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Recognition Memory for Emotional Words: An Event Related Potential Study

Catherine C. Balderston
University of South Florida

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by

Catherine C. Balderston

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Major Professor: Cynthia R. Cimino, Ph. D.
Geoffery Potts, Ph. D.
Douglas Rohrer, Ph. D.

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ABSTRACT

Evidence suggests that emotion affects memory often yielding enhanced recall and recognition of stimuli with emotional content. The nature of the relationship between emotion and memory for words has been particularly difficult to parse in part because of the stimulus characteristics. For example, emotional words tend to engender greater levels of physiological and psychological arousal, which have also been shown to enhance memory. Inter item relatedness has also been suggested as playing a part in the observed effects (i.e., emotional words belong to a closed semantic category compared to neutral words and are therefore easier to remember). While the enhancement of memory for emotional material has been demonstrated across a variety of stimuli and experimental conditions, the neural underpinnings of these effects remain unclear. The Old/New effect is an event related potential finding where electrophysiologic waveforms elicited by previously presented stimuli (i.e., old) are more positive going than those elicited by stimuli that were not previously presented (i.e., new). A few prior studies have investigated Old/New effects for emotional words, mostly comparing negative to neutral words and failing to equate their stimuli for the crucial confounding effects of arousal and inter item relatedness. The present study employed event related potentials to investigate recognition memory for words of positive, negative, and neutral valences in a sample of thirty healthy college undergraduates. It was predicted that positive and negative words would yield greater participant accuracy, response bias and Old/New effects in comparison to neutral words. The observed results yielded some variability in support for all of the hypotheses and predictions that were made a priori. Possible explanations for these results are discussed and directions for future research recommended.

Introduction

The general overarching purpose of the present study was to examine the pattern and timing of electrophysiological indices of recognition memory for emotional words. One consistent event related potential (ERP) effect associated with episodic memory is the Old/New effect. The Old/New effect refers to the tendency for previously presented (i.e., old) words to elicit more positive going ERP waveforms than words that were not previously presented (i.e., new words).

Previous research investigating Old/New effects for emotional words has predominantly focused on negative and neutral words only. The current study extended previous research with the inclusion of positive words to determine if prior Old/New effects generalized to this other class of emotional stimuli. Because the decision to respond old or new can be due to accurate memory, response bias, or some combination of the two, the current study examined Old/New effects from multiple perspectives other than the conventional manner where only correctly identified trials are used to compare waveforms associated with old and new trials. Specifically Old/New effects were also examined from a Subjective perspective (where the Old/New effect consists of differences in ERPs elicited from trials in which the subject endorsed items as being previously presented, regardless of accuracy) and an Objective perspective (where ERPs to previously presented items are compared to those not previously presented, regardless of accuracy). Previous research has highlighted the importance of such additional comparisons, as they are differentially sensitive to individual response bias.

The remainder of the chapter that follows critically reviews contemporary literature regarding emotion, memory, ERPs and their relevant permutations. The review concludes with a summary and critique of existing literature, followed by a more detailed discussion of the specific purposes of the current study, hypotheses and predictions suggested by the review and examined in this thesis.

Emotion & Memory

Studies pertaining to the interaction of emotion and memory can be separated into two distinct categories: Studies where memory performance is assessed in participants with a pre-existing or induced mood state, and studies where the stimuli that are to be remembered by the subject vary with respect to emotional valence (positive, negative, and/or neutral). For the purpose of the current study, only the latter will be reviewed.

It has been well established that memory for emotional material is better than memory for neutral information (Bradley, Greenwald, Petry, & Lang, 1992; Cahill & McGaugh, 1995; Heuer & Reisberg, 1990; Phelps, LaBar, & Spencer, 1997). The constructs of arousal and valence are most commonly implicated as factors underlying the observed phenomena of enhanced memory for emotional stimuli. These two dimensions have been confirmed via factor analyses to account for the majority of the variance observed in verbal judgments of emotional stimuli (Russell, 1980; Lang, Bradley & Cuthbert, 1990).

Arousal can be defined as “a dimension of emotion that varies from calm to excitement” (LaBar & Cabeza, 2006, p. 54). More generally however, in studies of emotion and memory, arousal refers to the amount of stimulation (psychological and/or physiological) engendered in the subject when presented with a particular stimulus (in this case, emotional words). Evidence suggests that arousal has a variety of effects on the various aspects of memory processes (e.g., encoding, consolidation, storage, retrieval.). Specifically, using healthy controls and patients with amygdala lesions, LaBar and colleagues (LaBar, Gatenby, Gore, LeDoux, & Phelps, 1998) revealed that memory for high vs. low arousal words was better in the control group after longer delays suggesting that arousal may enhance memory by modulating the consolidation process. Soetens and others (Soetens, Casaer, D'Hooge, & Hueting, 1995) used a series of experiments to investigate the effects of arousal (induced by oral or intramuscular administration of amphetamine) on memory. Using recall and recognition tasks over various time delay intervals the authors demonstrated that administration of amphetamine either before or after encoding positively modulated recall and recognition of the subjects' memory for the verbal stimuli. The authors concluded that the increased arousal (via amphetamine administration) improved memory by acting on consolidation processes as evidenced by greater enhancement of memory with the passage of time. Furthermore, Cahill and colleagues (Cahill, Prins, Weber, & McGaugh, 1994) demonstrated that the administration of a β-adrenergic receptor blockade inhibited the enhancement of emotionally arousing words presumably by preventing activation of β-adrenergic receptors within the amygdala and modulating (arresting) the consolidation process by influencing hippocampal function.

Clearly, arousal plays an important modulatory role in memory processes. This knowledge is particularly salient to the study of memory for emotional stimuli because emotional stimuli tend to possess higher levels of arousal. If accurate conclusions are to be drawn about the effects of affective valence on memory, arousal must be controlled for across valence conditions. Unfortunately, this is by far the exception rather than the rule in the existing literature.

Decades of literature generally support the idea that emotionally valenced (positive or negative) stimuli are recalled and recognized more accurately and more quickly than neutral items. These enhancing effects of valence on memory have been observed across sensory modalities and for a wide variety of stimuli including pictures (Bradley et al., 1992), sounds (Bradley & Lang, 2000), videos (Cahill et al., 1996), events (Rubin & Schulkind, 1997), and words (Vanderploeg, Brown, & Marsh, 1987). As noted above, the exact nature and magnitude of valence effects on memory are difficult to glean from existing literature due to confounds posed by the effects of arousal and lack of controlling for its influence. There are, however, a modest number of studies that have successfully isolated the effects of valence on memory. Ochsner (2000), for example, through a series of studies using the remember/know procedure (see Tulving, 1985 for details), determined that negative stimuli (pictures) were recognized significantly more than neutral pictures. Positive items were recognized more often than neutral pictures, but not sufficiently to reach statistical significance.

In a recognition memory task, the participant is presented with a number of stimuli (e.g., words) to remember (i.e., a study or target list). After the participant views the study list (and often following a specified delay period), they are presented with the so-called test list composed of the previously viewed targets interspersed with novel items (i.e., foils). Test list items are generally presented individually and the participant is prompted to decide whether or not the item was old (i.e., a target previously presented as part of the study list) or new (i.e., a foil that was not previously presented as part of the study list). Responses can be classified into one of four types according to the Table 1 set fourth by signal detection theory.

Table 1. Signal detection theory response categories

		Was this item studied? "Yes"	"No"
Item Novelty	Old item	Hit	Miss
	New item	False Alarm	Correct Rejection

In addition to arousal and valence driving the enhancement of memory, semantic cohesion has also been implicated as a possible contributing factor. Semantic cohesion refers to the tendency for emotional stimuli (particularly words) to belong to the same semantic category and therefore possess high levels of inter-item association. This theory emerged relatively recently in the literature (Maratos, Allan, & Rugg, 2000), has been empirically tested by just two further studies, yielding conflicting results. In a small sample (n=13) of healthy undergraduates, McNeely, Dywan & Segalowitz (2004) investigated recognition memory for negative and neutral words equated for semantic cohesion. Results indicated that despite high semantic cohesion between both groups of words, the emotional words were still recognized more often. The authors also examined response bias to address findings often reported in prior studies of recognition memory for emotional stimuli where a tendency exists for false alarms rates to be larger for emotional items (a phenomenon also attributed to semantic cohesion according to the

Maratos group). In this particular study, emotional foils elicited higher false alarm rates than the highly related (animals) neutral comparison condition suggesting that the observed memory enhancement (as well as the response bias) is not due to semantic cohesion of emotional words. Conversely, in a study published in the same timeframe, Talmi & Moscovitch (2004) used three sets of words (emotionally related, neutral related, and neutral unrelated) in a series of experiments to test Maratos' semantic cohesion hypothesis. Overall, the 60 participants recalled significantly more of the related (both negative and neutral) than the unrelated words but the emotional words provided no additional recall enhancement than the related unemotional words. Clearly, further replications of these experiments are needed before the role of semantic cohesion in memory for emotional words can be determined.

ERPs and Emotion

While emotion has been studied for centuries it was only relatively recently that scientists were able to measure the electrocortical activity associated with emotional processing. Because of their high temporal resolution (milliseconds), and stimulus locked nature, ERPs provide information about the timing and scalp distribution of neural activity that cannot be obtained through other methods. As such, emotional processing of pictures (Carretie, Iglesias, & Garcia, 1997; Carretie, Iglesias, Garcia, & Ballesteros, 1997; Schupp et al., 2000) and words (Naumann et al., 1992) has generally been observed to evoke P300 components greater in amplitude when compared to nonemotional pictures and words. With the exception of perhaps clinical research comparing healthy control subjects and groups with neurological or psychiatric pathology ERPs are used most often to investigate the neural underpinnings of emotion and another construct, most commonly memory.

ERP's Associated with Episodic Memory

There are two main ERP phenomena associated with episodic memory. The first, known as the subsequent memory effect or the difference due to memory (dm) effect, refers to differences in ERPs elicited at encoding by words that are later recalled at test. Specifically, ERPs recorded during the study phase and elicited by items that are subsequently remembered are more positive than those to items that are not remembered at test (see Johnson, 1995 for a review). Subsequent memory effects have been noted across a variety of stimuli (e.g., words, faces etc.) and in varying test formats (e.g., recall, recognition etc.) (e.g., Benson & Kutas, 1993; Fabiani & Donchin, 1995). Studies employing the subsequent memory paradigm that use emotional stimuli consistently find the electrophysiological brain activity elicited by subsequently remembered emotional items occurs significantly faster than activity associated with neutral stimuli (e.g., Dolcos & Cabeza, 2002). Because the paradigm utilizes waveforms elicited by words that are later successfully retrieved and not those that are forgotten, the subsequent memory effect is thought to index activity associated with successful encoding of stimuli. The second ERP effect related to episodic memory refers to differences in ERPs elicited by items during the recognition phase of a memory test. These so called Old/New effects are the focus of this thesis and will be discussed in detail in the following sections.

Old/New Effects

The Old/New ERP effect is a robust finding in recognition memory tasks where previously presented items (i.e., old or so called "target" items) elicit more positive going (i.e., larger) waveforms than items that were not previously presented (i.e., new or foil items). Traditionally, the Old/New waveforms are composed solely of trials where the subject correctly responded to the stimuli; that is, hits and correct rejections. The remaining responses (misses and false alarms) are not used.

Several spatiotemporal patterns have been identified within ERP studies of recognition memory and linked to various aspects of the recognition memory process (e.g., encoding, retrieval, etc.). The first component generally observed occurs at approximately 300-500 ms post stimulus, and is distributed bilaterally over frontal brain regions. The dual process model of recognition memory posits that recognition decisions may be based on both the actual recollection of the item (i.e., the memory trace), and some degree of feeling of familiarity it may engender in the subject (e.g. Yonelinas, 1994). This so called early frontal Old/New effect has been described by Rugg and others (e.g., Donaldson & Rugg, 1998; M. D. Rugg, 1995; Tendolkar & Rugg, 1998; Wilding, Doyle, & Rugg, 1995) as representing the familiarity subcomponent of recognition within this dual process model. Support for this idea is also provided by Curran (2000). Specifically, he had participants study lists of singular and plural words and then discriminate previously presented words from new words and related lures that were presented in the opposite plurality to that of the study words. Hypothesizing that the lures were comparable to the studied items in terms of familiarity the finding that the early, frontally distributed Old/New effect differentiated the new words from the old words and the related lures was interpreted as evidence that this early Old/New effect represents familiarity. Additionally, this early frontal effect has been associated more so with ‘know’ judgments when remember/know experiments are employed (Gardiner, Java, & Richardson-Klavehn, 1996). The second Old/New effect occurs around 400-800 ms post-stimulus, is positive in polarity, and has a left parietal scalp distribution. This left parietal Old/New effect is thought to represent the putative neural correlate of recollection for previously presented items. Support for this view has been provided by Rugg (1987). Specifically, the item encoding phase of a recognition task was manipulated by instructing subjects to study items in a shallow manner, (determining whether or not the first and last letters of each word fell in alphabetical order) or more deeply (incorporating the word into a sentence) and recorded subsequent ERPs during the test phase in an attempt to dissociate neural generators associated with recognition and familiarity. Rugg reasoned that words from the shallow study phase recognized at test were representative of familiarity whereas the deeply encoded words would reflect the recollection process more purely. Results revealed that only the deeply studied items (not shallow) elicited a left parietal Old/New effect leading the authors to interpret this particular ERP component/effect as an index of recollection. This left parietal Old/New effect has also been associated with 'remember' judgments in remember/know experiments (Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997) and has been observed in association with the recollection of specific contextual information such as source and temporal time tags (i.e., the parietal Old/New effect is observed when such information about an item can be recalled and conversely is not typically observed when such information cannot be recalled). Recalling specific details about studied items is thought to provide evidence for strength of the underlying memory trace (recollection). The third and final observed Old/New effect occurs between 500-700 ms post stimulus, is also positive in polarity and has a right frontal focus. This so called right frontal

Old/New effect is thought to reflect post retrieval/recollection processing (Rugg & Allan, 2000). Much of the empirical support for this interpretation is garnered from studies of false recognition. False recognition or false memory refers to a phenomenon where individuals tend to endorse non-target items that are highly associated with study list items (i.e., targets, a.k.a., lures) as being previously presented when they are in fact novel. Such tasks are thought to rely heavily on post-retrieval monitoring because the memory trace is weak and/or compromised by the highly associated lures. Curran, Schacter, Johnson and Spinks (2001) compared subjects with high false recognition rates to those with low false recognition rates from a false memory experiment and found that only the ERPs from subjects that were better at discriminating between studied items and lures showed right frontal differences between new items and the studied items or lures. Old/New effects were initially thought of as being comprised of the N400, the amplitude of which was attenuated by old items, and a subsequent late positive component, the amplitude of which was enhanced. The N400 is a well-studied ERP component thought to index semantic aspects of sentence processing. In ERP studies of recognition memory where Old/New effects are extrapolated the first frontal Old/New effect is often referred to as the frontal N400 (FN400) as it is similar (both in polarity and latency) to the well-known N400 component. Importantly though, the frontal scalp distribution observed in the Old/New effect differs from the N400 seen in language studies as that particular N400 has a centro-parietal focus.

With the advent of dual-process theories of recognition memory came a need to integrate ERP findings. Prior theoretical explanations of recognition memory performance generally focused on single process models that posited a single "strengthlike” memory trace or signal {e.g. Shiffrin and Steyvers’ (1997) retrieving effectively from memory; REM}. Dual process models are conceptualized as having two sub processes: recollection and familiarity (Jacoby & Kelley, 1992; Mandler, 1981) that interact and better account for previously unexplained or incongruent scientific findings. Recollection generally refers to the ability to locate and retrieve the specific memory trace associated with a particular item during a recognition test. Familiarity is often conceptualized as a feeling of association or prior experience with a stimulus; an automatic process that gives rise to a sense of pastness (Yonelinas & Jacoby, 1996). Recollection is accompanied by explicit details or evidence (e.g., contextual & temporal tags) from the encoding phase of the test whereas familiarity is not.

ERP studies provided a unique contribution to the understanding of dual-process theories because of their high temporal resolution in addition to their aid in making inferences about potential neuroanatomical loci of active neuronal populations. Despite the unique contributions of this methodology, dissociation of recollection and familiarity was not evident at the outset. Rather, as is the case in most scientific research, elucidation was a lengthy process that eventually led to a better understanding of the subcomponents of recognition memory (according to dual-process models).

Smith and Halgren (1989) believed the N400 was elicited by the integration of the semantic attributes for the evoked item and the current “cognitive context”. The result, in their view, was the formation of an episodic memory trace. Subsequent repetition of the item in the same context then reactivated the trace, preventing the formation of a standard (i.e., that typically seen in studies of language comprehension) N400. Instead, the late positive component was enhanced. Support for these views as well as lesion data to bolster the dual-process model came from Smith and Halgren's report that left temporal lobectomy patients did not generate reliable old new effects to verbal information whereas right-sided lobectomy patients did. Furthermore, the authors noted that only a mild decrement in behavioral performance was observed in the left lesioned patients suggesting they had poor recollection but intact abilities to make familiarity judgments (thus yielding only mild accuracy impairments).

In a subsequent attempt to tease apart recollection from familiarity Potter et al. (1992) used the anticholinergic drug scopolamine to impair explicit memory and spare implicit memory. Prior research demonstrated that administration of such a receptor antagonist renders subjects impaired on free recall tasks (explicit memory; Kopelman & Corn, 1988) yet spares the ability to complete word-stem tasks accurately (implicit memory; Nissen, Knopman, & Schacter, 1987). Results indicated that, contrary to the findings of Smith and Halgren, their results showed that impairments of recollection (i.e., explicit memory) do not yield reduced Old/New effects (early or late). Rugg and Nagy (1989) also demonstrated a lack of association between memory retrieval and early Old/New effects using normal subjects. Specifically, the two used a continuous recognition task where study words were repeated after either 6 or 19 intervening words followed by a 45-minute delay period and administration of a traditional recognition memory task using words from the continuous recognition test. The continuous recognition task yielded Old/New effects beginning around 250ms post stimulus (thus encompassing both the P300 and the N400). The traditional recognition task also elicited Old/New effects the amplitudes of which were smaller and the latency longer (starting around 550ms post stimulus). Because of the increased latency (despite continuing to perform quite accurately) Rugg and Nagy postulated that the N400 component was not necessary to perform the task. Furthermore, they argued that early Old/New effects were related to the time delay (i.e., recollection, or the memory trace was weak or absent after 45 minutes so judgments were made according to familiarity levels) between the two tasks rather than discrimination itself. Taken together it has been suggested (e.g., Rugg, Brovedani, & Doyle, 1992; Smith, 1993) that early Old/New effects do not seem to contribute to recognition memory processes over intervals of more than a few minutes.

Unlike early effects, late Old/New effects persist over long delays between study and test phases. For this reason, it is generally assumed that late Old/New effects reflect the neural underpinnings of recognition memory.

In 1990, Rugg had participants detect non-words mixed amongst a list of actual words, some of which were repeated at either high or low levels to investigate electrophysiological responses to words of varying frequencies (an effect observed behaviorally that words of lower frequency show enhanced recollection compared to high frequency words). ERP results indicated that the repetition of low frequency words tended to enhance the amplitude of the late positive wave but repetition of high frequency words did not. In light of his findings, Rugg hypothesized that the observed frequency effect could be indexing familiarity and raised the question of whether or not recollection and familiarity could be teased apart within late Old/New effects. Follow-up experiments were conducted (Rugg & Doyle, 1994; Rugg et al., 1992) to investigate the possible dissociation of Old/New effects using this indirect task. Using a delay period of 20 minutes Old/New effects were larger for low than for high frequency words suggesting that the previously observed word frequency effect was driven by the influence of familiarity.

Paller and Kutas (1992) used a novel approach to investigate Old/New effects. Specifically, subjects were required to process a list of words both orthographically and, in a separate list, imaginal processing. They subsequently presented an additional list of words composed of items from the orthographic and imaginal lists along with new, never presented words. ERPs elicited by correctly identified items differed according to how they were encoded (studied) in that words from the imagery task elicited more positive waveforms then those from the orthographic processing study phase. The authors reasoned that words from the imaginal task were judged by subjects as having been experienced more recently then the words from the orthographic task and interpreted the findings as evidence for a 'neural signature' for conscious recollection.

In an attempt to dissociate recollection and familiarity, Gardiner and Java (1991) employed a paradigm in which subjects endorsed descriptors to reflect their recognition judgments. Specifically, after identifying a test item as being old, participants reported whether their decision was based on an explicit memory of its initial presentation (a "remember" judgment) or on the basis of a familiarity feeling in absence of an explicit memory of the initial presentation (a "know" judgment). Results indicated Old/New effects were larger for the words judged as being "remembered" than for the "know" judgments. Smith (1993) later replicated these findings and concluded that Old/New effects were generated by neural processes engaged during recollection (not familiarity) in recognition memory tasks. Importantly, in all of the Old/New studies employing remember/know judgments, words judged old on the basis of familiarity (know judgments) elicited reduced, but not absent Old/New effects when compared to "remember" judgment words and with the same accompanying scalp distribution (i.e., midline foci).

In sum, Old/New effects refer to the tendency for ERPs elicited by previously presented words to be more positive going than those elicited by words that were not previously presented. These robust effects are conceptualized as consisting of an increased positivity superimposed on the well-studied N400 component and are often divided into two categories: early and late Old/New effects. Early effects are hypothesized to be associated with the familiarity component of recognition memory whereas the late counterpart is thought to index recollection.

ERPs, Emotion, and Recognition Memory

Numerous ERP studies exist within the domains of emotion and memory separately. Relatively few, however, have examined the ERPs resulting from recognition memory for emotional stimuli.

Johansson, Mecklinger, & Treese (2004) recently examined Old/New effects in recognition memory for faces differing in affect (i.e., positive, negative, and neutral). Results indicated that the negative faces were remembered more frequently than the neutral and positive faces as evidenced by a greater parietal Old/New effect associated with the negative faces. Furthermore, frontally distributed ERPs elicited by correctly rejected new faces were modulated in a positive direction by the negative valence in the correctly rejected new faces (i.e., negative faces elicited more positive going waveforms than positive and neutral faces). Therefore, the authors concluded that emotional stimuli appear to relax the criterion set by prefrontal cortical areas resulting in a bias towards such stimuli as evidenced by better recognition and greater parietal Old/New effects. These findings were a replication and extension of Ochsner's (2000) experiment where participants recognized negative photos more accurately than their positive and neutral counterparts.

Several investigators have examined the effects of emotional context on recognition memory performance. By testing recognition for emotionally neutral objects that were associated with positively or negatively valenced background context during the task's study phase, Smith, Dolan, and Rugg (2004) were able to probe ERP correlates of retrieval for emotional (and nonemotional) material. Results did not support the previous fMRI findings of Maratos and Rugg (2001) in that the emotional context of the stimuli failed to affect the amplitude of the left parietal Old/New effect.

Although words have not traditionally been used to study the interplay between emotion and memory because their elicited responses are less intense than that of pictures, they possess many desirable qualities as stimuli. Most importantly, a substantial literature regarding the factors thought to affect memory for emotional stimuli (e.g., frequency, recallability, concreteness) has given rise to normative data (e.g., arousal and valence ratings) for stimuli allowing for greater experimental control of these important variables. ERP studies of recognition memory for emotional words have been conducted most recently and are therefore fewer in number.

Using a small (n = 16) sample of healthy young adults Maratos et al. (2000) examined Old/New effects of emotionally negative and emotionally neutral words in a recognition memory paradigm. Behavioral data revealed a false alarm rate nearly twice as large for negative words when compared to their neutral counterparts. That is, subjects were more likely to incorrectly identify new negative words as having previously been presented on the study word list. In addition, electrophysiological responses elicited by correct rejections of negative items were larger in magnitude and identical in scalp topography to those elicited by the neutral words. Because the authors did not find evidence for qualitatively distinct neural systems as a function of valence they concluded that the results bolstered their semantic cohesion hypothesis. That is, emotional words influence memory because they belong to the same (or similar) semantic category.

Windmann and Kutas (2001) later attempted to replicate the findings of Maratos, Allan, and Rugg (2001) and extend the study to investigate “subjective Old/New effects”. Traditionally, the Old/New waveforms are composed solely of trials where the subject correctly responds to stimuli; that is, hits and correct rejections. The remaining responses (misses and false alarms) are not used. Subjective Old/New effects refer to ERP waveforms elicited by words that the participant judges to be old (i.e., hits or false alarms) or new (i.e., correct rejections or misses) regardless of whether or not the items are actually old or new. Unlike Maratos’ findings, Windmann and Kutas found no quantitative Old/New differences as a result of valence within the Traditional/Correct comparison (i.e., using correct trials only). Analysis of the Subjective Old/New effects, however, revealed that only neutral (not negative) items elicited a large Old/New difference over prefrontal scalp regions during the early epoch (300-500ms). Behaviorally, however, participants classified negative words faster and more frequently as being old regardless of whether or not the items were actually old. The authors interpreted the findings as being congruent with the idea of the prefrontal cortex relaxing the criterion for negative stimuli so that they are better remembered and are less frequently overlooked. The authors also argued that this function plays an adaptive role to protect against potentially threatening situations.

Dietrich et al. (2001) employed a continuous recognition memory test to investigate the effects of negative, neutral, and positive words on Old/New effects. Subjects were presented with an ongoing (as opposed to the typical recognition memory format where subjects are presented with a list of words followed by a delay period and then the recognition portion of the test) list of words and asked to make decisions about whether each word had been seen before (i.e., old) or not (i.e., new). The greatest Old/New effects were elicited by negative words, followed by positive and then neutral items. This was the first study to utilize positive words as stimuli in their experiment. However, two significant limitations of this study are that 1) valence ratings of words were obtained from a very small sample of subjects (n = 12) and 2) words were not balanced for levels of arousal across the three different valence conditions. Emotional stimuli are associated with higher levels of arousal and have been shown to affect recall and recognition (see Christianson, 1992) for a review. Furthermore, negative words tend to possess higher levels of arousal than their positive or neutral counterparts (Hamann, 2001).

In a subsequent study, Windmann, Urbach, & Kutas, (2002) divided their sample (n = 30) into two groups based on individual response styles (i.e., bias; high or low predisposition to endorse items as having been previously presented) and examined Old/New effects for negative and neutral words according to the following classifications: Traditional/Correct Old/New effects where only the correct trials are compared, Subjective Old/New effects where comparisons are made between trials that the subject believes to be old are those the subject believes to be new (regardless of whether or not the items are actually old or new), and Objective Old/New effects where all of the trials are used to compare waveforms elicited by old vs. new items (regardless of accuracy). Recognition accuracy and ERP patterns elicited by items that actually were old versus new (Objective Old/New effect) were comparable between the two groups. It was not until items were analyzed according to the subjects' perspectives as to which items were old and new (Subjective Old/New effect) that differences emerged. These differences were maximal over prefrontal sights and occurred between 300-500 ms poststimulus leading the authors to conclude that response bias influences early memory retrieval processes. The Traditional/Correct classification (i.e., hits and correct rejections) yielded differences intermediate to the Objective and Subjective Old/New effects.

Most recently, Inaba, Nomura, and Ohira (2005) used positive, negative, and neutral words to examine Old/New effects in 20 students. They found greater Old/New effects for negative targets, followed by positive, and then neutral targets. These differences were maximal at midline and left centro-parietal sites. As was the case for all but perhaps one (Maratos' study is unclear) of the above ERP studies of recognition memory for emotional words, items were not balanced for arousal; only valence. Therefore, interpretation of results is difficult, at best, due to the tendency for arousal to influence memory performance and to be higher for emotional words as compared to neutral words. Furthermore, for all but the two studies from the Windmann group, Old/New effects were extrapolated from ERPs elicited by correct trials only. This is the traditional method of measuring Old/New effects. However, as the Windmann group revealed, Old/New effects composed of correct trials only can be confounded by response bias in that correct trials could be due to accurate memory, response bias, or a combination of memory and bias. Therefore, accurate conclusions cannot be made without accounting for this individual subject bias. Additionally, by examining the full range of responses (hits, misses, false alarms, and correct rejections) and the accompanying Old/New effects one is able to obtain a more comprehensive view of the Old/New effects and how they interact with varying levels of response bias.

Purpose

The current study had two specific purposes. The first, overarching purpose was to investigate the pattern and timing of electrophysiological indices of Old/New recognition memory effects for negative, neutral, as well as positive words. Secondly, this study examined behavioral and electrophysiological indices of subject response bias in Old/New recognition memory.

This investigation attempted to replicate previous findings of increased positivity elicited by negative words previously presented in a recognition memory paradigm (i.e., the Old/New effect) and extend those findings to include positively valenced words. Of the few existing studies in the literature on the influence of valence on Old/New effects, only two have used positive words in addition to negative and neutral ones (both investigations have yielded findings indicating greatest Old/New effects for negative words, followed by positive words, and then neutral). However, neither of these studies controlled for the confounding effects of arousal on memory. Investigating positive words will help elucidate the mechanisms by which these phenomena operate.

Windmann, Urbach, and Kutas (2002) have demonstrated the importance of examining Subjective Old/New effects where the Old/New status of words are determined solely by the subject's response of old versus new as opposed to the standard comparison where only the ERPs elicited by correct classification of responses. Traditional analyses of Old/New effects are confounded by response bias due to the fact that recognition memory judgments can result from accurate memory, bias, or some combination of the two. The Windmann study used three separate types of trial comparisons to probe varying degrees of response bias within Old/New effects that will also be used in the present study. They are:

- Traditional/Correct Old/New Effects. This classification utilizes ERP waveforms elicited only by trials where the participant correctly responded targets (i.e., hits) or foils (i.e., correct rejections).
- Objective Old/New Effects. This classification utilizes ERP waveforms elicited by targets (i.e., hits and misses) and foils (i.e., correct rejections and false alarms). This includes all the participant's responses (correct and incorrect) regardless of whether or not they were correctly identified by the participant as old or new (i.e., hits, correct rejections, false alarms, and misses)
- Subjective Old/New Effects. This classification utilizes ERPs elicited by words that the participant judges to be old (i.e., hits or false alarms) or new (i.e., correct rejections or misses) regardless of whether or not the items are actually old or new.

Using groups with comparable levels of recognition memory accuracy and ERP patterns to Objective Old/New items, but either with or without a predilection (i.e., high bias and low bias, respectively) to respond old, the Windmann group found significant differences between the high and low bias groups when the Subjective Old/New classification was used. Furthermore, they found the Traditional/Correct Old/New comparison to have peak amplitude differences intermediate to the Objective and Subjective comparisons. These findings suggest that response bias influences the magnitude of the observed Old/New effects and that valid interpretation of Traditional/Correct Old/New effects cannot be made without accounting for this subject response bias.

Hypotheses and Predictions

Behavioral

Hypothesis 1:

Based on prior research, it is hypothesized that positive and negative words will elicit more hits and false alarms than neutral items.

Hypothesis 2:

The bias to respond old will be greater for negative words and positive words (compared to neutral items) and reaction times will be shorter (i.e., participant responses will be faster) for correct responses and responses to negative and positive words compared to neutral words.

Hypothesis 3:

If emotional words are truly remembered more frequently due to their high semantic cohesion then controlling for semantic cohesion across positive, negative, and neutral words should eliminate any enhancement of the emotional words as compared to the neutral items. If, however, the bias for negative words seen in previous research exists as a function of adaptation to potentially threatening stimuli, then positive words should yield behavioral data equivalent to that of the neutral items.

ERP

Hypothesis 4:

With respect to the ERP data, it is hypothesized that all three word classes (i.e., negative, neutral, and positive) will elicit Old/New effects. The largest effects are predicted to be within the Traditional/Correct classification, followed by the Subjective and the Objective classifications (respectively).

Hypothesis 5:

Based on Windmann and Kutas' assertion that bias for negative words serves an adaptive function, whereby the cognitive system is prompted to assign greater significance and a higher priority to the processing of potentially threatening stimuli is correct it is predicted that Old/New effects will be greatest for negative items compared to positive and neutral because the positive and neutral items lack threatening connotations.

Method

Participants

Forty-five participants were initially recruited from the on line participant pool of undergraduate psychology students at the University of South Florida. Fifteen participants were subsequently excluded from the study for the following reasons: non-native English speakers (2 females), stimulus presentation software crash (1 male), elevated depression scores (>10 on the Beck Depression Inventory; BDI) (3 females), braided hair/extensions rendering proper electrode placement impossible (2 females), extremely low trial counts in multiple categories (e.g., 2 negative misses) (1 male), and too many (>15%) bad channels (due to motion artifact, eye blinks etc.) for the EEG data to be averaged (5 females). Also, one participant refused to consent, as she did not wish to get her hair wet. The final sample consisted of thirty participants (15 male, 15 female) with a mean age of 20.3(SD = 3.3) years. Of these remaining participants all were right handed, had normal or corrected to normal vision, reported a history free of major neurological and psychiatric symptoms (including any head injury with a loss of consciousness $\geq$ 10 minutes), and were native English speakers, above the age of 18.

Apparatus

All stimuli (i.e., words) that composed the recognition memory test were presented using a DELL Genuine Intel x86 Family 6 model 8 computer and a 21-inch Sony Multiscan 220GS monitor. The computer software E-prime (version 3.0; Schneider, Eschman, & Zuccolotto, 2002) was used to present all recognition memory stimuli, collect responses and valence ratings. Participants' responses were recorded via a standard keyboard. Collection of ERP data was carried out through the use of the Electrical Geodesics Incorporated System200 (EGI, Eugene, OR). Brain electrophysiology was recorded with a 128-channel Electrical Geodesics Incorporated sensor net in conjunction with NETSTATION 4.2 acquisition software powered by a Macintosh G4 computer. Electroencphalographic data were sampled at 250Hz.

Materials

In addition to the aforementioned ERP equipment, materials included two self-report questionnaires and two published bodies of words containing extensive normative data on many variables.

Due to the nature of the current study (perception/judgment of emotional stimuli) depressive symptoms were assessed using the Beck Depression Inventory (2nd edition; BDI-II; Beck & Steer, 1987) scale to avoid any confounds from participants with affective disturbances. The BDI-II has demonstrated excellent reliability/validity, is brief to administer, and is often used as a screening tool in research settings (Beck, Steer, & Garbin, 1988). The Edinburgh Handedness Inventory (Oldfield, 1971) was used to assess type and degree of laterality. This 22 item self-report measure is preferred because it assesses not only hand preference, but foot and eye preferences as well. These additional preference types have been shown to reflect a more accurate representation of degree and type of laterality (Williams, 1991)

Five hundred and twenty-eight total (i.e., 176 positive, 176 negative and 176 neutral) words were obtained from the Affective Norms for English Words (ANEW; Bradley & Lang, 1999). This large body of words has been rated in terms of pleasure, arousal, and dominance. A random number generator was used to assign a number to the words in each valence list (numbers 1 though 176). The first half (numbers 1 through 88) of each valence list became part of the pool of targets and the second half (numbers 89 through 176) of each valence list became part of the pool of foils. Target words did not differ significantly according to arousal [$F(2,261) = .196, p=.822$], or frequency [$F(2,252) = 2.69, p=.070$]. Additionally, the University Colorado's Latent Semantic Analysis (LSA; Landauer, Foltz, & Laham, 1998) program was used to equate for effects due to high semantic cohesion among target words. LSA is a theory and method for extracting and representing the contextual-usage meaning of words by statistical calculations applied to a large body of text. The analysis is based on the hyperspace analogue to language (HAL) model of memory and works by encoding a co-occurrence learning algorithm of the context in which words occur. Through the use of the LSA program target words did not differ significantly across the three valences [$F(2,261) = 1.02, p=.363$]. Word lists can be found in Appendix A.

Design and Procedure

After procedures were explained, and an opportunity for participants to ask questions was provided, written informed consent was obtained. The first portion of the study included administration of the paper and pencil measures (i.e., demographic information, BDI-II, and Edinburgh Handedness Inventory). During this time the experimenter prepared an electrolyte solution composed of 1 liter distilled H_2O, 1.5 teaspoons of NaCl, and .75 teaspoons of baby shampoo and submersed the appropriately sized net for absorption of said solution. Upon completion of all questionnaires, the participant's head was measured, their vertex was marked and the128 channel net described above was fitted on the participant's head and adjusted as needed for proper fit and to insure channel impedances were below 50kΩ. Once the participants were seated in the experiment room alone in front of the monitor the preprogrammed instructions lead them through the remainder of the experiment. The participants were instructed to memorize the list of words for a subsequent memory test and to try to remain still.

Words were randomly presented (one at a time) in the middle of the screen for 300 milliseconds (ms) with an interstimulus interval of 2200 ms. After presentation of the two-hundred and sixty-four target/study words, participants were moved to a different room and asked to engage in a five minute distracter task consisting of multiplication problems. Immediately following the delay period subjects were moved back into the experiment room, impedances were rechecked (electrodes rehydrated as needed) and the study commenced with the recognition memory test. Participants used either their right or left hand (counterbalanced across subjects) to indicate whether each word (presented individually) was old or new according to a confidence rating scale. Test list words were also presented in random order. Instructions to the participant were as follows:

If you are:

Highly confidant the word was studied, press 1

Less confidant the word was studied, press 2

Less confidant the word was NOT studied, press 3

Highly confidant the word was NOT studied, press 4

Two hundred and sixty-four foil words (88 positive, 88 negative, 88 neutral) in addition to the 264 target words from the study phase comprised the recognition portion of the test. All words were displayed for a period of 400ms with each subsequent word appearing 1600ms after the participant gave a response.

Upon completion of the study, ERPs were digitally filtered with a 20hz low-pass filter and segmented into 1600ms epochs around the test list words (200ms before/1400ms after the presentation of each test word). Epochs were screened for noncephalic artifact and marked as bad (i.e., excluded from further analysis) if they contained more than 10 bad channels. Individual participant files with fewer than 15% good trials per category were excluded from further analysis. ERPs were baseline corrected by 200ms and transformed using an average reference montage. Individual participant ERPs were averaged together to create grand average waveforms. Mean amplitude values were used as the dependent variables in the following time windows: 300-640 ms post stimulus over frontal leads (electrodes 12, 18, 19, 23 and 24 composed the left frontal region, and electrodes 3, 4, 5, 10, and 124 composed the right frontal region) to capture the early bilateral frontal Old/New effect, 400-1000 ms post stimulus over parietal leads (electrodes 31, 36, 37, 41, 42, 47, 51, 52, 53, 54, 59, 60, and 61 composed the left parietal region, and electrodes 78, 79, 85, 86, 87, 91, 92, 93, 97, 98, 103, and 104 composed the right parietal region) to capture the left parietal Old/New effect, and 400-1400ms over frontal leads (electrodes 12, 18, 19, 20, 22, 23, 24, 26, 27, 28, 29, 33, 34, and 35 composed the left frontal region, and electrodes 2, 3, 4, 5, 9, 10, 110, 111, 116, 117, 118, 122, and 123 composed the right frontal region) to capture the late right frontal Old/New effect. Spatial/temporal regions of interest are graphically depicted in Figure 1. All of the aforementioned mean amplitudes reflect the average voltage value of channels within each montage. See Table 2 for descriptive statistics for each of the trial categories (i.e., number of hit, miss, false alarm, correct rejection trials retained for analysis). Grand average waveform amplitudes were topographically plotted and visually inspected to determine the regions of interest listed above.

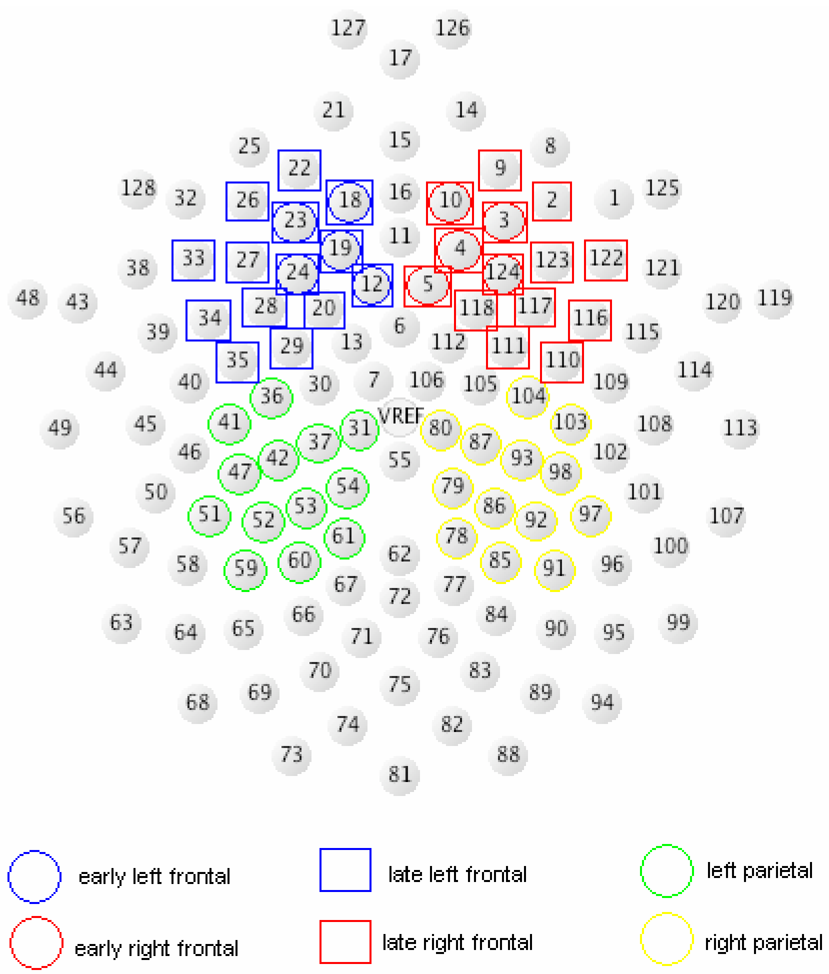


Figure 1. Electrodes used in spatial/temporal analyses.

Table 2. Mean (SD) ERP category trial counts

Positive

Hit: 48.17(11.12)	False Alarm: 36.66(15.01)
Miss: 30.53(10.02)	Correct Rejection: 42.63(15.84)

Negative

Hit: 52.57(9.45)	False Alarm: 33.27(11.29)
Miss: 26.17(8.79)	Correct Rejection: 45.10(13.10)

Neutral

Hit: 46.30(10.73)	False Alarm: 28.43(14.15)
Miss: 33.43(9.85)	Correct Rejection: 51.30(15.13)

Results

Data diagnostics

Before hypothesis testing all data were screened to determine whether or not the necessary assumptions were met to conduct valid statistical analyses. Histograms and boxplots were visually examined to confirm that the assumption of normality was met. Several significant outliers existed within the behavioral data so analyses that included these variables were run twice (once with and once without the addition of the participant with the extreme score). Exclusion of outliers did not yield a different pattern of results so analyses reported below included the entire sample. Skewness and kurtosis values were also examined for each of the variables and determined to be within normal limits. Examination of sphericity tests revealed that all of the variables met this assumption.

Behavioral Analyses

Hypothesis 1: Positive and negative words will elicit more hits and false alarms than neutral items.

Hit Rate/False Alarm Rate

Participant responses of either a “1” (i.e., “Highly confidant the word was studied”) or a “2” (i.e., “Less confidant the word was studied”) were coded as an “old” endorsement. Conversely, a response of either a “3” (i.e., “Less confidant the word was NOT studied”) or a “4” (i.e., “Highly confidant the word was NOT studied”) was coded as a “new” endorsement. As such, a hit can be thought of as an “old” response to an old word (i.e., target). A false alarm is an “old” response to a new word (i.e., foil). A correct rejection is a “new” response to a new word and a miss is a “new” response to an old word.

Each participant’s Hit Rate (probability of old items that are correctly classified as old) and False Alarm Rate (i.e., the probability of new items that were incorrectly classified as old) were calculated and served as the dependent variables in a one-way MANOVA; Valence served as the independent variable. Means and standard deviations for each Hit Rate and False Alarm Rate from the three experimental conditions (i.e., positive, negative, and neutral) are listed in Table 3. Results of the overall MANOVA indicated the Hit Rate and False Alarm Rate differed significantly from each other as a function of Valence [λ = .314; F (4,26) = 14.17, p < .001].

Table 3. Mean (SD) Hit and False Alarm Rates across valences (N=30)

	Hit Rate	False Alarm Rate
Positive	.60(.12)	.45(.19)
Negative	.67(.10)	.43(.14)
Neutral	.58(.12)	.36(.17)

Univariate ANOVAs for Hit Rate and False Alarm Rate both revealed significant main effects of Valence [F (2,58) = 14.96, p < .001 and F (2,58) = 12.68, p < .001 respectively]. For Hit Rate data, Bonferroni adjusted pairwise comparisons revealed that negative words elicited a significantly higher hit rate (M=.67, SD = .10) then positive words ($M = .60$, $SD = .12$, $p<.01$) and neutral words ($M = .58$, $SD = .12$). The Hit Rate for positive words was not significantly different than the Hit Rate for neutral words ($p=.18$).

Analysis of the False Alarm Rate using Bonferroni adjusted pairwise comparisons revealed negative and positive words elicited significantly higher False Alarm Rates ($M =.43$, $SD = .14$ and .45, $SD = .19$) than neutral words ($M = .36$, $SD = .17$) words ($p<.01$ and $p<.001$ respectively. The False Alarm Rate for negative words did not differ significantly from the False Alarm Rate for positive words ($p=.86$).

Sensitivity

An ancillary analysis was conducted using the sensitivity index d′ as this index takes into account both hits *and* false alarms. The formula used to derive d′ can be found in Appendix A. When d′ was entered as the dependent variable and Valence was kept as the independent variable in a one-way repeated-measures ANOVA, the previously seen main effect of Valence emerged again [$F(2,58) = 15.03$, $p < .001$]. Bonferroni adjusted paired comparisons revealed accuracy was significantly greater for negative ($M = .65$, $SD = .36$) and neutral words ($M = -.61$, $SD = .34$) compared to positive words ($M = .41$, $SD = .37$). The difference between neutral and negative words was not significantly different ($p=1.0$).

Hypothesis 2: The bias to respond old will be greater for negative words and positive words (compared to neutral items) and reaction times will be shorter (i.e., participant responses will be faster) in response to negative and positive words compared to neutral words.

Response Bias

Results of the repeated-measures ANOVA where the three level (i.e., positive, negative, and neutral) independent variable of Valence was entered and the bias index C served as the dependent variable revealed a main effect of Valence [$F(2,58) = 10.67$, $p < .001$]. Bonferroni adjusted paired comparisons revealed that participants adopted a significantly more liberal response bias for negative ($M = -.13$, $SD = .30$) and positive ($M = -.04$, $SD = .35$) compared to neutral words ($M = .10$, $SD = .39$; $p<.001$ and $p = .011$ respectively). The difference between negative and positive words was not significantly different ($p=.32$). The formula used to derive C can be found in Appendix A.

Reaction Times

A two-way repeated measures ANOVA was employed to test differences in median reaction times of the four possible response types (i.e., hit, miss, false alarm, and correct rejection). For this analysis Valence (with the three levels of positive, negative, and neutral) as well as Response Type were entered as independent variables and Median Reaction Time as the dependent variable. Results indicated a trend towards a significant main effect of Valence [$F(2,58) = 2.66$, $p = .078$] and a main effect of Response Type [$F(3,87) = 9.74$, $p < .001$]. Bonferroni adjusted pair wise comparisons revealed reaction times were significantly faster (i.e., smaller) when participants responded correctly to targets (i.e., hits; $p<.001$) compared to all other response types. Median reaction times for each of the four response types (i.e., hit, miss, false alarm, and correct rejection) can be seen in Figure 2. Although a Valence trend was observed it was not in the expected direction as the longest reaction time was observed for negative words.

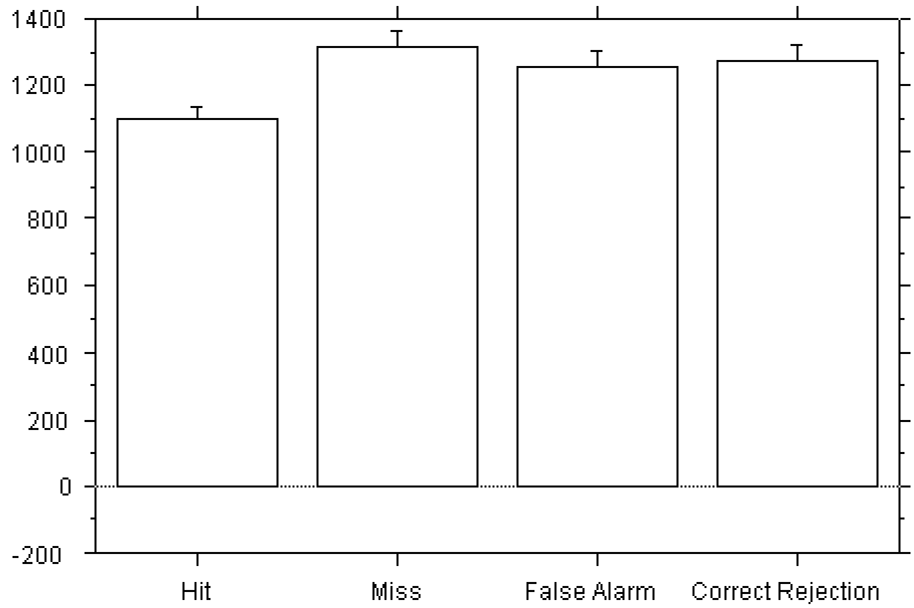


Figure 2. Mean reaction times (in ms) for each response type.

Since participant responses were made according to various levels of confidence (as opposed to yes/no only) ancillary analyses were conducted to determine what role, if any, level of confidence contributed to reaction times. Chi square tests were employed first to determine if the frequency of each possible rating response differed within each of the four response types (hit, miss, false alarm, correct rejection). Within the hit response type there were significantly more ‘1’ (i.e., ‘Highly confidant the word was studied’) responses χ^2 (1, N = 30) = 393.32, p < .001, indicating hits were responded to more frequently with a ‘highly confidant’ rating as opposed to the less confidant rating (i.e., ‘2’). Within the miss response type there were significantly more ‘3’ responses (i.e., ‘Less confidant’ the word was NOT studied’) χ^2 (1, N = 30) = 57.84, p < .001, indicating misses were responded to more frequently with a ‘less confidant’ rating as opposed to the ‘highly confidant’ rating (i.e., ‘Highly confidant the word was NOT studied). Within the false alarm response type there were significantly more ‘2’ responses (i.e., Less confidant the word was studied) χ^2 (1, N = 30) = 21.54, $p < .001$, indicating false alarms were responded to more frequently with a ‘less confidant’ rating as opposed to the ‘highly confidant’ rating (i.e., ‘Highly confidant the word was studied). Within the correct rejection rating there were significantly more ‘3’ responses (i.e., ‘Less confidant the word was NOT studied’) χ^2 (1, N = 30) = 33.50, $p < .001$, indicating correct rejections were responded to more frequently with a ‘less confidant’ rating as opposed to the ‘highly confidant’ rating (i.e., ‘Highly confidant the word was NOT studied).

Given the significant differences among the frequency of confidence (i.e., highly confidant vs. less confidant) ratings for each response type (i.e., hit, miss, false alarm, correct rejection) reaction time data was re-analyzed using a two-way repeated measures ANOVA where Confidence Level (highly confidant, less confidant) and Response Type (hit, miss, false alarm, correct rejection) were entered as independent variables and reaction time stood as the dependent variable. Results indicated a main effect of Response Type [$F(3,87) = 3.45$, $p = .02$] as well as a main effect of Confidence Level [$F(1,29) = 12.29$, $p = .002$]. A significant interaction between Response Type and Confidence Level was not observed [$F(3,87) = 1.99$, $p = .121$]. Bonferroni adjusted post hoc tests indicated that ‘highly confidant’ responses (M = 1174.69, SE = 72.74) were made significantly faster than ‘less confidant’ responses (M = 1567.45, SE = 119.80).

In order to reveal possible reaction time differences between the four response types, ‘less confidant’ ratings were discarded and ‘highly confidant’ trials were reanalyzed. In a one-way repeated measures ANOVA where Response Type (hit, miss, false alarm, correct rejection) served as the independent variable and Reaction Time as the dependent variable results indicated a main effect of Response Type [$F(3,87) = 13.29$, $p < .001$]. Bonferroni adjusted post hoc tests revealed hit responses ($M = 1006.62$, $SE = 56.20$) were made significantly faster than false alarms ($M = 1097.88$, $SE = 67.80$; $p = .025$), misses ($M = 1295.43$, $SE = 98.69$; $p < .01$), and correct rejections ($M = 1298.82$, $SE = 92.16$; $p < .001$). False alarms were made significantly faster than correct rejections ($p = .022$) and there was a trend towards false alarms being made significantly faster than miss responses ($p = .058$). Reaction times associated with correct rejections and misses did not differ from each other. These reaction times can be seen in Figure 3.

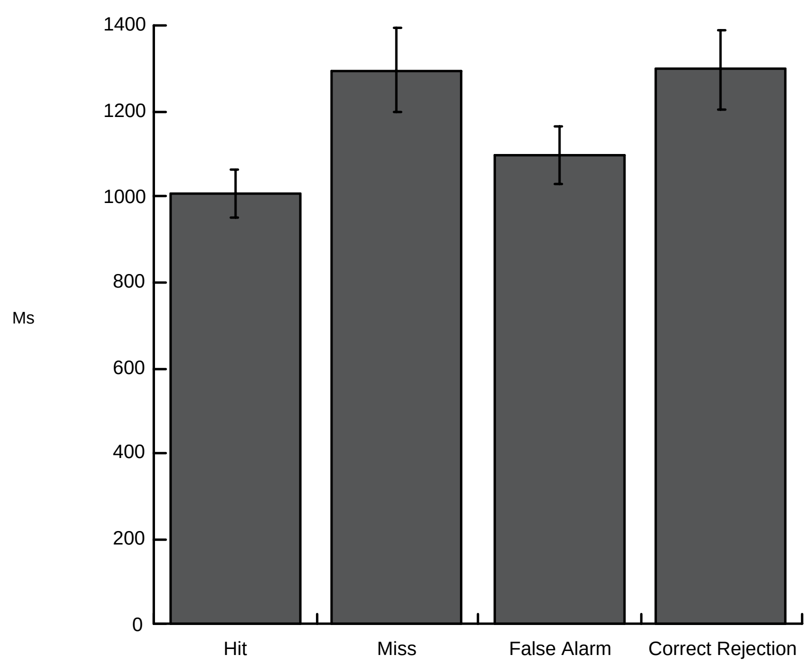


Figure 3. Mean reaction times for highly confidant responses for each response type.

Hypothesis 3: If emotional words are truly remembered more frequently due to their high semantic cohesion then controlling for semantic cohesion across positive, negative, and neutral words should eliminate any accuracy enhancement of the emotional words as compared to the neutral items. If, however, the accuracy enhancement of negative words seen in previous research exists as a function of adaptation to potentially threatening stimuli, then positive words should yield behavioral data equivalent to that of the neutral items.

As noted above, participants did exhibit accuracy differences as a function of valence (i.e., accuracy, as indexed by d′, was significantly greater for negative and neutral words compared to positive items). The current study did control for possible effects of semantic cohesion. Thus, controlling for semantic cohesion across stimuli did not eliminate the increased accuracy for negative words in this sample.

ERP Analyses

Hypothesis 4: With respect to the ERP data, it is hypothesized that all three word classes (i.e., negative, neutral, and positive) will elicit Old/New effects. The largest effects are predicted to be within the Traditional/Correct classification, followed by the Subjective and the Objective classifications (respectively).

For analysis of ERP data, repeated measures ANOVAs were conducted using Valence (negative, neutral, positive), Old/New status (old, new), and Hemisphere (left, right) as IVs, and mean amplitudes (averaged across channels within each region of interest) from each of the spatial/temporal regions of interest as DVs. Refer to Table 4 for Old/New classification type information.

Table 4. Old/New classifications according to response type

	OLD	NEW
Traditional	Hits	Correct Rejections (CRs)
Subjective	Hits & False Alarms (FAs)	CRs & Misses
Objective	Hits & Misses	CRs & FAs

Traditional Old/New Comparison

A repeated measures ANOVA was conducted where Valence (negative, neutral, positive), Old/New status (old, new), and Hemisphere (left, right) served as IVs and the mean amplitude (averaged across leads) from frontal leads recorded from 300-640ms served as the DV. Results revealed a main effect of Old/New status [$F(1,29) = 6.35$, $p = .02$] indicating old waveforms ($M = .68$, $SE = .192$) were significantly more positive in mean amplitude than new waveforms ($M = .19$, $SE = .71$). The effects of Valence [$F(2,58) = .663$, $p = .52$] and Hemisphere [$F(1,29) = .067$, $p = .80$], as well as all interactions were not statistically significant indicating that the Old/New effect was bilaterally distributed, but did not vary as a function of Valence (see Figure 4).

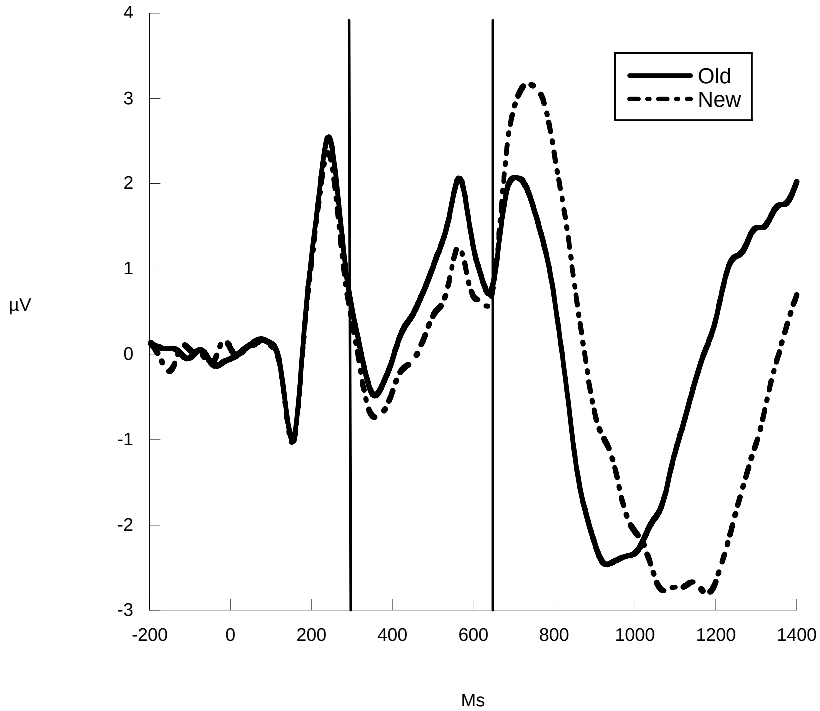


Figure 4. Bilateral frontal Old/New effect (n.b., vertical bars denote analysis epoch).

When a repeated measures ANOVA was conducted where Valence (negative, neutral, positive), Old/New status (old, new), and Hemisphere (left, right) served as IVs and the mean amplitude (averaged across leads) from parietal leads recorded from 400-1000ms served as the DV the main effect of Old/New status [$F(1,29) = 7.77$, $p < .01$] emerged again, where old waveforms ($M = .28$, $SE = .33$) were significantly more positive in amplitude than old waveforms ($M = .009$, $SE = .36$). This analysis also revealed a very strong trend towards a main effect of Hemisphere [$F(1,29) = 3.99$, $p = .055$] although not in the expected direction as the mean amplitude from the right hemisphere ($M = .49$, $SE = .42$) was larger than that of the left hemisphere ($M = -.20$, $SE = .34$). Although a main effect of Valence was not observed [$F(2,58) = 2.39$, $p = .10$], there was a significant three-way interaction between Valence, Old/New status, and Hemisphere [$F(2,58) = 3.82$, $p = .03$] where the Old/New effect was greatest in response to positive words in the left hemisphere (see Figure 5).

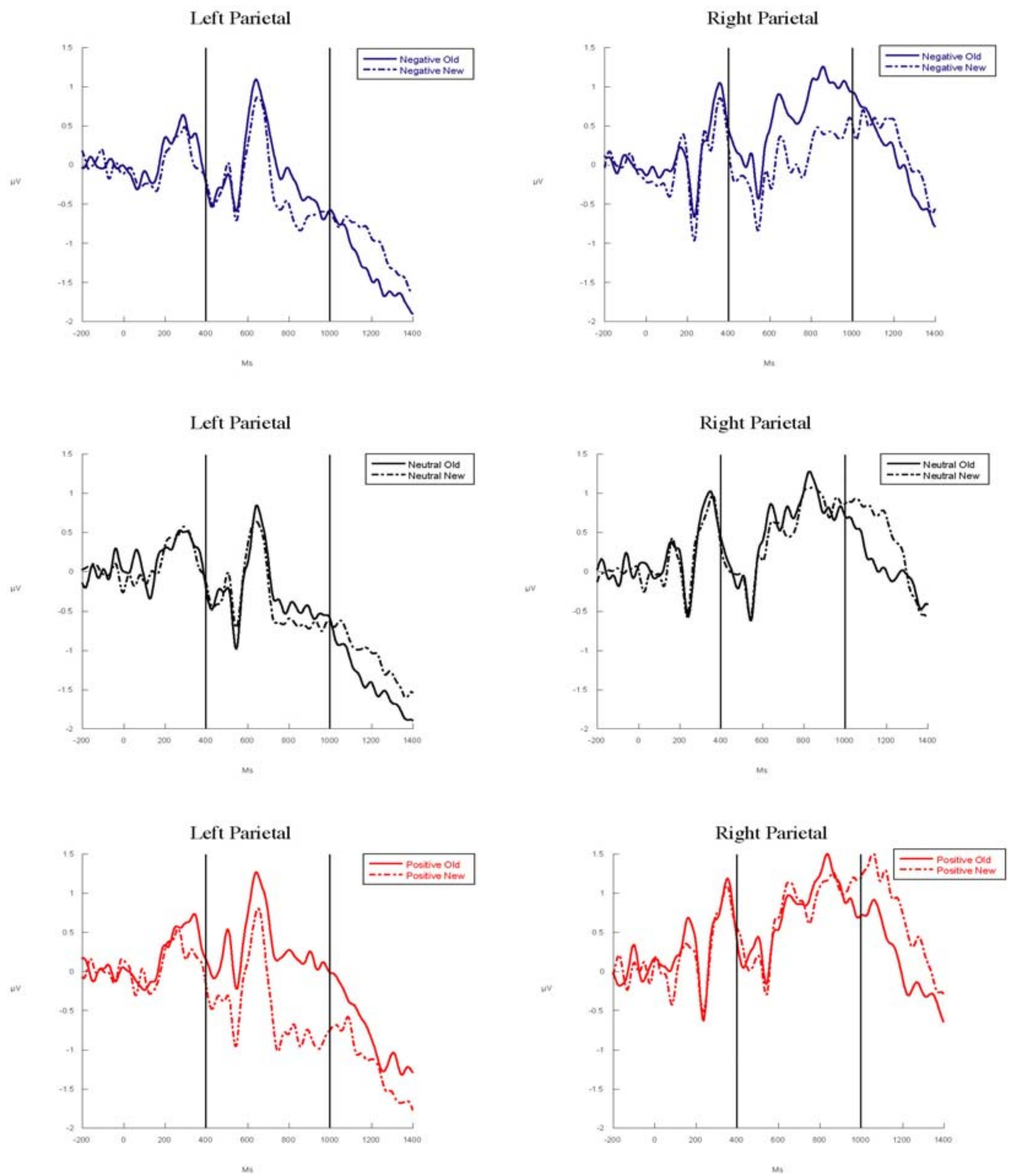


Figure 5. Interaction between Valence, Old/New status, and Hemisphere (n.b., vertical bars denote analysis epoch).

When mean amplitudes (averaged across leads) from frontal leads recorded from 400-1400ms served as the DV and Valence (negative, neutral, positive), Old/New status (old, new), and Hemisphere (left, right) served as IVs in a repeated measures ANOVA a main effect of Hemisphere was observed [$F(1,29) = 9.90$, $p < .01$] indicating mean amplitudes were greater in the right hemisphere ($M = 1.67$, $SE = .75$) compared to the left hemisphere ($M = -1.21$, $SE = 1.13$). Although significant main effects of Valence [$F(2,58) = 1.10$, $p = .34$] and Old/New status [$F(1,29) = 1.90$, $p = .18$] were not observed in this analysis, there was a trend towards a significant two-way interaction between Old/New status and Hemisphere [$F(1,29) = 3.64$, $p = .07$] where the Old/New effect was greater in the left hemisphere.

Objective Old/New Comparison

A repeated measures ANOVA was conducted where Valence (negative, neutral, positive), Old/New status (old, new), and Hemisphere (left, right) served as IVs and the mean amplitude (averaged across leads) from frontal leads recorded from 300-640ms served as the DV. There were no significant main effects of Valence [$F(2,58) = .845$, $p = .44$], Old/New status [$F(1,29) = 1.43$, $p = .24$], or Hemisphere [$F(1,29) = .302$, $p = .59$].

When the mean amplitudes (averaged across leads) from parietal leads recorded from 400-1000ms served as the DV and Valence (negative, neutral, positive), Old/New status (old, new), and Hemisphere (left, right) served as IVs in a repeated measures ANOVA a significant main effect of Old/New status emerged [$F(1,29) = 7.48$, $p = .01$] indicating old waveforms ($M = .13$, $SE = .33$) were significantly more positive than the new waveforms ($M = -.04$, $SE = .34$). Grand average waveforms illustrating this parietal Old/New effect can be seen in Figure 6. The effects of Valence [$F(2,58) = 2.04$, $p = .14$]

and Hemisphere [F(1,29) = 2.49, p = .13] on mean amplitudes were not statistically significant. Significant interactions did not result from this analysis.

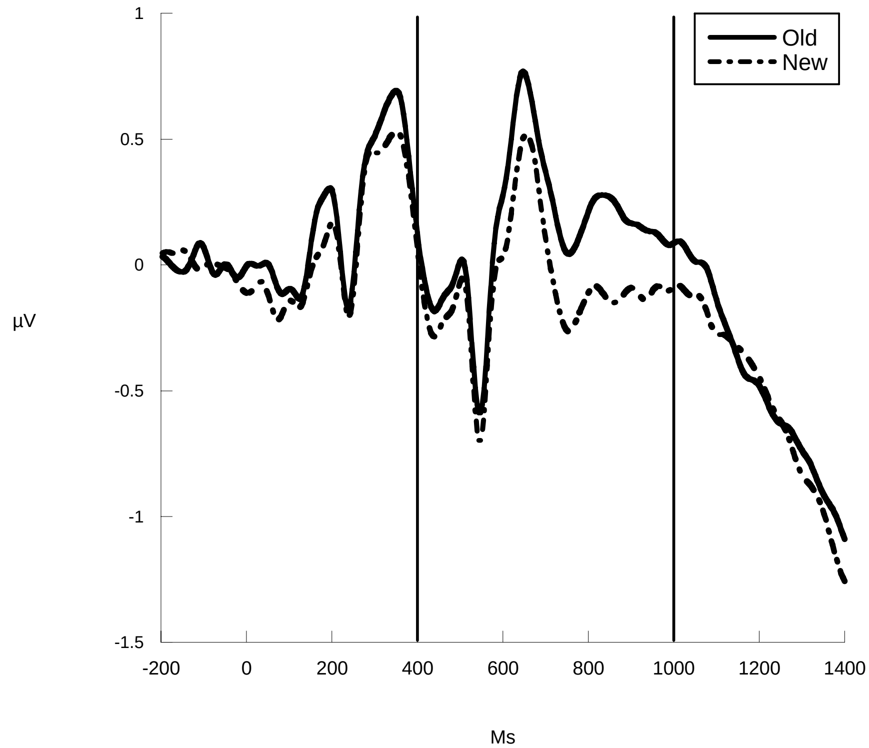


Figure 6. Grand average waveforms from the parietal region (n.b., vertical bars denote analysis epoch).

When mean amplitudes (averaged across leads) from frontal leads recorded from 400-1400ms served as the DV and Valence (negative, neutral, positive), Old/New status (old, new), and Hemisphere (left, right) served as IVs in a repeated measures ANOVA a significant main effect of Old/New status was again observed [F(1,29) = 5.81, p = .023] as well as a significant main effect of Hemisphere on amplitude [F(1,29) = 9.25, p < .01]. Inspection of amplitude means revealed that the old waveforms in this analysis were less positive (M = .176, SE = .85) than the new waveforms (M = .490, SE = .84) and amplitudes recorded from the right hemisphere leads were significantly more positive (M = 1.7, SE = .73) than those from the corresponding region of the left hemisphere (M = =1.04, SE = 1.14). This analysis did not yield a significant main effect of Valence [F(2,58) = 2.10, p =.132] or any significant interactions.

Subjective Old/New Comparison

A repeated measures ANOVA was conducted where Valence (negative, neutral, positive), Old/New status (old, new), and Hemisphere (left, right) served as IVs and the mean amplitude (averaged across leads) from frontal leads recorded from 300-640ms served as the DV. A significant main effect of Old/New status was observed [F(1,29) = 10.98, p < .01] where old waveforms were more positive in amplitude (M = .77, SE = .64) than new waveforms (M = .14, SE = .67). Grand average waveforms (collapsed across valence and hemisphere) of this Old/New effect can be seen in Figure 7. Significant main effects of Valence [F(2,58) = .845, p = .44] and Hemisphere [F(1,29) = .303, p = .59], as well as significant interactions were not observed in this analysis.

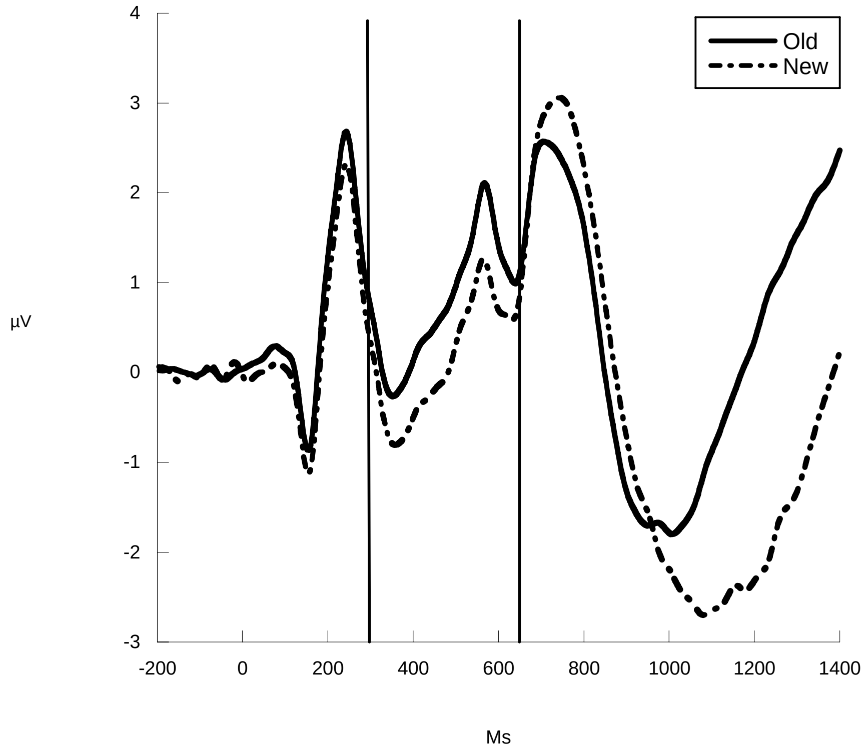


Figure 7. Grand average waveforms of the bilateral frontal Old/New effect (n.b., vertical bars denote analysis epoch).

When the mean amplitudes (averaged across leads) from parietal leads recorded from 400-1000ms served as the DV and Valence (negative, neutral, positive), Old/New status (old, new), and Hemisphere (left, right) served as IVs in a repeated measures ANOVA neither Valence [$F(2,58) = 2.04$, $p = .14$], Old/New status [$F(1,29) = 1.27$, $p = .27$], nor Hemisphere [$F(1,29) = 2.50$, $p = .13$] yielded significant main effects.

When mean amplitudes (averaged across leads) from frontal leads recorded from 400-1400ms served as the DV and Valence (negative, neutral, positive), Old/New status (old, new), and Hemisphere (left, right) served as IVs in a repeated measures ANOVA a significant main effect of Old/New status was observed [$F(1,29) = 9.54$, $p < .01$] where amplitudes of old waveforms were significantly more positive (M = .64, SE = .82) than those of new waveforms (M = .02, SE = .88). Additionally, a significant main effect of Hemisphere was observed [$F(1,29) = 9.25$, $p < .01$] where amplitudes of waveforms from the right hemisphere (M = 1.70, SE = .73) were more positive than those of waveforms recorded from the left hemisphere (M = -1.04, SE = 1.14). A significant interaction between Old/New status and Hemisphere also emerged [$F(1,29) = 4.90$, $p = .04$] reflecting a larger Old/New effect in the left hemisphere.

To test the prediction that Old/New effects would be largest within the Traditional/Correct classification, followed by the Subjective and the Objective classifications ERP waveforms associated with each of the four response types (i.e., hit, miss, false alarm, correct rejection) were analyzed separately. This was done to avoid violations of the independence assumptions of MANOVA that would come with an analysis directly comparing Old/New effects within the three classification types (i.e., Traditional, Objective, Subjective).

Within the early frontal spatial temporal region of interest a two-way ANOVA was employed where Response Type (Hit, Miss, False Alarm, Correct Rejection), and Hemisphere (Left, Right) served as the independent variables and mean amplitudes (averaged across frontal leads recorded from 300-640ms) served as the dependent variable. Results indicated a main effect of Response Type [$F(3,87) = 4.91$, $p = .003$] only. Bonferroni adjusted post hoc tests revealed that mean amplitudes elicited by False Alarms (M = .86, SE = .66) were significantly more positive than misses (M = .08, SE = .64; $p = .03$). A trend towards mean amplitudes elicited by Hits (M = .68, SE = .65) to be significantly greater than Misses was also observed ($p = .052$). Mean amplitudes associated with Correct Rejections (M = .19, SE = .71) did not differ from the other three response types. This effect can be seen in Figure 8.

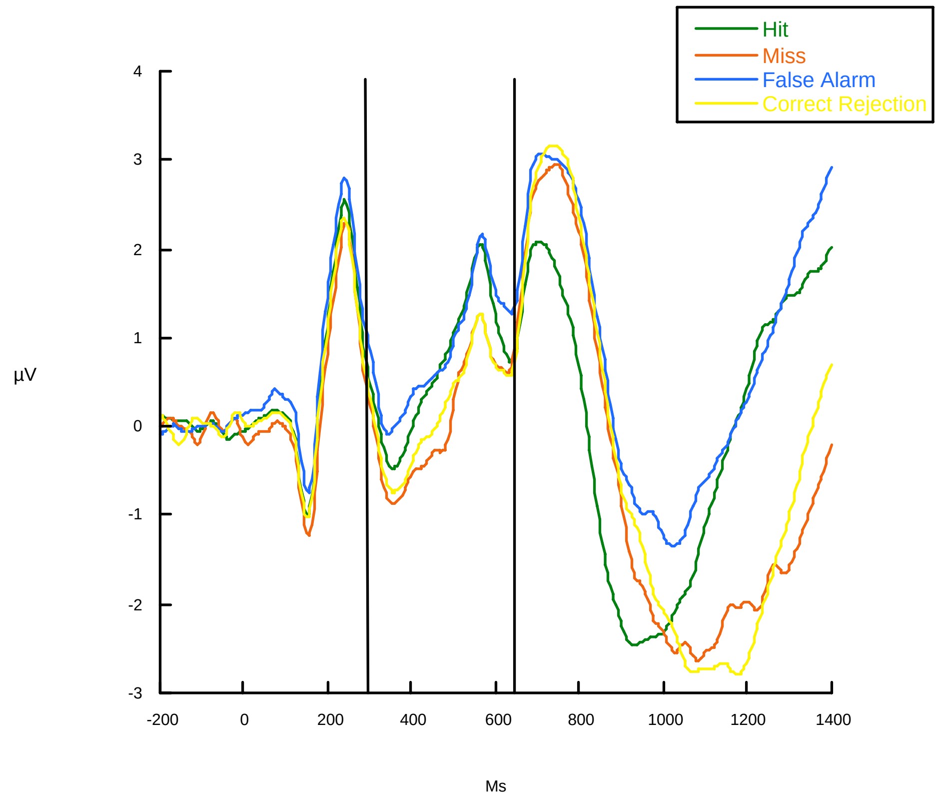


Figure 8. Grand average waveforms of mean amplitudes associated with each response type within the early frontal (hemispheres were averaged together) spatial temporal region of interest (n.b., vertical bars denote analysis epoch).

Since false alarms were significantly greater (i.e., more positive) than misses in the above analysis and greater than the difference between hits and correct rejections the conclusion can be made that within this spatial temporal region of interest (early frontal), subjective Old/New effects were larger than traditional, and objective (respectively).

Within the parietal spatial temporal region of interest a two-way ANOVA was employed where Response Type (hit, miss, false alarm, correct rejection), and

Hemisphere (left, right) served as the independent variables and mean amplitudes (averaged across parietal leads recorded from 400-1000ms) served as the dependent variable. Results indicated a main effect of Response Type [$F(3,87) = 5.33$, $p = .002$] and a significant interaction between Response Type and Hemisphere [$F(3,87) = 3.26$, $p = .025$]. Bonferroni adjusted post hoc tests revealed that mean amplitudes associated with hit ($M = .28$, $SE = .33$) responses were significantly greater than those associated with false alarms ($M = -.97$, $SE = .34$; $p = .007$) and misses ($M = -.24$, $SE = .34$; $p = .03$). There was also a trend towards significantly greater mean amplitudes associated with hits when compared to correct rejections ($M = .01$, $SE = .36$; $p = .056$). Misses, false alarms and correct rejections did not differ from each other. The significant interaction between Response Type and Hemisphere was driven by less positive amplitudes associated with false alarms in the left hemisphere ($M = -.23$, $SE = .36$) when compared to their right hemisphere counterpart ($M = .04$, $SE = .42$). These results are depicted graphically in Figure 9.

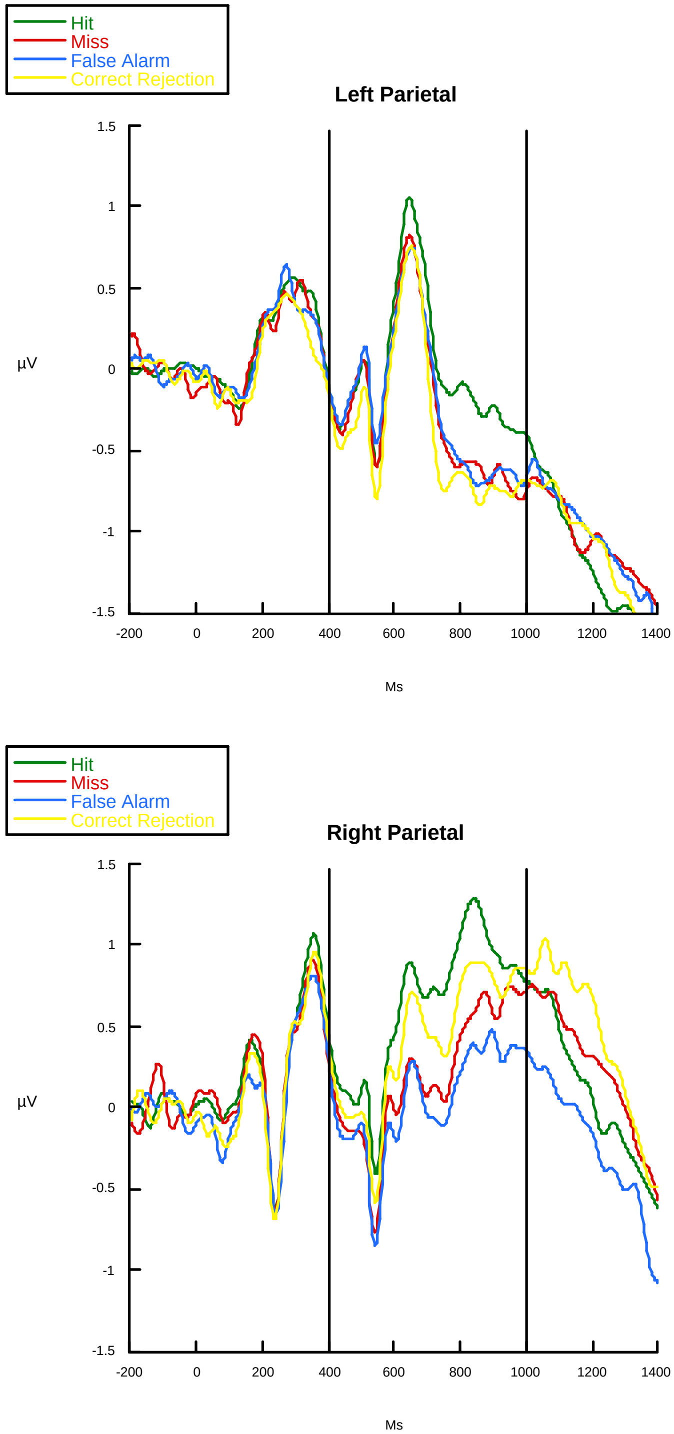
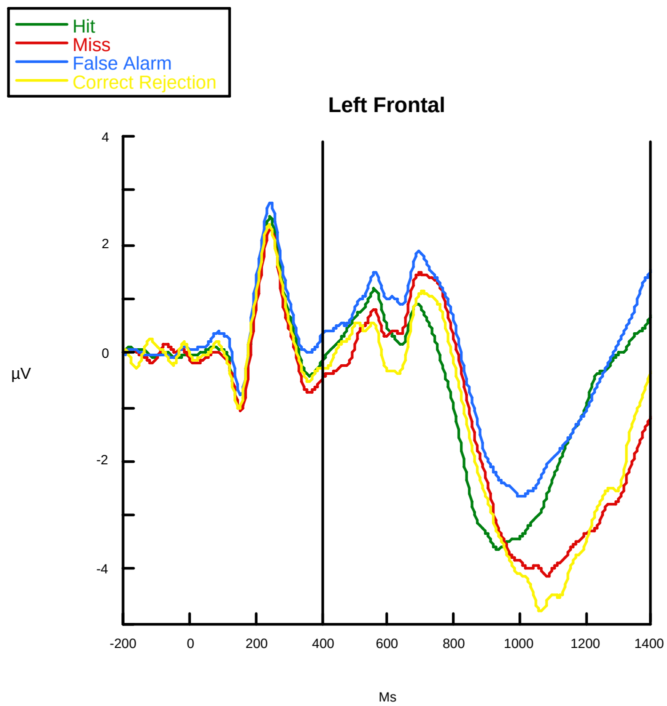


Figure 9. Grand average waveforms from parietal regions associated with each response type (n.b., vertical bars denote analysis epoch).

Since the difference between hits and false alarms is greater than the difference between hits and correct rejections, the conclusion can be made that within the parietal spatial temporal region of interest, the objective Old/New effect is larger than the traditional Old/New effect and the subjective Old/New effect (respectively).

Within the late frontal spatial temporal region of interest a two-way ANOVA was employed where Response Type (hit, miss, false alarm, correct rejection), and Hemisphere (left, right) served as the independent variables and mean amplitudes (averaged across frontal leads recorded from 400-1400ms) served as the dependent variable. Results indicated a main effect of Response Type [$F(3,87) = 6.69$, $p < .001$], a main effect of Hemisphere [$F(1,29) = 11.20$, $p = .002$], and a significant interaction between Response Type and Hemisphere [$F(3,87) = 8.18$, $p < .001$]. Bonferroni adjusted post hoc comparisons revealed mean amplitudes associated with false alarms (M = .90, SE = .83) were significantly greater than those associated with misses (M = -.03, SE = .89; p = .006), and correct rejections (M = .08, SE = .88; p = .02). There was no difference between mean amplitudes associated with hits (M = .38, SE = .82) and those of false alarms, correct rejections, or misses. The main effect of Hemisphere resulted from greater mean amplitudes in the right hemisphere (M = 1.14, SE = .77) when compared to the left hemisphere (M = -.47, SE = .97). The significant interaction between Response Type and Hemisphere resulted from more positive amplitudes resulting from false alarms within the left hemisphere (M = 2.04, SE = 3.83) when compared to amplitudes associated with false alarms measured in the right hemisphere (M = -.23, SE = 6.20). These results are depicted graphically in figure 10.



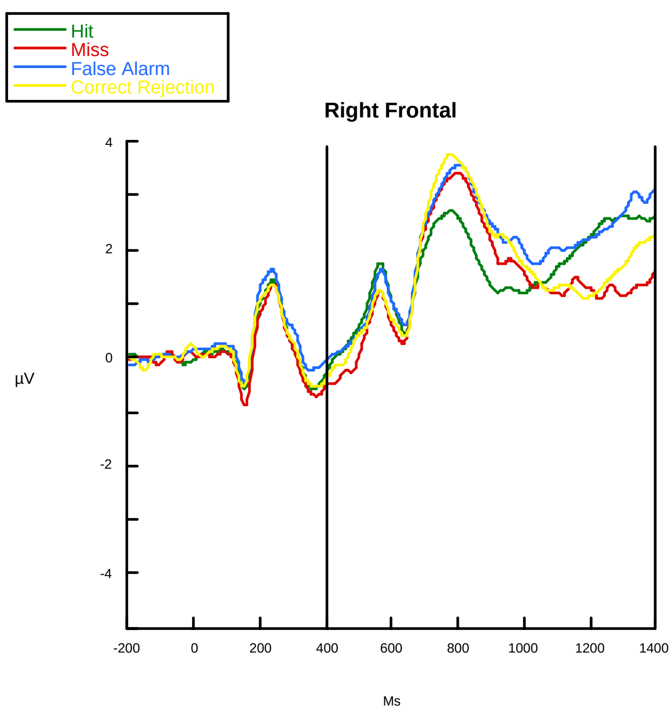


Figure 10. Grand average waveforms from the late frontal regions associated with each response type (n.b., vertical bars denote analysis epoch).

Since the traditional comparison of Old/New effects (i.e., hits vs. correct rejections) was not significant we can disregard the influence of hits and correct rejections in the objective and subjective comparisons. As such, the absolute value of the difference between old and new in each of these comparisons (i.e. objective and subjective) is identical. Therefore, the conclusion can be made that within this particular spatial temporal region of interest (i.e., late frontal) the objective and subjective Old/New effects are larger in absolute magnitude than those observed in the Traditional comparison, but that they do not differ from each other.

Hypothesis 5: Based on Windmann and Kutas' assertion that bias for negative words serves an adaptive function, whereby the cognitive system is prompted to assign greater significance and a higher priority to the processing of potentially threatening stimuli is correct then it is predicted that Old/New effects will be greatest for negative items compared to positive and neutral because the positive and neutral items lack threatening connotations.

Although main effects of Valence were not observed, there was a significant three-way interaction between Valence, Old/New status, and Hemisphere [$F(2,58) = 3.82$, $p = .03$] where the Old/New effect was greatest in response to positive words in the left hemisphere.

Discussion

The purpose of the present study was to investigate the pattern and timing of electrophysiological indices of Old/New recognition memory effects for negative, neutral, as well as positive words. Secondly, this study examined behavioral and electrophysiological indices of subject response bias in Old/New recognition memory. Previous research in this area employed (almost exclusively) negative and neutral stimuli only. Furthermore, the majority of studies neglected to control for the potentially confounding characteristics of the stimuli such as arousal and inter-item relatedness (i.e., semantic cohesion). The current study extended the previous literature by including a list of positively valenced words in addition to the standard negative and neutral word lists. All word lists were carefully balanced (i.e., equated) for valence, frequency, and semantic cohesion.

The behavioral data prediction that emotional words (i.e., positive and negative) would elicit more hits than neutral words was partially supported in that the Hit Rate associated with negative words was significantly greater compared to the Hit Rate for positive and neutral stimuli. This finding is consistent with others in the literature (e.g., Kensinger & Corkin, 2003) where only negative and neutral words were compared. However, when positive words are also used as stimuli in addition to negative and neutral words findings generally support enhancement of recognition memory for both negative and positive words when compared to neutral stimuli (e.g., Kuchinke, Jacobs, Vo, Conrad, Grubich, & Herrmann, 2006). The frequency statistics associated with the list of positive stimuli employed in the current study were, on average, higher than those from the negative and neutral lists. Although this frequency difference did not achieve statistical significance, there was a trend (p = .07) towards the positive word list having a higher frequency estimate than the negative and neutral lists. This trend could account for the finding that negative words yielded a higher Hit Rate than positive words since less frequent items tend to be remembered better (Shiffrin & Steyvers, 1997).

False Alarm Rate analyses revealed that both positive and negative words elicited a significantly higher False Alarm Rate compared to neutral words. Along with an elevated Hit Rate for negative words being commonly reported in the literature, there is an equally prevalent finding of a significantly elevated False Alarm Rate for negative and positive words (e.g., Maratos et al., 2000; McNeely et al., 2004; Windmann & Kutas, 2001; Vo, Jacobs, Kuchinke, Hofmann, Conrad, Schacht, & Hutzler), although there are far fewer studies that have used positive stimuli. These results highlight the importance of examining positive words in addition to negative and neutral as not all types of emotional words produce similar results.

Obviously, one cannot rely on Hit Rate alone as a measure of accuracy as it yields an incomplete picture of performance. Such a method could, theoretically, yield equal Hit Rate values for the participant who responds ‘Old’ to every item and the participant who only responds ‘Old’ to the actual old items. One must combine both the Hit Rate and the False Alarm Rate in order to obtain a clear picture of participant performance. This combination is best reflected in an accuracy/sensitivity index that takes into account both correct and incorrect responses to old items. For these reasons, an ancillary analysis using the sensitivity index d′ was employed. This analysis revealed a somewhat different pattern of results. Specifically, participants made more accurate judgments in response to negative and neutral words compared to positive stimuli. The previous note regarding increased frequency ratings within the positive word list applies to the results of this analysis as well. That is, the trend towards positive words having significantly higher frequency ratings compared to the negative and neutral word lists could account for the decreased accuracy for positive words. These results also underscore the importance of including positive stimuli, as they may yield important differences across categories of emotional words that would not be apparent had only negative stimuli been used and. Moreover, the use of a sensitivity/accuracy index provides unique information that is not captured by Hit Rate and False Alarm Rate analyses alone.

With respect to tests of the first hypothesis that Hit Rate and False Alarm Rate would be greater for emotional words, there was some variability in support across the three dependent measures (i.e., Hit Rate, False Alarm Rate, d′). Main effects of valence were found across all three dependent measures but not always consistently greater performance for both positive and negative words as Hit Rate was greater for negative words only and sensitivity/accuracy was greater for negative and neutral words.

The second prediction that both classes of emotional words (i.e., positive and negative) would elicit greater levels of response bias was fully supported. These effects are congruent with published studies that generally find an increased bias for emotional words (positive and negative) compared to neutral (e.g., Maratos, Allan, & Rugg, 2000; Windmann & Kutas, 2001; Vo et al., 2008).

With respect to reaction time, only a significant main effect of response type was observed where hit responses (M = 1095.17, SE = 66.21) were made faster than misses (M = 1308.44, SE = 86.14), false alarms (1253.04, SE = 85.910, and correct rejections (M = 1273.39, SE = 78.59) is in keeping with similar behavioral literature (e.g., Bentin & McCarthy, 1994; Windman & Chimielewski, 2007). However, the prediction that reaction times would be fastest in response to emotional (i.e., positive and negative) words was not supported. A trend was observed for this analysis (p=.078) but it was not in the correct direction (i.e., reaction times to negative words were slowest).

As noted above, the prediction that valence effects in accuracy would exist after controlling for the confounding effects of arousal and semantic cohesion was supported. To our knowledge, the current study was the first to control for *both* of these confounding variables so as to make legitimate inferences about the interplay between them.

With respect to the ERP data, the hypothesis that all three classes of words (negative, neutral, and positive) would elicit Old/New effects was partially supported. When significant Old/New effects were observed they occurred in all valences. However, significant Old/New effects were not observed in every spatial/temporal region of interest (i.e., early frontal, parietal, late frontal) across all three Old/New comparison types (i.e., traditional, objective, subjective). See Table 5 for details.

Table 5. Significant Old/New effects observed according to spatial/temporal region of interest (left-most column), and comparison type (top row).

	Traditional	Objective	Subjective
Early frontal	Old > New		Old > New
Parietal	Old > New	Old > New	
Late frontal		New > Old	Old > New

As can be seen in Table 5, significant Old/New effects in the early frontal regions were observed in the traditional and subjective comparisons, but not in the objective comparison. In the parietal regions, significant Old/New effects were noted in the traditional and objective comparisons, but not in the subjective comparison. Within the objective Old/New comparison, miss trials are used to construct the ‘Old’ waveform, and trials where false alarms are made are used to construct the ‘New’ waveform. The opposite is true for the subjective comparison. In order for this dissociation to occur (i.e., significant subjective but not objective Old/New effects in the early frontal regions and significant objective but not subjective Old/New effects in parietal regions) the difference between false alarms and misses must be positive in the early frontal regions between 300ms and 640ms whereas the difference between false alarms and misses must be negative in parietal regions between 400ms and 1000ms. This finding is in keeping with dual-process models of recognition memory from an ERP perspective. Specifically, the parietal Old/New effect is thought to index recollection (Rugg, 1987; Rugg et al, 1998) and is larger for ‘remember’ (vs. ‘know’) judgments in remember/know experiments (Duzel, Yonelinas, Mangun, Heinze, & Tulving, 1997). Logically, the neural signature of the memory trace (as indexed by the parietal Old/New effect) should be larger for misses than for false alarms because miss trials are elicited by words that were actually studied (i.e., targets). Conversely, false alarms are elicited by words that cannot be recollected because they were never actually studied (i.e., foils). Early frontal Old/New effects are hypothesized as representing the neural correlate of familiarity (Curran, 2000; Paller, Voss, & Boehm, 2007) and associated more so with ‘know’ judgments when remember/know experiments are employed (Gardiner, Java, & Richardson-Klavehn, 1996). As such, familiarity-driven False alarms should be most apparent (i.e., greater/more positive) in this cortical region (i.e., the putative neural correlate of familiarity).

Recent evidence provided by Goldman et al. (2003) suggests that the late frontal component observed in some ERP studies of recognition memory is an index of post-retrieval processing. This component is thought to be most prominent when Old/New discrimination is difficult. With this idea in mind, incorrect responses (i.e., misses and false alarms) are considered more effortful (as opposed to correct responses) and more likely to engage the post-retrieval processing indexed by the late frontal Old/New effect. This would explain why a significant late frontal Old/New effect within the traditional comparison was not observed (the rendering of correct judgments was not effortful enough to engage post-retrieval processing). The addition of incorrect (and thus effortful) trials (i.e., false alarms and misses) to Old/New comparisons (i.e., objective and subjective) allows the late frontal Old/New effect to be revealed. The inverse pattern of late frontal Old/New effects seen in the current study (i.e., Old waveforms greater than New waveforms in the subjective comparison and new waveforms greater than old waveforms in the objective comparison) is again driven by potentials associated with false alarms and misses. Incorrect acceptance of a word that was not previously studied (i.e., false alarm) would have to be more positive going compared to incorrect rejections of words that were not previously studied (i.e., misses) in order to make the objective new waveform more positive than its old counterpart. The notion that false alarms are associated with more positive amplitudes has been observed in previous research (Goldmann et al., 2003 & Windmann et al., 2002) although the epochs analyzed were arguably too early to capture this late effect in one of these studies (Windmann et al., 2002) and the other (Goldmann et al., 2003) did not analyze the amplitudes of their waveforms according to the subjective comparison.

Analysis of waveforms associated with each response type (hit, miss, false alarm, correct rejection), along with the pattern of results observed between the three Old/New comparison types revealed that inclusion of error trials (i.e., misses and false alarms) yields varying results across spatial temporal regions of interest. This finding is in keeping with that of Windmann et al. (2002) who found differential effects between the three comparison types although the results don’t map directly onto those of the current study as Windmann also employed a grouping factor (high response bias vs. low response bias).

With respect to the lack of significant valence effects within the ERP data previous research provides little aid in the explanation of such results. There is a paucity of research investigating Old/New effects for negative, neutral, and positive words and, as noted in the introduction, the results are somewhat equivocal. The most obvious difference, however, between the existing literature and the results of the current study is that the current study assessed, and controlled for, the possible confounding effects of arousal, whereas the others did not. It is also possible that the degree of emotionality within the valenced word lists differs between studies (and is smaller in the current study) and has differential effects on the observed results. There may exist a valence threshold of sorts below which these effects go undetected. Perhaps the word lists used in the current study were below this threshold (i.e., the negative words were not negative enough to produce valence effects in the ERPs etc.).

Limitations and Directions for Future Research

As noted above in the discussion, some of the behavioral findings can be attributed to the increased level of frequency among the words in the positive list. This difference can be considered a limitation as the results would certainly be clearer without having to account for this possible confound. Additionally, reaction times may have been shorter, and valence effects observed had the response style been altered. Specifically, if the number of choices the participant could respond with was shortened (e.g., a basic yes/no decision instead of a confidence rating), then the participants would likely be faster to respond. Explicitly instructing the participants to respond as quickly as possible (an element not employed in the current study) also has the potential to reduce reaction times.

Overall, the present study helped elucidate the relationship between emotion and recognition memory for words. Specifically, increased accuracy and response bias for emotional words was observed even after word lists were equated to prevent possible memory enhancement by stimulus characteristics (e.g., arousal and semantic cohesion/inter item relatedness). The need to meticulously control for arousal and semantic cohesion in studies within this area is important in order to make clear inferences about the effects of emotion on memory and to ensure that it is not actually differences in arousal level or semantic cohesion that account for differential rates of recall across emotional and nonemotional conditions. Objective ratings from available normative data should be used to confirm equivalence on these dimensions rather than relying on subjective judgments and statistical analyses used to confirm equivalence across conditions. Furthermore, as noted above, different types or classes of emotional words may not always behave similarly given the same cognitive operation (i.e. accuracy, false alarm rate, etc.) and these differences may provide future insights into differential influences the emotional nature of a stimulus has on specific cognitive processes within memory. Therefore, including positive as well as negative stimuli may allow more precise understanding of differential influences of these stimuli on distinct memory processes.

The effect(s) of emotion on memory will undoubtedly continue to intrigue scientists and the general public for decades to come. This relationship is not only interesting but has implications for many areas of research beyond the field of cognitive neuroscience. Forensic (e.g., conceptualization and credibility of eye-witness testimony) and clinical implications (e.g., classification and treatment of panic disorder and post traumatic stress disorder) will likely become more evident as research advances and knowledge of the interplay between emotion and memory in the healthy adult brain increases.

References

Beck, A.T., Steer, R.A., (1987). Manual for the Revised Beck Depression Inventory. Psychological Corporation, San Antonio, TX.

Beck, A.T., Steer, R.A., & Garbin, M.G., (1988). Psychometric properties of the Beck Depression Inventory: twenty-five years of evaluation. Clinical Psychology Review, 8, 77-100.

Bentin, S., McCarthy, G. (1994). The effects of immediate stimulus repetition on reaction time and event-related potentials in tasks of different complexity. Journal of Experimental Psychology. 20, 130-149.

Bradley, M. M., & Lang, P. J. (1999). Affective norms for English words (ANEW): Stimuli, instruction manual and affective ratings. Technical report C-1. Gainesville, FL: The Center for Research in Psychophysiology, University of Florida.

Bradley, M. M., Greenwald, M. K., Petry, M. C., & Lang, P. J. (1992). Remembering pictures: Pleasure and arousal in memory. Journal of Experimental Psychology. Learning, Memory, and Cognition; Journal of Experimental Psychology.Learning, Memory, and Cognition, 18(2), 379-390.

Bradley, M. M., & Lang, P. J. (2000). Affective reactions to acoustic stimuli. Psychophysiology; Psychophysiology, 37(2), 204-215.

Cahill, L., Haier, R. J., Fallon, J., Alkire, M. T., Tang, C., & Keator, D., et al. (1996). Amygdala activity at encoding correlated with long-term, free recall of emotional information. Proceedings of the National Academy of Sciences of the United States of America; Proceedings of the National Academy of Sciences of the United States of America, 93(15), 8016-8021.

Cahill, L., & McGaugh, J. L. (1995). A novel demonstration of enhanced memory associated with emotional arousal. Consciousness and Cognition; Consciousness and Cognition, 4(4), 410-421.

Cahill, L., Prins, B., Weber, M., & McGaugh, J. L. (1994). Beta-adrenergic activation and memory for emotional events. Nature; Nature, 371(6499), 702-704.

Carretie, L., Iglesias, J., & Garcia, T. (1997). A study on the emotional-processing of visual stimuli through event-related potentials. Brain and Cognition; Brain and Cognition, 34(2), 207-217.

Carretie, L., Iglesias, J., Garcia, T., & Ballesteros, M. (1997). N300, P300 and the emotional processing of visual stimuli. Electroencephalography and Clinical Neurophysiology; Electroencephalography and Clinical Neurophysiology, 103(2), 298-303.

Christianson, S. (Ed.). (1992). The handbook of emotion and memory: Research and theory. London: Lawrence Erlbaum Associates.

Curran, T. (2000). Brain potentials of recollection and familiarity. Memory & Cognition; Memory & Cognition, 28(6), 923-938.

Curran, T., Schacter, D. L., Johnson, M. K., & Spinks, R. (2001). Brain potentials reflect behavioral differences in true and false recognition. Journal of Cognitive Neuroscience; Journal of Cognitive Neuroscience, 13(2), 201-216.

Dietrich, D. E., Waller, C., Johannes, S., Wieringa, B. M., Emrich, H. M., & Munte, T. F. (2001). Differential effects of emotional content on event-related potentials in word recognition memory. Neuropsychobiology; Neuropsychobiology, 43(2), 96-101.

Dolcos, F., & Cabeza, R. (2002). Event-related potentials of emotional memory: Encoding pleasant, unpleasant, and neutral pictures. Cognitive, Affective & Behavioral Neuroscience, 2(3), 252-263.

Donaldson, D. I., & Rugg, M. D. (1998). Recognition memory for new associations: Electrophysiological evidence for the role of recollection. Neuropsychologia; Neuropsychologia, 36(5), 377-395.

Duzel, E., Yonelinas, A. P., Mangun, G. R., Heinze, H. J., & Tulving, E. (1997). Event-related brain potential correlates of two states of conscious awareness in memory. Proceedings of the National Academy of Sciences of the United States of America;

Proceedings of the National Academy of Sciences of the United States of America, 94(11), 5973-5978.

Gardiner, J.M., Java, R.I., Richardson-Klavehn. (1996). How level of processing really influences awareness in recognition memory. Canadian Journal of Experimental Psychology, 50, 114-122.

Gardiner, J. M., & Java, R. I. (1991). Forgetting in recognition memory with and without recollective experience. Memory & Cognition, 19(6), 617-623.

Gratton, G., Coles, M. G., Sirevaag, E. J., Eriksen, C. W., & Donchin, E. (1988). Pre- and poststimulus activation of response channels: A psychophysiological analysis. Journal of Experimental Psychology. Human Perception and Performance; Journal of Experimental Psychology. Human Perception and Performance, 14(3), 331-344.

Goldmann, R. E., Sullivan, A. L., Droller, D. B. J., Rugg, M. D., Curran, T., Holcomb, P. J., et al. (2003). Late frontal brain potentials distinguish true and false recognition. NeuroReport, 14(13), 1717-1720.

Hamann, S. (2001). Cognitive and neural mechanisms of emotional memory. Trends in Cognitive Sciences, 5(9), 394-400.

Heuer, F., & Reisberg, D. (1990). Vivid memories of emotional events: The accuracy of remembered minutiae. Memory & Cognition; Memory & Cognition, 18(5), 496-506.

Inaba, M., Nomura, M., & Ohira, H. (2005). Neural evidence of effects of emotional valence on word recognition. International Journal of Psychophysiology : Official

Journal of the International Organization of Psychophysiology; International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology, 57(3), 165-173.

Inaba, M., Kamishima, K., & Ohira, H. (2007). An electrophysiological comparison of recollection for emotional words using an exclusion recognition paradigm. Brain Research, 1133, 100-109.

Jacoby, L. L., & Kelley, C. (1992). Unconscious influences of memory: Dissociations and automaticity. In A. D. Milner, & M. D. Rugg (Eds.), The neuropsychology of consciousness (pp. 201-233). London: Academic Press.

Johansson, M., Mecklinger, A., & Treese, A. C. (2004). Recognition memory for emotional and neutral faces: An event-related potential study. Journal of Cognitive Neuroscience; Journal of Cognitive Neuroscience, 16(10), 1840-1853.

Kopelman, M. D., & Corn, T. H. (1988). Cholinergic 'blockade' as a model for cholinergic depletion. A comparison of the memory deficits with those of alzheimer-type dementia and the alcoholic korsakoff syndrome. Brain; a Journal of Neurology; Brain : A Journal of Neurology, 111 (Pt 5)(Pt 5), 1079-1110.

Kensinger, E.A., & Corkin, S. (2003). Memory enhancement for emotional words: Are emotional words more vividly remembered than neutral words? Memory & Cognition, 31(8), 1169-1180.

Kuchinke, L., Jacobs, A. M., Vo, M. L.-H., Conrad, M., Grubich, C., & Herrmann, M. (2006). Modulation of prefrontal cortex activation by emotional words in recognition memory. Brain Imaging, 17(10), 1037-1041.

LaBar, K. S., & Cabeza, R. (2006). Cognitive neuroscience of emotional memory. Nature Reviews. Neuroscience; Nature Reviews. Neuroscience, 7(1), 54-64.

LaBar, K. S., Gatenby, J. C., Gore, J. C., LeDoux, J. E., & Phelps, E. A. (1998). Human amygdala activation during conditioned fear acquisition and extinction: A mixed-trial fMRI study. Neuron; Neuron, 20(5), 937-945.

Landauer, T. K., Foltz, P. W., & Laham, D. (1998). Introduction to Latent Semantic Analysis. Discourse Processes, 25, 259-284.

Macmillian, N. A. & Creelman, C. D. (1991). Detection theory: A user's guide. Cambridge, England: Cambridge University Press.

Mandler, G. (1981). The recognition of previous encounters. American Scientist; American Scientist, 69(2), 211-218.

Maratos, E. J., Allan, K., & Rugg, M. D. (2000). Recognition memory for emotionally negative and neutral words: An ERP study. Neuropsychologia; Neuropsychologia, 38(11), 1452-1465.

Maratos, E. J., & Rugg, M. D. (2001). Electrophysiological correlates of the retrieval of emotional and non-emotional context. Journal of Cognitive Neuroscience; Journal of Cognitive Neuroscience, 13(7), 877-891.

McNeely, H. E., Dywan, J., & Segalowitz, S. J. (2004). ERP indices of emotionality and semantic cohesiveness during recognition judgments. Psychophysiology; Psychophysiology, 41(1), 117-129.

Naumann, E., Huber, C., Maier, S., Plihal, W., Wustmans, A., & Diedrich, O., et al. (1992). The scalp topography of P300 in the visual and auditory modalities: A comparison of three normalization methods and the control of statistical type II error. Electroencephalography and Clinical Neurophysiology; Electroencephalography and Clinical Neurophysiology, 83(4), 254-264.

Nelson, D. L., McEvoy, C. L. & Schreiber, T. A. (1998). The university of south Florida word association, rhyme, and word fragment norms.http://www.usf.edu/FreeAssociation/

Nissen, M. J., Knopman, D. S., & Schacter, D. L. (1987). Neurochemical dissociation of memory systems. Neurology; Neurology, 37(5), 789-794.

Ochsner, K. N. (2000). Are affective events richly recollected or simply familiar? the experience and process of recognizing feelings past. Journal of Experimental Psychology. General; Journal of Experimental Psychology. General, 129(2), 242-261.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The edinburgh inventory. Neuropsychologia; Neuropsychologia, 9(1), 97-113.

Paller, K. A., & Kutas, M. (1992). Brain potentials during retrieval provide neurophysiological support for the distinction between conscious recollection and priming. Journal of Cognitive Neuroscience, 4, 375-391.

Paller, K. A., Voss, J. L., & Boehm, S. G., Validating neural correlates of familiarity. Trends in Cognitive Sciences. 11(6), 243-250.

Phelps, E. A., LaBar, K. S., & Spencer, D. D. (1997). Memory for emotional words following unilateral temporal lobectomy. Brain and Cognition; Brain and Cognition, 35(1), 85-109.

Potter, D. D., Pickles, C. D., Roberts, R. C., & Rugg, M. D. (1992). The effects of scopolamine on event-related potentials in a continuous recognition memory task. Psychophysiology; Psychophysiology, 29(1), 29-37.

Rubin, D. C., & Schulkind, M. D. (1997). The distribution of autobiographical memories across the lifespan. Memory & Cognition; Memory & Cognition, 25(6), 859-866.

Rugg, M. D. (1987). Dissociation of semantic priming, word and nonword repetition by event-related potentials. Journal of Experimental Psychology, 39, 123-148.

Rugg, M.D., Allan, K. (2000). Memory retrieval: An electrophysiological perspective. In M. S. Gazzaniga (Ed.), The cognitive neurosciences (2nd ed., pp. 805-816). Cambridge, MA: MIT Press.

Rugg, M. D., & Doyle, M. C. (1994). Event related potentials and stimulus repetition in direct and indirect tests of memory. In H. Hienze, T. Munte & G. R. Mangun (Eds.), Cognitive electrophysiology (pp. 124-148). Boston: Birkhauser.

Rugg, M. D. (1995). Memory and consciousness: A selective review of issues and data. Neuropsychologia; Neuropsychologia, 33(9), 1131-1141.

Rugg, M. D. (1990). Event-related brain potentials dissociate repetition effects of high- and low-frequency words. Memory & Cognition; Memory & Cognition, 18(4), 367-379.

Rugg, M. D., Brovedani, P., & Doyle, M. C. (1992). Modulation of event-related potentials (ERPs) by word repetition in a task with inconsistent mapping between repetition and response. Electroencephalography and Clinical Neurophysiology; Electroencephalography and Clinical Neurophysiology, 84(6), 521-531.

Rugg, M. D., Mark, R. E., Walla, P., Schloerscheidt, A. M., Birch, C. S., & Allan, K. Dissociation of the neutral correlates of implicit and explicit memory. Nature 392, 595-598.

Rugg, M. D., & Nagy, M. E. (1989). Event-related potentials and recognition memory for words. Electroencephalography and Clinical Neurophysiology; Electroencephalography and Clinical Neurophysiology, 72(5), 395-406.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). E-Prime users guide [Computer software]. Pittsburgh: Psychology Software Tools, Inc.

Schupp, H. T., Cuthbert, B. N., Bradley, M. M., Cacioppo, J. T., Ito, T., & Lang, P. J. (2000). Affective picture processing: The late positive potential is modulated by motivational relevance. Psychophysiology; Psychophysiology, 37(2), 257-261.

Shiffrin, R.M., Steyvers, M. (1997). A model for recognition memory:REM-retrieving effectively from memory. Psychonomic Bulletin & Review, 4, 145-166.

Smith, M. E. (1993). Neurophysiological manifestations of recollective experience during recognition memory judgments. Journal of Cognitive Neuroscience, 5, 1-13.

Smith, A. P., Dolan, R. J., & Rugg, M. D. (2004). Event-related potential correlates of the retrieval of emotional and nonemotional context. Journal of Cognitive Neuroscience; Journal of Cognitive Neuroscience, 16(5), 760-775.

Smith, M. E., & Halgren, E. (1989). Dissociation of recognition memory components following temporal lobe lesions. Journal of Experimental Psychology. Learning, Memory, and Cognition; Journal of Experimental Psychology.Learning, Memory, and Cognition, 15(1), 50-60.

Snodgrass, J. G., & Corwin, J. (1988). Pragmatics of measuring recognition memory: Applications to dementia and amnesia. Journal of Experimental Psychology: General, 117(1), 34-50.

Soetens, E., Casaer, S., D'Hooge, R., & Hueting, J. E. (1995). Effect of amphetamine on long-term retention of verbal material. Psychopharmacology; Psychopharmacology, 119(2), 155-162.

Swets, J. A. (1996). Signal Detection Theory and ROC Analysis in Psychology and Diagnostics: Collected Papers. Mahwah, NJ: Lawrence Erlbaum Associates.

Talmi, D., & Moscovitch, M. (2004). Can semantic relatedness explain the enhancement of memory for emotional words? Memory & Cognition; Memory & Cognition, 32(5), 742-751.

Tendolkar, I., & Rugg, M. D. (1998). Electrophysiological dissociation of recency and recognition memory. Neuropsychologia; Neuropsychologia, 36(6), 477-490.

Tulving, E. (1985). Memory and consciousness. Canadian Psychology, 26(1), 1-12.

Vanderploeg, R. D., Brown, W. S., & Marsh, J. T. (1987). Judgments of emotion in words and faces: ERP correlates. International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology; International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology, 5(3), 193-205.

Vo, M. L.-H., Jacobs, A. M., Kuchinke, L., Ofmann, M., Conrad, M., Schacht, A., & Hutzler, F. (2008). The coupling of emotion and cognition in the eye: Introducing the pupil old/new effect. Psychophysiology, 45, 130-140.

Wickens, T. D. (2002). Elementary signal detection theory. Oxford; New York: Oxford University Press.

Wilding, E. L., Doyle, M. C., & Rugg, M. D. (1995). Recognition memory with and without retrieval of context: An event-related potential study. Neuropsychologia; Neuropsychologia, 33(6), 743-767.

Windman, S., & Chmielewski, A. (2007). Emotion-induced modulation of recognition memory decisions in a Go/NoGo task: Response bias or memory bias?. Cognition and Emotion, 1-16.

Windmann, S., & Kutas, M. (2001). Electrophysiological correlates of emotion-induced recognition bias. Journal of Cognitive Neuroscience; Journal of Cognitive Neuroscience, 13(5), 577-592.

Windmann, S., Urbach, T. P., & Kutas, M. (2002). Cognitive and neural mechanisms of decision biases in recognition memory. Cerebral Cortex (New York, N.Y. : 1991); Cerebral Cortex (New York, N.Y.: 1991), 12(8), 808-817.

Williams, S.M., (1991). Handedness inventories: Edinburgh versus Annett. Neuropsychology, 5, 43-48.

Yonelinas, A.P., (1994). Receiver-operating characteristics in recognition memory: Evidence for a dual-process model. Journal of Experimental Psychology: Learning, Memory, & Cognition, 20, 1341-1354.

Yonelinas, A. P., & Jacoby, L. L. (1996). Noncriterial recollection: Familiarity as automatic, irrelevant recollection. Consciousness and Cognition; Consciousness and Cognition, 5(1-2), 131-141.

Appendices

Appendix A: Word Lists

Negative Targets

accident	alimony	alone	beggar	blind	bored	broken	bullet
burial	burn	cell	coward	crime	criminal	crisis	cut
dead	death	debt	deceit	defeated	deformed	depressed	depression
despise	detached	disdainful	dummy	dump	dustpan	failure	false
fat	fault	fear	feeble	filth	flood	frustrated	funeral
fungus	garbage	grime	handicap	headache	hell	hinder	hungry
ignorance	immature	immoral	impotent	infection	injury	jail	knife
lonely	malaria	manure	measles	meek	mold	noose	nuisance
overcast	poison	prison	pungent	punishment	resent	rigid	rusty
sad	scorching	scornful	severe	sin	slave	slum	spanking
stupid	tobacco	tomb	tragedy	trouble	ugly	war	waste

Neutral Targets

alien	alley	anxious	army	autumn	bake	beast	blond
book	boxer	boy	cat	chance	chaos	city	cliff
clock	coast	cold	concentrate	dark	dawn	defiant	dentist
derelict	detail	diver	elevator	embattled	employment	excuse	fabric
face	fall	field	foam	fur	garter	gymnast	hammer
haphazard	hard	hat	hide	hospital	industry	lantern	legend
listless	market	material	modest	mystic	naked	nursery	obey
office	overwhelmed	paint	patient	person	rattle	reunion	revolt
revolver	rough	runner	saint	salute	save	shadow	ship
skeptical	skull	stomach	swift	truck	trumpet	vampire	vanity
virgin	virtue	voyage	whistle	white	wife	wonder	writer

Appendix A: (Continued)

Positive Targets

ace	advantage	affection	agreement	angel	answer	art	baby
bath	bird	bless	breast	bride	bright	bunny	butterfly
car	carefree	child	chocolate	circus	cozy	dancer	dollar
earth	easy	easygoing	eat	food	gift	glory	heal
honest	hug	impressed	innocent	inspire	jewel	lake	learn
leisurely	lottery	luscious	mobility	money	mother	movie	natural
nectar	ocean	optimism	palace	pasta	peace	pet	politeness
rabbit	radiant	rainbow	relaxed	respectful	restaurant	reward	river
sapphire	satisfied	silk	smooth	snow	snuggle	song	spirit
spouse	sun	sunrise	sunset	tender	terrific	thankful	toy
travel	untroubled	useful	valentine	vision	waterfall	wedding	woman

Negative Foils

ache	addict	agony	allergy	blackmail	blister	blubber	coffin
controlling	corpse	cruel	crutch	dagger	damage	despairing	destruction
devil	dirty	disappoint	discomfort	discouraged	dreary	fatigued	fever
foul	fraud	frigid	germs	gloom	greed	grief	guilty
hurt	idiot	illness	impair	inferior	insult	lice	lie
loneliness	messy	mildew	mistake	moody	morbid	mosquito	mucus
nasty	needle	obesity	offend	pest	pity	poverty	rat
ridicule	robber	rotten	scapegoat	scar	scum	shamed	sick
sickness	slime	slow	snob	sour	spider	stench	stink
suffocate	suicide	terrible	thorn	timid	traitor	trash	unhappy
upset	urine	venom	victim	wasp	weapon	weary	wounds

Appendix A: (Continued)

Neutral Foils

air	alert	aloof	ankle	avenue	bar	black	body
bottle	busybody	cane	cannon	cellar	church	clumsy	coin
cook	curious	custom	doctor	doll	dress	event	favor
flag	fragrance	garment	glass	grass	green	hand	hawk
highway	hit	hotel	icebox	idol	kick	knot	lightning
limber	lion	manner	medicine	mischief	month	moral	muddy
mushroom	name	news	noisy	nonsense	nurse	obsession	odd
opinion	pancakes	pie	pig	plane	priest	python	quality
queen	razor	red	rock	scissors	serious	skyscraper	spray
startled	stiff	stool	storm	stove	tank	teacher	tennis
thought	tool	trunk	vehicle	village	watch	wine	yellow

Positive Foils

adult	beach	beauty	bed	beverage	blue	breeze	brother
cake	candy	charm	color	comedy	comfort	crown	cuddle
cute	decorate	diamond	dignified	dog	dove	dream	family
fantasy	father	flower	freedom	friend	game	garden	gentle
girl	god	gold	grateful	health	home	honey	honor
house	humor	intellect	kind	kindness	king	kitten	knowledge
letter	life	loyal	luxury	magical	mail	melody	memory
mountain	music	nice	perfume	pillow	pizza	pleasure	prestige
pretty	protected	safe	secure	sky	sleep	soft	soothe
space	spring	star	talent	taste	treat	tune	twilight
vacation	warmth	wise	wish	wit	world	young	youth

Appendix B: Signal Detection Formulas

Sensitivity/accuracy:

$d' = z_{FA} - z_H$

Response bias:

$C = z_{FA} - d'/2 = 0.5\,(z_{FA} + z_H)$,

where z_H is the z score in the old distribution having H proportion (i.e., Hit Rate) above it and z_{FA} is the z score in the new distribution having FA proportion above it (i.e., False Alarm Rate; Snodgrass & Corwin, 1988).