Neural Modulation of Directed Forgetting by Valence and Arousal: An Event-Related Potential Study

Sara Nicole Gallant [1]

Benjamin James Dyson [2]

[1]Ryerson University, 350 Victoria Street, Toronto, Canada, M5B 2K3

[2]University of Sussex, School of Psychology, Pevensey Building, Falmer, UK, BN1 9QH

Corresponding Author: Sara Nicole Gallant

Department of Psychology, Ryerson University

350 Victoria Street

Toronto, Ontario, Canada

M5B 2K3

Email: s7gallan@psych.ryerson.ca

Phone: 416.979.5000 ext. 4987

Abstract

Intentional forgetting benefits memory by removing no longer needed information and promoting processing of more relevant materials. This study sought to understand how the behavioural and neurophysiological representation of intentional forgetting would be impacted by emotion. We took a novel approach by examining the unique contribution of both valence and arousal on emotional directed forgetting. Participants completed an item directed forgetting task for positive, negative, and neutral words at high and lower levels of arousal while brain activity was recorded using electroencephalography (EEG). Behaviourally, recognition of to-be-remembered (TBR) and to-be-forgotten (TBF) items varied as a function of valence and arousal with reduced directed forgetting for high arousing negative and neutral words. In the brain, patterns of frontal and posterior activation in response to TBF and TBR cues respectively replicated prior EEG evidence to support involvement of inhibitory and selective rehearsal mechanisms in item directed forgetting. Interestingly, emotion only impacted cue-related posterior activity, which varied depending on specific interactions between valence and arousal. Together, results suggest that the brain handles valence and arousal differently and highlights the importance of considering in a collective manner the multidimensional nature of emotion in experimentation.

Keywords: valence; arousal; emotion; directed forgetting; memory; event-related potentials

Word count: 6,449

1. Introduction

Although we tend to prioritize storing meaningful moments in memory, understanding how we forget is just as critical. The current paper seeks to understand the electrical brain activity associated with intentional forgetting of information with varying emotional intensity. While generally perceived as a failure of memory, there are many instances where forgetting or de-prioritizing information might be more favourable, such as for a phone number that has gone out of service or a painful event we wish to push from awareness. Researchers have long been interested in how we will ourselves to forget and argue that, when intentional, forgetting allows memory to operate more efficiently by reducing clutter. In other words, no longer needed information is deleted or made less accessible and resources are released for processing and storing more relevant information (e.g., Bjork, LaBerge, & Legrand, 1968; Bjork, 1970). Such work led to a theory of intentional forgetting and development of a laboratory method for testing this process termed the “directed forgetting” task (see reviews by Bjork, 1972; Gallant & Yang, 2015; MacLeod, 1998).

In the directed forgetting paradigm, forgetting is manipulated through implementation of memory cues that instruct participants to remember or forget previously learned material. The task is conducted using either a list- or item-based approach, which differ primarily in the timing of cue presentation (Basden & Basden, 1998). In the list-based version, two groups of participants study an entire list of stimuli after which one group receives a cue to forget the list and the other receives a cue to remember. Both groups then study a second list of words that are to-be-remembered. In this version, the directed forgetting “effect” is observed when the group receiving the forget cue shows reduced memory for the first list on a subsequent memory test than the group receiving the remember cue. In the item-based task (the version relevant to the current study), cues are delivered following presentation of each item. Different from the list-based task, the directed forgetting effect is revealed in a within-subjects comparison of memory for stimuli cued as to-be-remembered (TBR) versus to-be-forgotten (TBF), with TBF items again being reduced relative to TBR items. The item method is particularly useful for the ERP technique as cues are presented several times throughout the procedure, allowing for multiple observations of cue-related activity. For this reason, moving forward, we focus on reviewing literature specific to the item method of directed forgetting.

Two main mechanisms have been proposed to underlie item directed forgetting, with the first describing a differential encoding account of TBR and TBF items. According to this hypothesis, participants selectively rehearse TBR stimuli to a greater degree than TBF stimuli, thereby producing the memory benefit for TBR items while TBF items passively decay. Another account proposes a more active inhibitory role in which mechanisms of cognitive control come online to suppress the representation of TBF items (for a review of accounts, see Anderson & Hanslmayr, 2014). Several behavioural and neural investigations merge to support these two theories. For instance, providing support for the inhibitory account, behavioural evidence has shown that implementation of a cue to forget is more cognitively demanding than a cue to remember, with fewer resources available to perform a secondary task following a forget- relative to remember-cue (Fawcett & Taylor, 2008).

Linking behaviour to brain activity, attempts to remember and forget have often been associated with differing patterns of activation in both functional magnetic resonance imaging (fMRI; Nowicka, Marchewka, Jednorog, Tacikowski, & Brechmann, 2011; Wylie, Foxe, & Taylor, 2008) and event-related potential (ERP) studies (e.g., Paz-Caballero, Menor, & Jimenez, 2004; van Hooff & Ford, 2011). Relative to TBF cues, cues to remember have been associated with more positive ERP activity over posterior or parietal regions (Bailey & Chapmann, 2012; Hauswald, Schulz, Jordanov, & Kissler, 2010; Hsieh, Hung, Tzeng, Lee, & Cheng, 2008; Paz-Caballero et al., 2004; van Hooff & Ford, 2011). Relatively early differences have been argued to reflect a P300-like response involved in enhanced use of attentional resources to TBR items, while activation in later epochs (i.e., a late positive component; LPC) is thought to reflect engagement of selective rehearsal mechanisms for encoding those items. In contrast, a reversed effect has been observed anteriorly, with greater positivity in frontal ERPs for TBF than TBR cues, patterns of activation thought to underlie an inhibitory mechanism that prevents processing of TBF items (Hauswald et al., 2011; van Hooff & Ford, 2011). Thus, current behavioural and cognitive neuroscience research provide evidence for a combined role of inhibition of TBF items coupled with selective rehearsal of TBR items in directed forgetting.

But what about when we want to forget emotional information? A question of increasing interest in the directed forgetting literature has been whether emotional material might be harder to forget relative to neutral stimuli, a logical question considering the priority that emotion often assumes in memory (Labar & Cabeza, 2006). An examination of the related literature reveals a mixed pattern of results. Some studies have found that negative words enhance directed forgetting by facilitating recognition of TBR negative items (Brandt et al., 2013), while others have argued that negative items reduce directed forgetting driven by increased recognition of TBF negative items (Bailey & Chapman, 2012; Hauswald et al., 2011; Yang, Lei, & Anderson, 2015). Further observations have shown equivalent rates of directed forgetting across emotional and neutral words (Gallant & Yang, 2014; Patrick, Kiang, & Christensen, 2015; Yang et al., 2012).

A deeper look at the methodological variations of these studies reveals a potential source for the discrepant findings. In its current state, there is a lack of distinction between the roles of valence and arousal in the emotional directed forgetting literature. Yet theoretical models of affect characterize emotion as varying along two dimensions of valence (i.e., pleasantness vs. unpleasantness) and arousal (i.e., activation vs. deactivation; Russell, 1980). The existing emotional directed forgetting studies have largely involved separate investigations of either highly arousing emotional stimuli against a low arousing neutral baseline (e.g., Brandt et al., 2013; Yang et al., 2015) or emotional stimuli matched on arousal to a neutral baseline (Gallant & Yang, 2014; Patrick et al., 2015). Although Bailey and Chapman (2012) attempt to disentangle the effects of valence and arousal in directed forgetting, their investigation used a simultaneous cuing procedure that did not allow for processing of emotional words prior to implementation of the cue. Furthermore, very few of these studies have included a positive emotion comparison condition, thereby limiting the discussion of emotional effects to negative stimuli. The current body of research therefore lacks a complete picture of emotional effects on item directed forgetting, specifically in terms of the interaction between valence and arousal and the role of positive emotion.

The importance of considering the role of valence and arousal in experimentation can be inferred by looking at how the brain responds to each dimension. fMRI studies have shown that processing of valence and arousal are supported by distinct brain networks (Kensinger & Corkin, 2004) and have varying temporal representations (Bayer, Sommer, & Schacht, 2010; Citron, Weekes, & Ferstl, 2013; Olofsson, Nordin, Sequeira, & Polich, 2008; Recio, Conrad, Hansen, & Jacobs, 2014). In the ERP literature, two prominent components associated with emotional word processing include the early posterior negativity (EPN) and the LPC (for reviews see Citron, 2012, and, Olofsson et al., 2008). Specifically, greater negative deflections have been found in response to words high in arousal during early time windows, typically 200-350 ms post onset of the word (i.e., the EPN). This early deflection is thought to reflect initial attentional orientation to emotional stimuli that is independent of task demands (e.g., Citron et al., 2013; Recio et al., 2014). Following this early component, the LPC peaks around 400-600 ms following stimulus onset but has also been shown to persist for up to one second following stimulus offset (Brown, Steenbergen, Band, de Rover, & Nieuwenhuis, 2012). The LPC is modulated by both valence and arousal with more positive activity emerging for stimuli that are highly arousing versus low arousing and also for items high in positive or negative valence relative to neutral stimuli. Although both valence and arousal seem to impact the LPC they do not necessarily interact such that greater amplification is often observed in emotional relative to neutral items *regardless* of arousal level (Bayer et al., 2010; Citron et al., 2013). In contrast to the EPN, the LPC is reflective of explicit processing and allocation of attentional resources.

In the literature, a few studies have examined ERPs associated with attempts to intentionally forget emotional relative to neutral words (e.g., Brandt et al., 2013; Hauswald et al., 2011; Yang et al. 2012). Consistent with prior research, these studies found enhanced LPCs for TBR relative to TBF stimuli coupled with greater frontal positivity for TBF than TBR items. When examining emotional effects, however, Brandt et al. (2013) suggest that emotion had a specific impact on brain processes involved in intentionally remembering TBR items, but not those required to suppress TBF information. That is, the LPC following TBR cues showed more positive activity during negative high arousing relative to neutral words. Frontal positivity following TBF cues, however, did not vary with emotion. Hauswald et al. (2011) support this latter finding but showed no impact of emotion on TBR-related activity. In contrast, Yang et al.

(2012) found that TBF-related frontal activity was more impacted by negative relative to neutral items. Thus, even within the ERP literature, there are inconsistencies with regard to how the brain deals with emotion in the context of directed forgetting. Taking into account the multidimensional nature of emotion by determining the role of valence and arousal may help in clarifying these discrepancies.

1.1 Objectives and Hypotheses

The present study therefore sought to determine the role of valence and arousal and their potential interaction in item directed forgetting at both a behavioural and neurophysiological level. Using an item-based approach, a directed forgetting paradigm for high and low arousing positive, negative, and neutral words was administered in a healthy young adult population while simultaneously recording encoding-based activity using EEG. Electrical brain activity associated with words and cues presented during encoding were separately analyzed. During word processing, the LPC was the component of interest as our primary focus was in the *intentional* processing of these words (Brown et al., 2012; Citron, 2012). Consistent with the literature, a greater LPC over centro-parietal and parietal electrodes was expected to emerge for words high in valence, despite arousal levels (e.g., Bayer et al., 2010; Olofsson et al., 2008; Recio et al., 2014). That is, we did not expect an interaction of valence and arousal for LPC activity time locked to presentation of the cue. As the LPC is often associated with engagement of attention and selective rehearsal, this effect may be most prominent for negative relative to positive words (regardless of arousal) given that young adults sometimes exhibit a negativity bias in attention and memory (e.g., Charles, Mather, & Carstensen, 2003; Citron et al., 2013).

When processing the cue, irrespective of the previous word’s emotional status, enhanced positivity at frontal sites was predicted for TBF relative to TBR cues reflecting engagement of inhibitory-based mechanisms to suppress TBF items. Posteriorly, TBR cues were hypothesized to elicit more positive deflections in late time windows indicative of an LPC to support the selective rehearsal of TBR words. When examining emotional effects on cue-related activity, consistent with prior studies, the emotional tone of words was not expected to modulate frontal activity associated with TBF words (Brandt et al., 2013; Hauswald et al., 2011). The LPC associated with TBR cues, however, may be more affected by the emotional tone of stimuli due to greater selective rehearsal of emotion, which – again – may be particularly enhanced for negative stimuli. Finally, we examined the potential influence of mood and depressive symptomology on our behavioural and neural outcomes as research has suggested that such factors can influence emotional biases in attention (Dalgleish et al., 2003; Fiedler, Nickel, Muehlfriedel, & Unkelbach, 2001; Lewis, Critchley, Smith & Dolan, 2005). This allowed us to gain insight on whether our main outcomes could be attributed to the inherent emotional content of the stimuli or certain characteristics of our participants.

Taken together, this study makes a novel contribution to the literature by examining the impact of arousal and valence on the neurophysiological and behavioural representation of item directed forgetting processes. Use of EEG to examine neural correlates associated with this task may also help in clarifying how the selective rehearsal and inhibitory processes associated with directed forgetting are differentially modulated by fluctuations in both valence and arousal.

2. Results

2.1 Behavioural Data

Proportion of hits as a function of valence, arousal, and cue are illustrated in Figure 1. Hits were analyzed in a 3 (valence) × 2 (arousal) × 2 (cue) repeated-measures analysis of variance (ANOVA; see Table 4 for summary statistics). Replicating the directed forgetting effect, hits were higher for TBR (*M* = .66, *SD* = .16) than TBF items (*M* = .52, *SD* = .16). A main effect of valence revealed more hits toward negative than positive ($p = .031$) and neutral words ($p < .001$), and positive relative to neutral words ($p = .041$). High arousal words (*M* = .60, *SD* = .16) also received a higher degree of hits than low arousal words (*M* = .57, *SD* = .14).

Valence interacted with cue, qualified by a three-way interaction between valence, arousal, and cue. When unpacking this interaction, it was found that arousal and valence differentially impacted the magnitude of directed forgetting. Relative to the other conditions, the difference between TBR and TBF hits was reduced for negative stimuli of high arousal ($p = .101$), driven by enhanced recognition of high arousal negative TBF relative to the positive ($p = .047$) and neutral high arousal TBF ($p = .017$) conditions. Upon visual inspection of negative low arousing items, the directed forgetting effect appeared reduced relative to the other non-negative conditions although the difference between the two conditions was statistically significant ($p = .030$; see Figure 1). Similar to high arousal negative TBF items, low arousing negative TBF items had higher hit rates than positive or neutral low arousal TBF items ($ps \leq .01$). In contrast, higher levels of arousal facilitated recognition of positive TBR relative to low arousal positive TBR words ($p = .016$), while high arousal in the neutral condition facilitated recognition of TBF relative to low arousal neutral TBF words ($p = .005$).

Next, false alarms (i.e., the proportion of new items recognized as old) were calculated and the resulting scores are displayed in Table 3 as a function of valence and arousal. These scores were entered to 3 (valence) × 2 (arousal) repeated measures ANOVA (see Table 5 for summary statistics). Although no main effects were observed, there was an interaction of valence and arousal. False alarms did not differ across arousal levels for negative and neutral items ($ps > .16$) but for positive items, false alarms for high arousal words were reduced relative to low arousal items (p = .006). False alarms for positive high arousal items were also significantly lower than for negative items (p = .006); no other differences were observed.

The calculated recognition bias (*Br*) scores for each of the valence and arousal conditions were less than 0.5, indicating an overall conservative bias across participants (see Table 3). These scores were submitted to a 3 (valence) × 2 (arousal) repeated-measures ANOVA where a main effect of valence emerged (see Table 6 for summary statistics). Collapsing across arousal, follow-up comparisons revealed higher *Br* scores for negative (M = .46, SD = .24) than positive items (M = .42, SD = .24; p = .033); *Br* for neutral items (M = .43, SD = .24) did not differ from positive or neutral items (*ps* > .11). Valence and arousal also interacted, with higher *Br* for negative high arousal relative to negative low arousal words (p = .001), a difference that did not exist within the other valence conditions (*ps* > .09). Bias scores for negative high arousing items were also greater than that of positive high arousal items (p < .001).

2.2 ERP Data

2.2.1 Word effects. Word-related ERPs consistent with the LPC were submitted to a 3 (valence) × 2 (arousal) ANOVA (see Table 7 for summary statistics). As expected, the analysis revealed a main effect of valence. Follow-up comparisons showed this was driven by a more positive LPC for negative than positive and neutral words, *ps* < .05 (see Figure 2). The main effect of arousal and the interaction of the two emotion factors were non-significant, *ps* > .16.

2.2.2 Cue effects.

2.2.2.1 Frontal activity. The 3 (valence) × 2 (arousal) × 2 (cue) ANOVA on frontal activity between 350 and 850 ms post-cue presentation revealed a marginal effect of cue in the predicted direction (see Table 8 for summary statistics). Specifically, there was more positive frontal activation in response to TBF relative to TBR cues (see Figure 3). Neither valence nor arousal modulated frontal ERPs, *ps* $> .12$.

2.2.2.2 Parietal activity. Parietal ERPs 350 to 850 ms following the cue were analyzed in a 3 (valence) × 2 (arousal) × 2 (cue) ANOVA (see Table 9 for summary statistics). In line with predictions, TBR cues evoked a more positive LPC than TBF cues; all other main effects were non-significant, *ps* $> .18$. There was an interaction between valence and arousal, qualified by a three-way interaction between valence, arousal, and cue. The three-way interaction revealed that TBR and TBF items were processed differently as a function of both valence and arousal (Figures 4-5). Across valence and arousal, more positive activity was observed for TBF negative low relative to negative high arousal words (p =.024), whereas a reversed (marginal) difference was seen for positive TBF items with more positive deflections for high relative to low arousal words (p = .060). This interesting crossover effect for TBF negative low arousal and positive high arousal words is more clearly illustrated in Figure 6. Finally, neutral words showed more positive activity for TBR items at low relative to high levels of arousal (p = .006).

2.3 Potential Confounding Variables

No significant correlations were observed between scores on the PANAS (positive or negative affect) or CES-D and the behavioural directed forgetting index across all valence and arousal conditions (*rs* > -.294 or < .356, *ps* > .120). Similarly, in the brain, there was no association between scores on these measures and cue-related activity in frontal (*rs* > -.336 or < .265, *ps* > .109) or parietal regions (*rs* > -.274 or < .338, *ps* > .106) across valence and arousal conditions. There was, however, an association between negative affect on the PANAS and the word-related LPC effects specific to negative high arousing words (r = .603, p = .002), negative low arousing words (r = .475, p = .019), and positive high arousing words (r = .682, p < .001).

3. Discussion

The current study sought to examine the differential effects of valence and arousal on the behavioural and neural representation of item directed forgetting. Behaviourally, directed forgetting was observed with greater recognition of TBR relative to TBF items, but this difference varied depending on the valence and arousal of items. The magnitude of directed forgetting was smaller for negative words at both levels of arousal, which was due to reduced suppression of negative TBF words relative to the other valence/arousal conditions. These findings are in line with prior studies suggesting that negative stimuli may be particularly difficult to intentionally forget (e.g., Hauswald et al., 2010; Yang et al., 2015). These findings also support the often observed "negativity bias" in which young adults show an advantage in attention and memory for negative relative to positive or neutral stimuli (Charles et al., 2003). A differential impact of arousal was also observed for neutral words with reduced forgetting of high relative to low arousal words, suggesting that higher levels of arousal without variation in valence can interfere with suppression of TBF items. In the positive condition, however, high arousal facilitated recognition of TBR words while no difference was seen in suppression of TBF positive items across arousal.

When examining response bias scores, we found that participants adopted a largely conservative bias during recognition, which suggests a reluctance to respond "old" unless participants had a strong feeling of familiarity associated with the item (Hill & Windmann, 2014; Snodgrass & Corwin, 1988). In the current study, recognition bias scores were elevated specifically for high arousal negative items relative to the other valence/arousal conditions, which is consistent with prior research in this field (e.g., Hauswald et al., 2011). Although scores for this condition remained within the "conservative" range, they shifted closer to a neutral/liberal bias, in which participants become more likely to respond “old” even in the absence of familiarity. This finding is also consistent with prior literature examining the impact of emotion on response bias such as that of Dougal and Rotello (2007) who found that negative arousing words consistently evoke a higher proportion of “old” responses on recognition tasks relative to positive or neutral words. With regards to recognition performance, the higher *Br* scores we observed here for negative arousing items might have thus contributed to the increased hit rates for negative TBF items. Taken together, the behavioural findings provide evidence that valence and arousal have a differential impact on the ability to intentionally encode TBR items and suppress those that are TBF during directed forgetting; however, shifts in response bias may modulate recognition performance particularly at higher levels of arousal for negative valence.

Brain responses were also modified by valence and arousal. When participants were studying the word, even before presentation of the cue, the brain had already begun to process items high in negative valence differently than the other conditions. As predicted, the LPC showed more positivity in response to negative items at both levels of arousal. That the LPC was more sensitive to fluctuations in valence despite arousal levels also falls in line with literature suggesting that valence exerts its greatest impact during later explicit stages of information processing (i.e., 400-1000 ms post-stimulus presentation; Bayer et al., 2010; Citron, 2012). According to the literature, the LPC is argued to reflect selective attention toward and processing of emotional stimuli (Brown et al., 2012). Moreover, the neural substrate of the LPC is thought to consist of a network of cortical and subcortical structures, such as the visual cortices, prefrontal cortex, parietal cortex, and deep emotion-processing structures (e.g., insula, amygdala; Liu, Huang, McGinnis-Deweese, Keil, & Ding, 2012). The involvement of these regions supports the notion that motivated attention may therefore lead to preferential processing of emotional information. As such, in the context of the current experiment, it is likely that participants devoted greater attention toward studying negative items relative to the other conditions, a finding that—much like our behavioural results—is consistent with a “negativity bias” in young adults’ attention and brain responses to emotional words (e.g., Wood & Kisley, 2006). The fact that these items may have received more attention may also be a factor in why recognition of high arousing negative TBF items was enhanced relative to the other similarly cued conditions.

Following cues, frontal ERPs differed on the basis of cue type, with TBF cues eliciting more positive activity relative to TBR cues, which may be indicative of cognitive control or inhibitory mechanisms working to suppress TBF items as suggested by prior investigations (Hauswald et al., 2010; van Hooff & Ford, 2011). Consistent with the literature, cue-related frontal activity did not vary by valence or arousal. Over parietal sites, TBR cues evoked greater positivity than TBF cues, replicating existing research (Brandt et al., 2013; Hauswald et al., 2010). As activation patterns over parietal regions in this time window are thought to reflect allocation of attentional resources, these results likely reflect selective rehearsal of TBR- relative to TBF-cued items. Taken together, these findings lend support to a combined role of inhibitory and selective rehearsal mechanisms in the neural representation of item directed forgetting.

Although emotional valence of the target word did not modulate anterior cue-related ERPs, valence and arousal had differential impacts on posterior TBR cue-related activity. Most notably was the difference observed for negative low arousing and positive high arousing conditions (Figure 6). Specifically, positive high and negative low arousing TBF words elicited more positive activity relative to their alternate valence/arousal TBF comparisons suggesting these items may have received greater attentional resources and information processing.

Interestingly, this is not the first time a differential pattern of brain responses toward positive high and negative low arousal words has been reported. In an earlier investigation of valence and arousal effects on written word recognition, Citron and colleagues (2013) found enhanced sustained slow positivity (SSP) over centro-parietal sites for positive words high in arousal as well as negative words low in arousal. The authors argued this reflected sustained attention toward those items, which may be rooted in conflicting approach-withdrawal reactions toward positive high and negative low arousing words. This draws on motivational theories suggesting that items with either positive valence or low arousal evoke an approach-orientation as they are presumed to be “safe”, whereas negative valence or high arousal items elicit a withdrawal-orientation as they induce a feeling of “threat” (Citron, 2012; Robinson, 1998). Citron et al. (2013) argue that when a conflict is created between the approach-withdrawal orientations, such as with high arousal positive and low arousal negative items, increased cognitive resources are required by the brain to deal with the conflict. Applying this to the current study, despite an instruction to forget, it appears that these conflicting valence/arousal combinations may have also elicited enhanced sustained attention from our participants as indicated by their increased positive deflections following TBF cues.

Moving to the middle of the valence continuum, neutral items showed differences in parietal positivity as a function of arousal. Following TBR cues, low arousal items showed enhanced positivity relative to their high arousal alternatives. This may be linked to the lack of saliency that neutral low arousal items exhibit when compared to items that are extreme in valence or high in arousal. As a result, these words may require greater processing and attention in order to be effectively encoded in memory, thus explaining the observed ERP differences for this condition (Citron et al., 2013). Altogether, these results clearly indicate that valence and arousal differentially impact how the brain deals with relevant (i.e., TBR) and irrelevant (TBF) stimuli over parietal but not frontal regions.

Finally, the main behavioural and neural directed forgetting results reported here did not correspond to affective state (positive or negative) or depressive symptomology suggesting these factors likely did not play a role in our observed effects. However, we did find a strong positive relationship between negative affect and the LPC evoked when viewing negative high and low arousing words as well as high arousing positive words prior to presentation of the cue. This interesting finding suggests that participants high in negative affect also showed greater LPCs for emotional items in general (with the exception of the positive low arousal condition). Mood-congruent ERP effects have been previously found during emotional word processing. Specifically, Kiefer, Schuch, Schenck, and Fiedler (2006) found that while studying positive words, those in positive relative to negative mood states evoked a smaller N400, a component sensitive to semantic incongruence. To the best our knowledge, this is the first study to show an association between negative mood and the emotion-related LPC when viewing emotional items. That the association with mood was specific to the LPC and not observed for cue-related findings (i.e., directed-forgetting effects) suggest that this mood-congruent relationship may be specific to mechanisms of attention evoked during word processing.

3.1 Conclusions

The current findings replicate existing research while providing novel evidence for the individual impact that valence and arousal can have on human memory performance and brain activity. Behaviourally, we observed varying recognition of TBR and TBF items as a function of valence and arousal such that directed forgetting of negative and neutral high arousal words was reduced, while intentional remembering of positive high arousal items was enhanced. At the neural level, we replicated previous neurophysiological findings that support involvement of both inhibitory and selective rehearsal mechanisms in directed forgetting (e.g., Hauswald et al., 2010; van Hooff et al., 2011). Moreover, whereas emotional valence of the target word did not impact frontal-based activity in response to cues (similar to Brandt et al., 2013), each dimension differentially influenced how the brain dealt with instructions to remember and forget over parietal sites. The interesting activation patterns we observed for positive high and negative low arousing words seem to be best explained by conflicting approach-withdrawal reactions that required greater processing to resolve (Citron, 2012; Robinson, 1998). All in all, and perhaps most importantly, the findings support a multidimensional model of emotion that should be taken into account during experimentation.

4. Experimental Procedure

4.1 Participants

Twenty-four young adults (8 males; aged 18-29) were recruited from Introductory Psychology courses at Ryerson University to participate in the study. Participants were included if they (1) had normal or corrected to normal vision, (2) were free of any neurological or psychiatric conditions affecting cognition, and (3) learned English prior to the age of six (due to the use of verbal stimuli). All participants received course credit for their participation. All procedures were approved by the Ryerson University Research Ethics Board and conformed to regulatory standards in conducting psychological research.

A battery of questionnaires was administered including a background questionnaire with queries on age and gender, the Shipley Institute of Living vocabulary test (Shipley, 1946), the Beck Anxiety Inventory (BAI; Beck, Epstein, Brown, & Steer, 1988), the Centre for Epidemiological Studies Depression scale (CES-D; Radloff, 1977), and the Positive and

Negative Affect Schedule (PANAS), which provides a measure of positive and negative affect (Watson, Clark, & Tellegen, 1988).

To ensure proficiency with the English language, participants were excluded and replaced if they scored less than 20 on the Shipley vocabulary test, suggesting poor vocabulary. As research has suggested that emotional biases in attention can vary in the presence of anxiety symptoms we excluded and replaced participants with scores above 26 on the BAI, suggesting high anxiety (Dalgleish et al. 2003; see Table 1 for sample characteristics). Overall, three participants were excluded and replaced due to poor EEG data and four participants were excluded and replaced due to scores on the BAI. We did not exclude participants with scores over the cut-off on the CES-D as depression has been shown not to impact emotional biases in memory (Charles, Mather, & Carstensen, 2003; Dalgleish et al., 2003). This data was instead used to determine if participants' depressive symptomology correlated with their memory performance and ERPs during the directed forgetting task across valence and arousal conditions. Similarly, scores on the PANAS were used to determine if there was an association between current mood state (positive or negative) and our main behavioural and ERP outcomes.

4.2 Stimuli and Apparatus

Stimuli characteristics are presented in Table 2 and the full list of items are displayed in Appendix 1. A total of 480 words was selected from the Affective Norms for English Words database (Bradley & Lang, 1999) according to valence and arousal ratings that each range from 1 (high negativity or low arousal) to 9 (high positivity or high arousal). The list contained equal proportions of words that were positive, negative, and neutral in valence with each condition differing on average valence (i.e., positive > neutral > negative, *ps* < .001). Within each valence condition, half the words were high in arousal and half were low in arousal (*ps* < .001). Positive and negative words were matched on mean arousal at each of the high and low arousal levels (*ps* > .08), while neutral words were always lower in arousal than emotional words, *ps* < .001.

This list was evenly separated into two lists to be counterbalanced as 'old' and 'new' lists across participants. Each sub-list was further evenly divided into a TBR and TBF list, also counterbalanced across participants. Within lists, there was always an equal representation of high and low arousal positive, negative, and neutral words, matched on stimulus frequency and length. Valence, arousal, frequency, and word length were also matched across all lists.

The experimental task was programmed using Presentation software (version 16.0, www.neurobs.com) and presented on a ACPI PC running Windows 7 Professional. Stimuli were displayed in white font against a black background on a Viewsonic VE175 monitor with a screen resolution of 1280 x 1024 and a viewing distance of approximately 60 cm. Responses during the recognition task were made using the '4' and '8' keys on the number pad of the keyboard, counterbalanced as old and new across participants.

4.3 Design and Procedure

The study adopted a 3 (valence: positive, negative, neutral) × 2 (arousal: high, low) × 2 (cue: TBR, TBF) within-subjects factorial design. Upon arrival to the lab, participants provided informed consent and were introduced to the experiment. Participants were asked to study a series of 240 words and to remember only those that were followed by the cue "RRRR" and to forget those followed by the cue "FFFF". They were aware that a memory test would follow, but were not told their memory for TBF stimuli would be tested. Each trial began with a fixation cross in the centre of the screen for 1000 ms, followed by a word for 2500 ms. After the word, a blank screen appeared as an inter-stimulus interval (ISI) that varied between 500 and 1000 ms equally across trials and was followed by a cue for 1000 ms. Another ISI appeared as a blank screen that again varied for 500 or 1000 ms before proceeding to the next trial. Words were presented randomly in four blocks of 60 words, which each took six minutes to complete. A 10 second break was provided between blocks.

After encoding, participants completed the Digit Symbol Substitution Test for two minutes as a distractor before proceeding to a recognition task for 240 old and 240 new words. Participants were instructed to indicate whether each word was old regardless of the cue it was presented with at encoding or to respond new if they did not study it. It was emphasized that a word should be classified as old even if the participant knew it was a word they were supposed to forget. Each trial began with a word in the centre of the screen that remained on the screen until a response was detected. Once a response was made, an ISI appeared as a blank screen that varied between 500 and 1000 ms equally across trials before moving on to the next word. Following recognition, the PANAS, Shipley, CES-D, BAI, and background questionnaire were administered.

4.4 ERP Recording and Processing

ERP activity was continuously digitized during encoding using ActiView (Bio-Semi; Wilmington, NC) with a band-pass filter of 208 Hz and a sampling rate of 1024 Hz. Recordings were taken from F3, Fz, F4, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, CP4, P3, Pz, P4, POz, and referenced to the CMS (Common Mode Source) and DRL (Driven Right Leg). Horizontal eye movements were recorded using channels placed at the outer canthi and vertical eye movements from channels at the inferior orbits. The resulting data were processed using BESA 5.3 Research (MEGIS; Gräfelfing, Germany). Horizontal and vertical eye artifacts (e.g., blinks and saccades) were corrected using the HEOG and VEOG automatic eye correction in BESA. Using a 0.1 Hz (12db/oct; zero phase) to 30 Hz (24 db/oct; zero phase) filter, epochs were time-locked to the onset of the stimulus (i.e., word or cue) for each respective analysis. Activity from 200 ms pre-stimulus baseline and 1000 ms post-stimulus was rejected if amplitude difference exceeded 100 μV, gradient between consecutive time points exceeded 75 μV, or, if there was signal lower than 0.01 μV, within any channel. All EEG channels were re-referenced off-line to the average of the left and right mastoids.

4.5 Data Analysis

4.5.1 Behavioural data. Following prior practice (e.g., Gallant & Yang, 2014; Nowicka et al., 2011) recognition performance was quantified by measuring the proportion of hits (i.e., ‘old’ responses to an old item) and false alarms (i.e., new words participants guessed as old) to studied items and analyzed in two separate repeated-measures analyses of variance (ANOVA). Hits were analyzed as a function of the within-subject factors valence, arousal, and cue whereas false alarms were analyzed as a function of valence and arousal. Due to the use of a binary response during recognition (i.e., ‘old’ vs. ‘new’), it was not possible to disentangle false alarms according to each cue and so this factor was removed from the analysis.

To determine if recognition arose from real memory effects or modulation of response bias, a measure of recognition bias was calculated according to the two-high threshold model (*Br* = false alarms / [1- (hits – false alarms)]; Snodgrass & Corwin, 1988). This model is built on theory suggesting that two distinct memory thresholds exist, one for recognizing old items and one for rejecting new items, and that only items exceeding each of these thresholds will be correctly recognized or rejected, respectively. The bias index of this model represents the probability of saying “yes” (or in this case “old”) to an item when in a state of uncertainty. A *Br* of 0.5 indicates neutral bias, greater than 0.5 indicates a liberal bias, and less than 0.5 a conservative bias. As the formula relies on false alarms rates, calculation of *Br* as a function of cue was not possible and thus scores were analyzed as a function of arousal and valence only. False alarm and recognition bias data are presented in Table 3.

4.5.2 ERP data. To examine the effect of word presentation on the LPC as a function of valence and arousal, mean amplitudes time-locked to onset of the word were analyzed. Consistent with the LPC, data were extracted from CP4, CPz, CP3, P3, Pz, and P4 in the 400-1000 ms epoch.

Cue-related effects at frontal and centro-parietal/parietal recordings were calculated in two separate ANOVAs on mean amplitudes time-locked to cue presentation as a function of valence, arousal, and cue. Frontal recordings were extracted from F3, Fz, and F4 in the 350 to 850 ms epoch while parietal recordings were pulled from CP4, CPz, CP3, P3, Pz, and P4.

4.5.3 Statistical analysis. All analyses were performed using IBM SPSS Statistics 19.0 with alpha levels set at 0.05 unless otherwise specified. Partial-eta squared was used as an estimate of effect size. Follow-up *t*-tests were performed to unpack any significant main effects or interactions. A summary of each ANOVA is presented in Tables 4-9.

Tables

Table 1

Characteristics of the Final Sample

Measure	*M (SD)*
Age in years	19.58 (2.36)
Positive Affect[a]	27.54 (16.82)
Negative Affect[a]	18.00 (9.29)
CES-D	18.04 (8.22)
BAI	13.13 (8.17)
Shipley Vocabulary	28.08 (4.22)

Note: [a]Measured with the Positive and Negative Affect Schedule (Watson et al., 1988).

Table 2

Characteristics of the Word Stimuli

	Valence	Arousal	Length	Frequency
Condition	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
Negative HA	2.55 (.53)	6.67 (.47)	6.10 (1.62)	25.53 (35.57)
Negative LA	2.67 (.53)	5.58 (.26)	6.60 (1.80)	22.68 (36.86)
Positive HA	7.69 (.56)	6.66 (.53)	6.51 (2.07)	38.49 (45.19)
Positive LA	7.54 (.44)	5.64 (.21)	6.33 (2.09)	41.61 (44.37)
Neutral HA	5.12 (.63)	4.42 (.30)	6.26 (1.74)	31.24 (41.82)
Neutral LA	5.12 (.45)	3.54 (.34)	5.83 (1.55)	38.43 (44.61)

Note: Norms extracted from the Affective Norms for English Words database (Bradley & Lang, 1999); HA = High Arousal, LA = Low Arousal.

Table 3

Proportion of False Alarms and Recognition Bias (Br)

	False Alarms[a]	Recognition Bias (*Br*)[a]
Condition	*M (SD)*	*M (SD)*
Negative HA	.39 (.26)	.48 (.24)
Negative LA	.35 (.33)	.42 (.25)
Positive HA	.31 (.30)	.39 (.26)
Positive LA	.38 (.26)	.43 (.22)
Neutral HA	.37 (.23)	.44 (.21)
Neutral LA	.39 (.23)	.42 (.25)

Note: [a] Due to the binary response during recognition, disentangling false alarms according to cue was not feasible and so false alarms and *Br* are only reported for valence and arousal conditions. HA = High Arousal; LA = Low Arousal.

Table 4

Summary of the three-way repeated measures ANOVA assessing the impact of valence and arousal on hits of TBR and TBF items.

Metric	Df	*F*	*MSE*	*P*	η_p^2
V	**2, 46**	**14.175**	**.198**	**<.001**	**.381**
A	**1, 23**	**5.349**	**.064**	**.030**	**.189**
C	**1, 23**	**35.550**	**1.333**	**<.001**	**.607**
V × A	2, 46	.864	.010	.428	.036
V × C	**2, 46**	**7.223**	**.081**	**.002**	**.239**
A × C	1, 23	1.482	.051	.236	.061
V × A × C	**2, 46**	**4.434**	**.054**	**.017**	**.162**

Note: V = Valence, A = Arousal, C = Cue; significant effects displayed in bold font.

Table 5

Summary of the two-way repeated measures ANOVA assessing the impact of valence and arousal on false alarms.

Metric	Df	*F*	*MSE*	*P*	η_p^2
V	2	1.649	.014	.203	.067
A	1	2.047	.166	.166	.082
V × A	**2**	**4.341**	**.032**	**.019**	**.159**

Note: V = Valence, A = Arousal, C = Cue; significant effects displayed in bold font.

Table 6

Summary of the two-way repeated measures ANOVA assessing the impact of valence and arousal on recognition bias.

Metric	Df	*F*	*MSE*	*P*	η_p^2
V	**2**	**3.559**	**.018**	**.037**	**.134**
A	1	1.093	.008	.307	.045
V × A	**2**	**4.088**	**.031**	**.023**	**.151**

Note: V = Valence, A = Arousal, C = Cue; significant effects displayed in bold font.

Table 7

Summary of the two-way repeated measures ANOVA assessing the impact of valence and arousal on the LPC during 400-1000ms post-onset of words during encoding.

Metric	Df	*F*	*MSE*	*P*	η_p^2
V	**2, 46**	**3.911**	**9.065**	**.027**	**.145**
A	1, 23	.015	.072	.905	.001
V × A	2, 46	1.699	6.368	.164	.069

Note: V = Valence, A = Arousal, C = Cue; significant effects displayed in bold font.

Table 8

Summary of the three-way repeated measures ANOVA assessing the impact of valence and arousal on frontal ERPs during 350-850 ms post-onset of TBR and TBF cues.

Metric	Df	*F*	*MSE*	*P*	η_p^2
V	2, 46	1.515	23.187	.231	.062
A	1, 23	2.628	28.664	.119	.103
C	**1, 23**	**3.933**	**92.570**	**.059**	**.146**
V × A	2, 46	.703	6.951	.500	.030
V × C	2, 46	1.312	9.601	.279	.054
A × C	1, 23	.225	2.893	.640	.010
V × A × C	2, 46	1.568	15.050	.219	.064

Note: V = Valence, A = Arousal, C = Cue; marginally significant effect displayed in bold font.

Table 9

Summary of the three-way repeated measures ANOVA assessing the impact of valence and arousal on parietal ERPs during 350-850 ms post-onset of TBR and TBF cues.

Metric	Df	*F*	*MSE*	*P*	η_p^2
V	2, 46	.259	1.862	.773	.011
A	1, 23	1.917	9.493	.179	.077
C	**1, 23**	**18.068**	**146.497**	**<.001**	**.440**
V × A	**2, 46**	**3.755**	**14.707**	**.031**	**.140**
V × C	2, 46	1.280	6.545	.288	.053
A × C	1, 23	1.531	9.110	.228	.062
V × A × C	**2, 46**	**6.263**	**36.885**	**.004**	**.214**

Note: V = Valence, A = Arousal, C = Cue; significant effects displayed in bold font.

Figure Legends

Figure 1. Proportion of items recognized as old as a function of valence, arousal, and cue.

Figure 2. Grand average ERP waveforms extracted from CP4, CPz, CP3, P3, Pz, and P4 recordings during word presentation. Data are displayed as a function of valence.

Figure 3. Grand average ERP waveforms extracted from F3, Fz, and F4 recordings during cue presentation. Data are displayed as a function of cue.

Figure 4. Grand average ERP waveforms extracted from CP4, CPz, CP3, P3, Pz, and P4 recordings during cue presentation. Data are displayed as a function of valence, arousal, and cue.

Figure 5. Mean cue-related amplitudes at 350 to 850 ms extracted from centro-parietal and parietal electrodes as a function of valence, arousal, and cue. Error bars represent standard error of the means.

Figure 6. Mean cue-related amplitudes at 350 to 850 ms extracted from parietal electrodes depicting the activation interaction between high and low arousal positive and negative TBF words. Error bars represent standard error of the means.

References

Anderson, M. C., & Hanslmayr, S. (2014). Neural mechanisms of motivated forgetting. *Trends in Cognitive Sciences, 18*(6), 279–282. doi: 10.1016/j.tics.2014.03.002

Bailey, K., & Chapmann, P. (2012). When can we choose to forget? An ERP study into item-method directed forgetting of emotional words. *Brain and Cognition, 78*, 133-147. doi: 10.1016/j.bandc.2011.11.004

Basden, B. H., and Basden, D. R. (1998). Directed forgetting: A contrast of methods and interpretations. In J. M. Golding & C. M. MacLeod (Eds.), *Intentional Forgetting: Interdisciplinary Approaches* (pp. 1-57). Mahwah, NJ: Lawrence Erlbaum Associates.

Bayer, M., Sommer, W., & Schacht, A. (2010). Reading emotional words within sentences: the impact of arousal and valence on event-related potentials. *International Journal of Psychophysiology, 78*, 299-307. doi: 10.1016/j.ijpsycho.2010.09.004

Beck, A. T., Epstein, N., Brown, G., & Steer, R. A. (1988). An inventory for measuring clinical anxiety: Psychometric properties. *Journal of Consulting and Clinical Psychology, 56*, 893-897. Retrieved from: http://www.ncbi.nlm.nih.gov/pubmed/3204199

Bjork, R. A., LaBerge, D., & LeGrande, R. (1968). The modification of short-term memory through instructions to forget. *Psychonomic Science*, 10, 55-56. DOI: 10.3758/BF03331404

Bjork, R. A. (1970). Positive forgetting: The noninterference of items intentionally forgotten. *Journal of Learning and Verbal Behaviour*, *9*, 255-268. doi: 10.1016/S0022-5371(70)80059-7

Bjork, R. A. (1972). Theoretical implications of directed forgetting. In A. W. Melton & E. Martin (Eds.), *Coding Processes in Human Memory* (pp. 217-235). Washington, DC: Winston.

Bradley, M. M., & Lang, P. J. (1999). Affective norms for English words (ANEW): Instruction manual and affective ratings. *Technical Report C-1*, The Center for Research in Psychophysiology, University of Florida. Retrieved from: http://www.uvm.edu/~pdodds/research/papers/others/1999/bradley1999a.pdf

Brandt, K. R., Nielson, M. K., & Holmes, A. (2013). Forgetting emotional and neutral words: An ERP study. *Brain Research, 1501,* 21-31. doi: 10.1016/j.brainres.2013.01.019

Brown, S. B. R., van Steenbergen, H., Band, G. P. H., de Rover, M., & Nieuwenhuis, S. (2012). Functional significance of the emotion-related late positive potential. *Frontiers in Human Neuroscience, 6,* 1-12. doi: 10.3389/fnhum.2012.00033

Charles, S. T., Mather, M., & Carstensen, L. L. (2003). Aging and emotional memory: The forgettable nature of negative images for older adults. *Journal of Experimental Psychology: General, 132,* 310-324. doi: 10.1037/0096-3445.132.2.310

Citron, F. (2012). Neural correlates of written emotion word processing: A review of recent electrophysiological and hemodynamic neuroimaging studies. *Brain and Language, 122,* 211-226. doi: 10.1016/j.bandl.2011.12.007

Citron, F. M. M., Weekes, B. S., & Ferstl, E. C. (2013). Effects of valence and arousal on written word recognition: Time course and ERP correlates. *Neuroscience Letters, 533,* 90-95. doi: 10.1016/j.neulet.2012.10.054

Dalgleish, T., Taghavi, R., Neshat-Doost, H., Moradi, A., Canterbury, R., & Yule, W. (2003). Patters of processing bias for emotional information across clinical disorders: a comparison of attention, memory, and prospective cog- nition in children and adolescents with depression, generalized anxiety, and posttraumatic stress disorder. *Journal of Clinical Child and Adolescent Psychology, 32,* 10–12. doi: 10.1207/15374420360533022

Fawcett, J. M., & Taylor, T. L. (2008). Forgetting is effortful: evidence from reaction time probes in an item-method directed forgetting task. *Memory & Cognition, 36,* 1168-1181. doi: 10.3758/MC.36.6.1168

Fiedler, K., Nickel, S., Muehlfriedel, T., & Unkelback, C. (2001). Is mood congruency an effect of genuine memory or response bias? *Journal of Experimental Social Psychology, 37,* 201-214. doi: 10.1006/jesp.2000.1442

Gallant, S. N., & Yang, L. (2015). Directed forgetting. In S. K. Whitbourne (Ed.), *The Encyclopedia of Adulthood and Aging.* Wiley Blackwell.

Gallant, S. N., & Yang, L. (2014). Positivity effect in source attributions of arousal-matched emotional and non-emotional information during item-based directed forgetting. *Frontiers in Psychology: Cognition, 5,* 1-8. doi: 10.3389/fpsyg.2014.01334

Hauswald, A., Schulz, H., Iordanov, T., & Kissler, J. (2010). ERP dynamics underlying successful directed forgetting of neutral but not negative pictures. *Social Cognitive and Affective Neuroscience, 6,* 450-459. doi: 10.1093/scan/nsq061

Hsieh, L.-T., Hung, D. L., Tzeng, O. J.-L., Lee, J. R., & Cheng, S. K. (2008). An event-related potential investigation of the processing of remember/forget cues and item encoding in item-method directed forgetting. *Brain Research, 1250,* 190-201. doi: 10.1016/j.brainres.2008.11.016

Kensinger, E. A., & Corkin, S. (2004). Two routes to emotional memory: Distinct neural processes for valence and arousal. *Proceedings of the National Academy of Sciences of the United States of America, 101,* 3310-3315. doi: 10.1073/pnas.0306408101

Kiefer, M., Schuch, S., Schenck, W., & Fiedler, K. (2006). Mood states modulate activity in semantic brain areas during emotional word encoding. *Cerebral Cortex*, *17,* 1516-1530. doi: 10.1093/cercor/bhl062

Labar, K. S., & Cabeza, R. (2006). Cognitive neuroscience of emotional memory. *Nature Reviews Neuroscience, 7,* 54-64. doi: 10.1038/nrn1825

Lewis, P. A., Critchley, H. D., Smith, A. P., & Dolan, R. J. (2005). Brain mechanisms for mood congruent memory facilitation. *NeuroImage, 25,* 1214-1223. doi: 10.1016/j.neuroimage.2004.11.053

Liu, Y., Huang, H., McGinnis-Deweese, M., Keil, A., & Ding, M. (2012). Neural substrate of the late positive potential in emotional processing. *Journal of Neuroscience, 32,* 14563-72. doi: 10.1523/JNEUROSCI.3109-12.2012.

MacLeod, C. M. (1998). Directed forgetting. In J. M. Golding & C. M. MacLeod (Eds.), *Intentional Forgetting: Interdisciplinary Approaches* (pp. 1-57). Mahwah, NJ: Lawrence Erlbaum Associates.

Nowicka, A., Marchewka, A., Jednorog, K., Tacikowski, P., & Brechmann, A. (2011). Forgetting of emotional information is hard. An fMRI study of directed forgetting. *Cerebral Cortex*, *21*, 539-549. doi:10.1093/cercor/bhq117

Olofsson, J. K., Nordin, S., Sequeira, H., & Polich, J. (2008). Affective picture processing: An integrative review of ERP findings. *Biological Psychology, 77,* 247-265. doi: 10.1016/j.biopsycho.2007.11.006

Patrick, R. E., Kiang, M., & Christensen, B. K. (2015). Neurophysiological correlates of emotional directed-forgetting in persons with Schizophrenia: An event-related brain potential study. *International Journal of Psychophysiology.* doi: 10.1016/j.ijpsycho.2015.01.006.

Paz-Caballero, M. D., Menor, J., & Jiménez, J. M. (2004). Predictive validity of event-related potentials (ERPs) in relation to directed forgetting effects. *Clinical Neurophysiology, 115,* 369-377. doi: 10.1016/j.clinph.2003.09.011

Radloff, L. S. (1977). The CES-D scale: A self-report depression scale for research in the general population. *Applied Psychological Measurement, 1,* 385-401. doi: 10.1177/014662167700100306

Recio, G., Conrad, M., Hansen, L. B., & Jacobs, A. M. (2014). On pleasure and thrill: The interplay between arousal and valence during visual word recognition. *Brain & Language, 134,* 34-43. doi: 10.1016/j.bandl.2014.03.009

Robinson, M. D. (1998). Running from William James' bear: A review of preattentive mechanisms and their contributions to emotional experience. *Cognition and Emotion, 12,* 667-696. doi:10.1080/026999398379493

Russel, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology, 39,* 1161-1178.

Shipley, W. C. (1946). *Shipley Institute of Living Scale.* Los Angeles: Western Psychological Services.

Snodgrass, J. G., & Corwin, J. (1988). Pragmatics of measuring recognition memory: Applications to Dementia and Amnesia. *Journal of Experimental Psychology: General, 117,* 34-50. doi: 10.1037/0096-3445.117.1.34

van Hooff, J. C., & Ford, R. M. (2011). Remember to forget: ERP evidence for inhibition in an item-method directed forgetting paradigm. *Brain Research*, *1392*, 80-92. doi: 10.1016/j.brainres.2011.04.004

Watson, D., Clark, L. A., & Tellegan, A. (1988). Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology, 54*, 1063. doi: 10.1037/0022-3514.54.6.1063

Wechsler, D. (1981). *Manual for the Wechsler Adult Intelligence Scale-Revised.* New York: Psychological Corporation.

Wood, S., & Kisley, M.A. (2006). The negativity bias is eliminated in older adults: Age-related reduction in event-related brain potentials associated with evaluative categorization. *Psychology and Aging, 21*, 815-820.

Wylie, G. R., Foxe, J. J., & Taylor, T. L. (2008). Forgetting as an active process: An fMRI investigation of item-method-directed forgetting. *Cerebral Cortex, 18,* 670-682. doi: 10.1093/cercor/bhm101

Yang, T., Lei, X., & Anderson, M. (2015). Decreased inhibitory control of negative information in directed forgetting. *International Journal of Psychphysiology*. doi: 10.1016/j.ijpsycho.2015.09.007

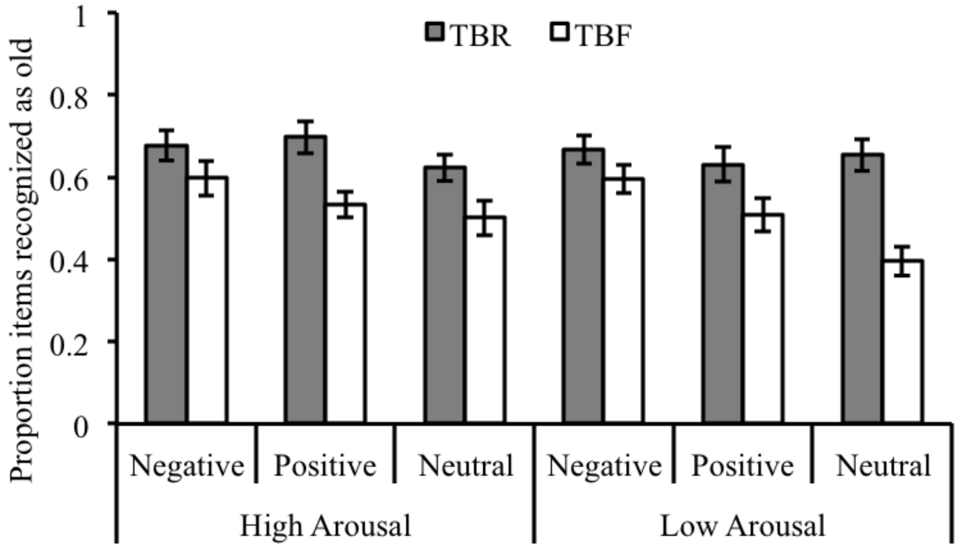
Yang, W., Liu, P., Xiao, X., Li, X., Zeng, C., Qiu, J., & Zhang, Q. (2012). Different neural substrates underlying directed forgetting for negative and neutral images: An event-related potential study. *Brain Research, 1441,* 53-63. doi: 10.1016/j.brainres.2011.10.042

Appendices

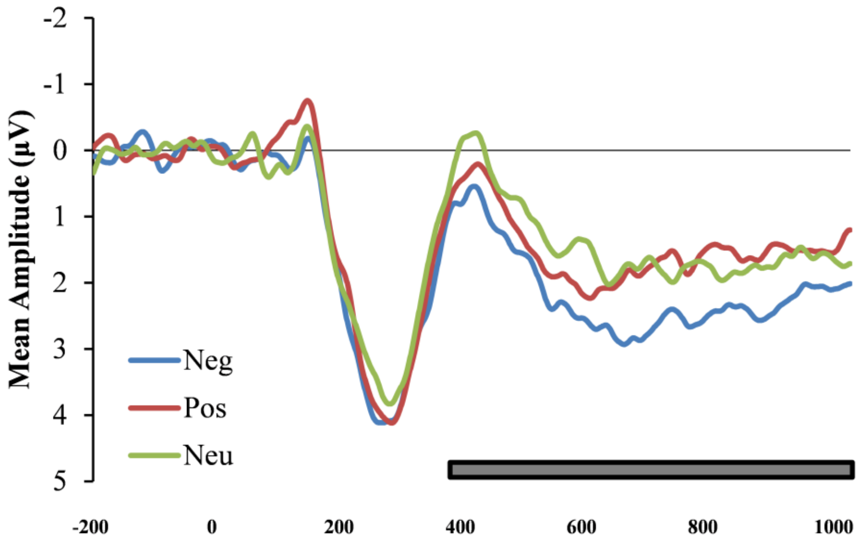
Appendix 1. List of stimuli selected from ANEW database (Bradley and Lang, 1999).

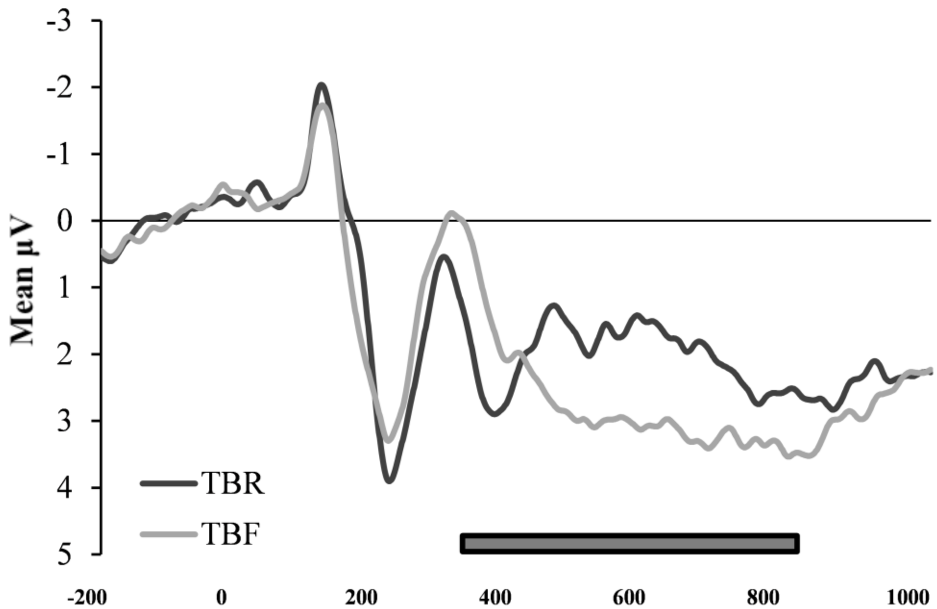
Negative High Arousal	Negative Low Arousal	Positive High Arousal	Positive Low Arousal	Neutral High Arousal	Neutral Low Arousal
abuse	abduction	admired	abundance	absurd	bandage
accident	abortion	adventure	acceptance	activate	banner
afraid	addict	affection	achievement	alley	barrel
ambulance	alcoholic	alert	alive	ankle	basket
anger	arrogant	aroused	ambition	appliance	bathroom
angry	avalanche	astonished	applause	avenue	bench
annoy	broken	athletics	awed	bereavement	bland
assault	bullet	beautiful	bold	black	board
bankrupt	burdened	birthday	bouquet	book	bowl
betray	crime	brave	bride	cane	building
bloody	crisis	car	bright	cannon	bus
bomb	cruel	cash	child	cellar	butter
burn	crushed	casino	circus	clock	cabinet
cancer	damage	cheer	comedy	coast	chair
crash	dead	christmas	cute	concentrate	chin
crucify	deceit	confident	dancer	consoled	circle
danger	delayed	dazzle	delight	contents	column
demon	deserter	desire	diamond	context	cord
despise	despairing	dollar	dinner	custom	cork
destroy	destruction	ecstasy	dog	dark	corner
detest	disgusted	elated	famous	derelict	corridor
disaster	displeased	engaged	fascinate	detail	cow
disloyal	disturb	erotic	freedom	excuse	curtains
distressed	dreadful	excitement	friend	fall	dirt
drown	embarrassed	exercise	gold	frog	elbow
enraged	execution	festive	heaven	fur	errand
fear	flood	fireworks	honest	gender	finger
fearful	fraud	flirt	honor	glacier	foot
fire	frustrated	fun	hope	glass	golfer
guillotine	gangrene	gift	hopeful	hammer	hairpin
gun	gossip	happy	hug	hand	history
hate	grenade	heart	idea	haphazard	horse
hatred	hell	holiday	imagine	hotel	humble
horror	helpless	infatuation	impressed	industry	indifferent
hostile	hurt	intercourse	improve	insect	iron
humiliate	injury	intimate	incentive	journal	item
hurricane	insane	joke	jewel	ketchup	jelly
intruder	insult	joy	jolly	kick	kerchief

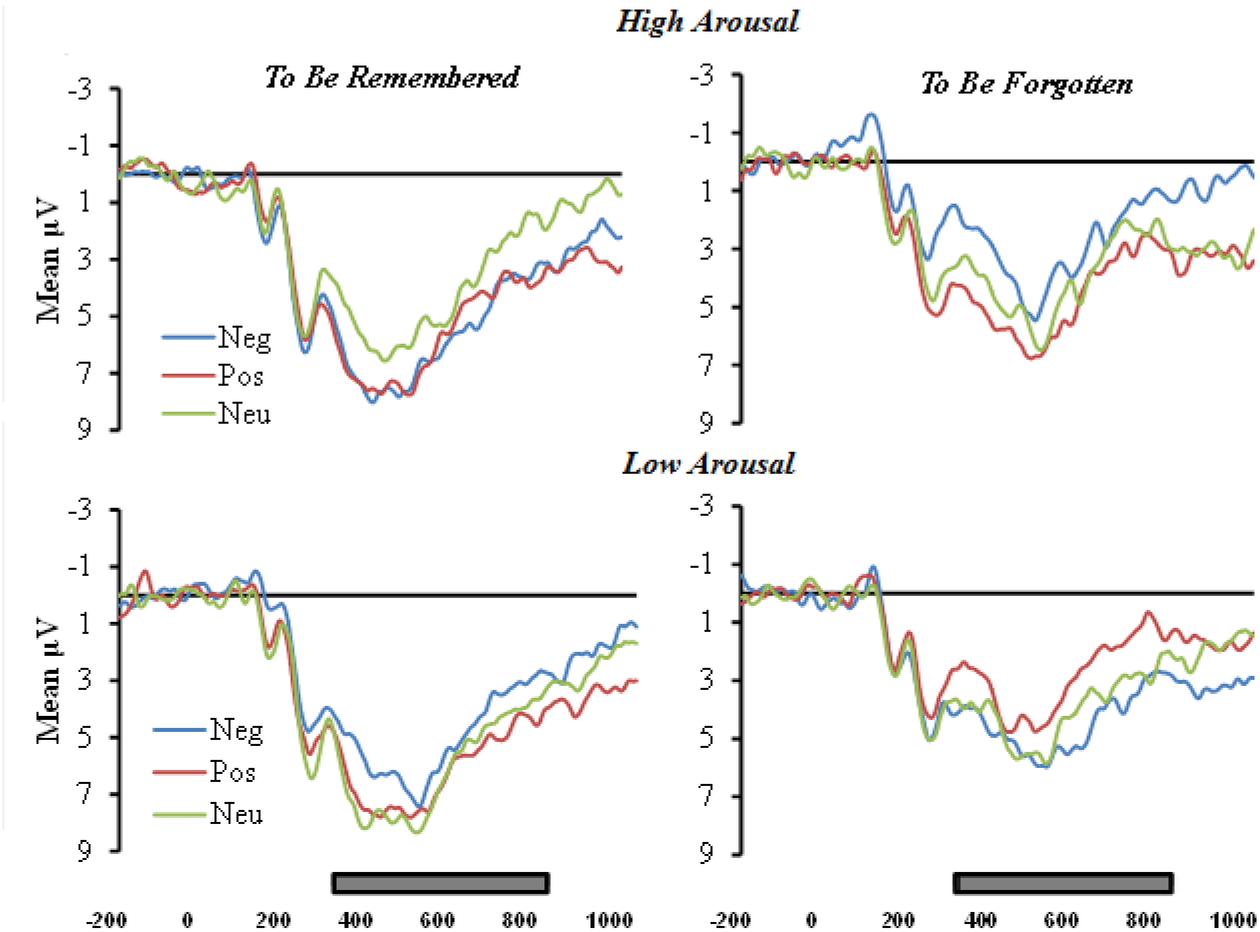
jealousy	irritate	kiss	joyful	lantern	kettle
killer	jail	laughter	justice	limber	lamb
leprosy	knife	leader	king	listless	lazy
mad	lie	love	knowledge	lump	locker
murderer	lost	lucky	learn	manner	machine
mutilate	madman	lust	liberty	market	mantel
nightmare	malice	memories	lively	material	metal
pain	mangle	millionaire	luscious	medicine	method
panic	maniac	miracle	magical	muddy	moment
pervert	massacre	mother	mail	mushroom	museum
poison	menace	nude	merry	mystic	nonchalant
pollute	needle	orgasm	mighty	name	nun
quarrel	offend	outstanding	money	narcotic	pamphlet
rabies	pest	party	mountain	nonsense	paper
rage	prison	passion	muscular	nursery	patent
rejected	punishment	plane	optimism	odd	pencil
rude	putrid	power	outdoors	passage	plain
scared	regretful	pretty	penthouse	privacy	plant
shark	robber	profit	perfection	radiator	poster
sinful	scalding	promotion	powerful	repentant	prairie
slaughter	scorn	quick	prestige	rock	quart
snake	seasick	rescue	pride	scissors	quiet
stress	selfish	reunion	puppy	sentiment	rain
suffocate	shriek	riches	radiant	shadow	reserved
surgery	sickness	rollercoaster	restaurant	sheltered	reverent
terrible	sin	romantic	scholar	ship	salad
terrified	slime	sex	silly	skeptical	seat
terrorist	smallpox	sexy	snow	skull	serious
thief	snob	skijump	spirit	stove	solemn
tornado	spanking	song	star	swamp	sphere
toxic	spider	success	strong	tamper	square
tragedy	starving	sunlight	sugar	tank	stagnant
trauma	suicide	surprised	thoughtful	teacher	statue
trouble	toothache	talent	treat	theory	stomach
tumor	traitor	terrific	triumph	tool	street
ulcer	troubled	thrill	trophy	truck	subdued
unfaithful	ugly	travel	wealthy	trumpet	table
vandal	upset	treasure	wedding	vanity	taxi
venom	vomit	triumphant	wink	village	umbrella
victim	wasp	valentine	wit	whistle	unit
violent	whore	victory	youth	wine	violin
war	wounds	win	zest	yellow	windmill

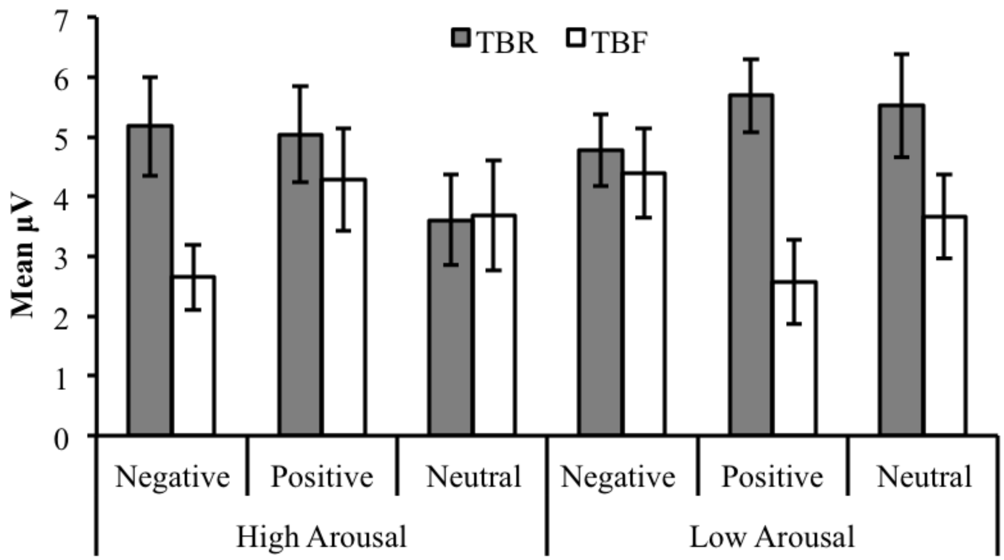


TBR
TBF
Proportion items recognized as old
1
0.8
0.6
0.4
0.2
0
Negative
Positive
Neutral
Negative
Positive
Neutral
High Arousal
Low Arousal

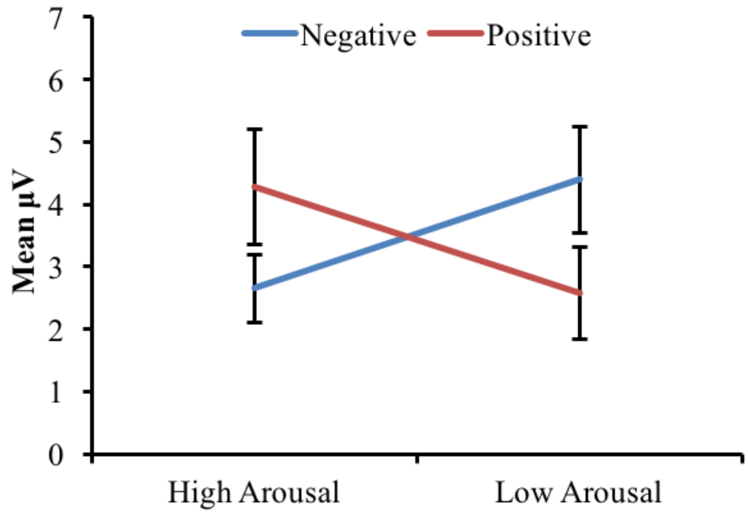

Mean Amplitude (μV)
-2
-1
0
1
2
3
4
5
Neg
Pos
Neu
-200
0
200
400
600
800
1000


-3
-2
-1
0
1
2
3
4
5
Mean µV
TBR
TBF
-200
0
200
400
600
800
1000


High Arousal
To Be Remembered
To Be Forgotten
Mean µV
-3
-1
1
3
5
7
9
Neg
Pos
Neu
Low Arousal
-200
0
200
400
600
800
1000



TBR
TBF
Mean µV
0
1
2
3
4
5
6
7
Negative
Positive
Neutral
Negative
Positive
Neutral
High Arousal
Low Arousal


Negative
Positive
Mean µV
7
6
5
4
3
2
1
0
High Arousal
Low Arousal