et al., 1997). In addition, healthy adults show enhanced recognition memory for both arousing and non-arousing negative words relative to neutral words, but these memory enhancements depend on two different neural networks, with successful retrieval of negative arousing words supported by left amygdala and hippocampus and successful retrieval of negative non-arousing words supported by left inferior prefrontal cortex and hippocampus (Kensinger & Corkin, 2004).

The psychological processes and/or stimulus properties responsible for emotional modulation of explicit memory in the absence of significant arousal are not yet well-specified. Kensinger and Corkin (2004) suggest that such effects may depend on the recruitment of controlled encoding processes, reflected in the increased activity of left inferior PFC during encoding of non-arousing emotional stimuli reported in their fMRI study. A complementary hypothesis is that the shared valence of emotional stimuli may serve as a broad semantic category that helps individuals organize the stimuli in memory (LaBar, 2003; Phelps et al., 1998; Phelps et al., 1997; Talmi & Moscovitch, 2004). Exposure to multiple stimuli of the same valence may cause widespread activation in semantic networks (Collins & Loftus, 1975). Once such networks are activated, processing of subsequent stimuli of the same valence (or encoded in the same valence context) may be facilitated. Because randomly selected neutral stimuli are typically semantically unrelated, their encoding would suffer relative to emotional stimuli.

This hypothesis receives strong support from a recent behavioral study by Talmi and Moscovitch (2004). In a series of three experiments, participants encoded emotional and categorized neutral words matched for semantic cohesion, as well as random neutral words. In each experiment, free recall of the categorized neutral words was as good or better than free recall of the emotional words, despite the fact that the categorized neutral words were significantly less arousing than the emotional words. Both categorized neutral words and emotional words were better remembered than random neutral words. The authors concluded that semantic relatedness serves as an organizing principle that supports either effective encoding, retrieval, or both, and noted that processes related to semantic relatedness and emotional arousal may work in tandem to support explicit memory performance.

4.4. Alternative interpretations

This study was conducted with the goal of better specifying the processes underlying LPPs elicited by emotional stimuli during their initial encoding, and the semantic cohesion effect has been interpreted in the context of that literature. Alternatively, one could interpret this effect in the context of the psycholinguistic literature. As described earlier (see Sections 3, 3.1, and 3.1.3), it is possible that the semantic cohesion effect is related to the N400. The amplitude of the N400 is larger for stimuli that are incongruous with their semantic context (Bentin, 1987; Holcomb, 1988; Kutas & Hillyard, 1980; Rugg & Nagy, 1987). Therefore, it seemed possible that the uncategorized neutral words used here might elicit large N400 responses, which could be manifested as an apparent increase in LPPs elicited by the other three word types. However, we tested this hypothesis and found that N400 amplitudes were statistically indistinguishable for all four word types. In addition, two other facts argue against the possibility that the LPP effects reported here actually reflect differences in N400. First, the difference between the categorized stimuli (negative, positive, and school-related words) and the uncategorized stimuli emerges at about 450 ms post-stimulus and peaks at about 550 ms post-stimulus. This effect is later than most N400 effects, where a difference between semantically congruous and incongruous stimuli typically emerges at about 200 ms and peaks at 400 ms (Kutas & Van Petten, 1994). Second, the effect reported here is lateralized to the left hemisphere, whereas N400 effects are often larger over the right hemisphere (Kutas & Schmitt, 2003; Kutas & Van Petten, 1994). However, it remains possible that the semantic cohesion effect identified here may reflect temporally extended processes related to the N400, which result in LPPs of smaller positive amplitude for the stimulus class (uncategorized neutral words) that is least semantically coherent.

The stimuli and design used in this study may not be optimal for detecting N400 effects. While the negative, positive, and school-related words used were clearly categorized, many studies that have identified N400 effects have used narrower categories (e.g., types of wood or breakfast foods) as in Olichney et al. (Olichney et al., 2000). Furthermore, N400 effects have often been revealed using tasks that highlight semantic relations to a greater degree than the arousal rating task used here, including determining whether individual words are members of a category (Olichney et al., 2000). These or other differences might contribute to the lack of N400 effects noted in this study, and future work could manipulate some or all of these variables in conjunction with emotional stimuli in order to determine the relationship between the N400 and the semantic cohesion effect identified here.

4.5. Limitations

The present study has three main limitations. First, like previous studies that have implicated semantic cohesion in emotional stimulus processing (Phelps et al., 1998; Phelps et al., 1997; Talmi & Moscovitch, 2004), this study used lexical stimuli. It is not clear whether the results obtained here will generalize to other types of stimuli (e.g., emotional scenes or faces). This is an important issue for future research, since many studies that have noted increased LPPs for emotional versus neutral stimuli have used pictorial stimuli. Second, because the P300 is known to be sensitive to task demands (Donchin & Coles, 1988), the arousal rating task used here may have resulted in more substantial arousal effects than would otherwise have been obtained. However, we viewed this task as orthogonal to the dimension of semantic cohesion, which was the stimulus dimension of greatest interest to us. Furthermore, if the task used here amplified ERP components sensitive to arousal, that would work against the detection of semantic cohesion effects and would therefore strengthen our main argument. Nonetheless, it would be desirable to conduct future studies in which participants are directed to classify the stimuli along a dimension unrelated to either arousal or semantic cohesion. Third, while we believe this study has implications for studies of emotional memory, ERP studies demonstrating a clear link between semantic cohesion effects at encoding and subsequent memory retrieval remain to be conducted.

5. Conclusions

The importance of semantic cohesion to studies of emotional information processing and emotional memory is beginning to be recognized. Previous behavioral work with both healthy adults and patient populations, as well as previous ERP studies of recognition memory, indicate that semantic processing can make a critical contribution to emotional effects on explicit memory. This study demonstrates that the contributions made by arousal and semantic cohesion to ERPs elicited during emotional stimulus encoding are dissociable. Future studies should further characterize the neural networks involved in processing semantically coherent groups of stimuli, and should relate encoding-related activity in those networks to subsequent retrieval.

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Appendix A

Stimuli presented at encoding, by category

Negative		Positive		School-related		Uncategorized Neutral	
abhor	herpes	abundance	kiss	absentee	honors	accrue	inform
accuse	horrify	ace	kitten	academic	instructor	adjust	inhabitant
ache	humiliate	admired	laughter	accredited	intelligence	agility	intentions
aggravate	hurt	adventure	lively	admission	janitor	align	introduce
agitate	ignore	affection	loyal	advisor	junior	alternative	invent
angry	impose	ambition	lucky	alcohol	law	applicable	knit
annihilate	imprison	applause	lust	algebra	lesson	arise	license
antagonize	infection	aroused	magical	alumni	library	behold	locate
anxiety	insult	astonished	memories	arithmetic	logic	blindfold	manifest
avenge	isolation	awed	merry	arts	lunchtime	border	margin
bastard	loathe	beverage	mighty	associate	major	cardboard	melt
betrayal	loneliness	birthday	miracle	athletics	mascot	ceiling	modulate
bitch	madden	blossom	mobility	award	medicine	chant	negotiate
blame	mock	bold	muscular	bachelors	memorize	clarify	outlaw
bribe	mortify	brave	nude	bibliography	mentor	collecting	panel
bully	numb	breast	optimism	biography	merit	compare	parking
cheat	offend	cake	orgasm	biology	poetry	compose	participate
coerce	outrage	champion	outdoors	cafeteria	presentation	conception	perform
commit	overthrow	charm	paradise	calculation	professor	confer	pertinent
conform	overwhelm	cheer	passion	certification	provost	contemplate	plastic
criticize	panic	chocolate	patriot	chancellor	psychology	convince	practice
curse	pester	christmas	perfection	chemistry	punctual	dangerous	preserve
damage	plunder	circus	perfume	classroom	ranking	denote	procure
damn	provoke	confident	pet	coach	reasoning	depot	prompt
death	punishment	cute	prestige	collegiate	recess	describe	pursue
deceive	putrid	dancer	profit	computer	recitation	designate	refine
denounce	resentment	delight	promotion	counselor	registrar	dial	render
deploy	reveal	diamond	radiant	cram	religion	dimension	restore
despise	ridicule	ecstasy	rescue	cumulative	report	dip	retrieve
devastate	ruin	enjoyment	savior	curriculum	research	discuss	revere
disappoint	sacrifice	erotic	silly	daydream	roommate	elucidate	review
disgust	scandalize	excellence	star	dean	roster	emanate	rotate

(continued on next page)

Appendix A (*continued*)

Negative		Positive		School-related		Uncategorized Neutral	
disturbing	scorn	fame	sunlight	dialogue	schedule	embody	route
divorce	shame	fantasy	sunrise	discipline	scholar	embroider	shadow
embarrass	shock	fireworks	sweetheart	doctorate	scholarship	estimate	sheet
emergency	sicken	glory	terrific	dormitory	senior	extra	smother
eradicate	sin	graduate	thoughtful	drama	socialize	fathom	sponsor
evil	slander	greet	thrill	economics	sophomore	folder	stunt
excuse	spoil	grin	treat	engineering	sorority	forge	symbolize
expose	terminate	holiday	triumph	ethics	sports	formation	track
flee	threat	hopeful	triumphant	faculty	student	formulate	trend
flog	toil	impressed	trophy	feedback	subject	generate	unravel
frighten	torment	incentive	vigorous	fraternity	tenure	glorify	update
frustrate	upset	infant	wealthy	freshman	trigonometry	hone	variables
gall	worsen	inspired	wedding	funding	tutor	humble	varnish
guilt	writhe	intercourse	wink	grade	university	immortalize	vehicle
harassment		intimate	wit	grammar	valedictorian	impart	visualize
		joke	zest	gym	varsity	impression	wash
		kids		homework		incense	

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