

ERP and behavioural measures of cognitive effort associated to forget negative and neutral words

Paula Alfonso, Julio Menor*

Department of Psychology, University of Oviedo, Oviedo, Spain

ARTICLE INFO

Keywords

ERPs
Visual detection task
Memory
Emotional content
Directed forgetting

ABSTRACT

The cognitive effort associated with remembering (R) vs forgetting (F) neutral and negative words was analyzed through a visual detection task integrated in an item-method directed forgetting task. Thirty-three younger adults participated in the experiment while their electrophysiological activity was registered in the study phase. The results shown: (1) negative words evoked more positive ERPs than neutral words on frontal regions, suggesting a preferential processing of negative words. (2) F-cues evoked more positive ERPs than R-cues did for neutral rather than negative words between 500 and 900 ms. This effect could reflect the difficulty in implementing inhibitory mechanisms on negative words. (3) At visual detection task, RTs for post-F probes were longer than for post-R probes. In 350–550 ms time window, ERPs were more positive for post-F probes than post-R probes in over right frontal regions and left medial parietal regions. Additionally, larger P2 were evoked by post-F negative probes than by post-R negative and post-F neutral ones. (4) In recognition test, participants recognized more negative TBF words than neutral ones. The ERP and behavioral results indicate that forgetting is more difficult than remembering, especially when words have a negative content, which implies a greater recruitment of parietal and frontal regions.

1. Introduction

Forgetting is usually viewed as a failure of memory; however, in certain circumstances, discarded unnecessary information is required for our memory system to operate efficiently. This would allow a greater memory for important aims (Bjork, 1989). To understand the nature of intentional forgetting some studies use the directed forgetting (DF) paradigm (MacLeod, 1998). Two methods are usually used to explore this ability. In the item-method, each stimulus is forward for remember (R) or forget (F) instruction. In the list-method, the instruction of memory (R, F) appears after presenting a set of items. In both methods, results showed better recall of to-be-remembered (TBR) than to-be-forgotten (TBF) items. This difference is known as the directed forgetting effect (Johnson, 1994; MacLeod, 1998). In the item-method, DF has generally been found in both free recall and recognition. However, in the list-method DF has only been observed in free recall. Furthermore, DF was observed across different materials including verbal stimuli (Bailey & Chapman, 2012; Brandt, Nielsen, & Holmes, 2013; Paz-Caballero & Menor, 1999), pictures (Hauswald, Schulz, Iordanov, & Kissler, 2011; Nowicka, Marchewka, Jednorog, Tacikowski, & Brechmann, 2011; Yang et al., 2012), autobio-

graphical events (Barnier et al., 2007; Joslyn & Oakes, 2005) and phone numbers (Gottlob, Golding, & Hauselt, 2006).

The results obtained with the item-method have been interpreted from two complementary views: the hypothesis of selective rehearsal and the hypothesis of attentional inhibition. In selective rehearsal, studies propose that DF is due at the rehearsal of TBR items (Bjork, 1972; Basden, Basden, & Gargano, 1993). According to this hypothesis, the item is maintained in short-term memory until memory instruction appears. If the instruction is to remember, then the item is deeply processed. However, when the instruction is to forget, the rehearsal of the item is stopped and the item passively decays from memory (MacLeod, 1998). Nevertheless, other studies suggest that attentional inhibition of TBF items during encoding is important in the DF effect (Zacks, Radvansky, & Hasher, 1996; Paz-Caballero, Menor, & Jimenez, 2004; Gallant & Dyson, 2016). That is, the instruction to forget activates inhibitory processes that hinder the encoding and rehearsal of TBF items, thereby enhancing the rehearsal of TBR items. Fawcett and Taylor (2008) identified both selective rehearsal, with its passive view of forgetting in which TBF items decay in absence of rehearsal, and attentional inhibition, with its active view in which TBF items are actively suppressed in working memory. In sum, behavioral results indicate that in DF, both selective rehearsal of R-items and in-

* Corresponding author at: Department of Psychology, University of Oviedo, Plaza Feijóo, s/n, 33003 Oviedo, Asturias, Spain.
E-mail address: jmenor@uniovi.es (J. Menor)

hibitory control processes of F-items are crucial (Basden, Basden, & Gargano, 1993; Fawcett & Taylor, 2008, 2010).

The brain correlates of item-method directed forgetting have been mainly explored with fMRI and event-related potentials (ERPs) techniques. The fMRI studies indicate that TBR trials were associated with the activation of a left-lateralized network of prefrontal cortex and medial temporal lobe, whereas TBF trials were associated with the activation of a right-lateralized network involving the frontal gyrus and inferior parietal cortex (Rizio & Dennis, 2013; Wylie, Foxe, & Taylor, 2008). The electrophysiological activity (ERPs) underlying DF, related to the processing of F and R instructions, has also been analyzed. Where the R-cue has been examined, the results have shown higher positivity over centro-parietal sites (P3 component) at around 300–400 ms (Bailey & Chapman, 2012; Brandt et al., 2013; Gallant & Dyson, 2016; Paz-Caballero et al., 2004). These findings support the interpretation that a selective rehearsal of R-items occurs. However, less conclusive results have been found for the processing of F instructions. Some studies have found more negativity (or less positivity) associated with F-cues over frontal sites in the range of the N2 component (Gao et al., 2016; Patrick, Kiang, & Christensen, 2015; Yang et al., 2012). This component is associated with inhibitory and suppression processes on tasks that need response inhibition (Folstein & Van Petten, 2008). So, the greater negativity associated with F-cues has been interpreted as the ERP correlate of the inhibition of F-items. However, in other studies, a *greater positivity* associated with F-cues on the frontal sites has also been interpreted as the action of inhibitory mechanisms. For example, in the study of Paz-Caballero et al. (2004) this positivity was observed in the period of 100–300 ms while other authors detected it at a later stage. Gallant and Dyson (2016) found that F-cues evoked more positivity than R-cues between 350 and 850 ms. Similarly, Hauswald et al. (2011) found more positive ERPs associated with F-cues between 450 and 660 ms using pictures. It may be that this divergence in polarity and time periods is due to reflecting different cognitive and executive functions of the frontal cortex (Fuster, 2013). Recent studies have suggested that the higher, late positivity associated with F-cues could reflect the retrieval of the original item as a way of checking what was to be actively forgotten (Schindler & Kissler, 2018). In addition to these effects on ERPs, other components relating to the memory instructions have also been analyzed in the DF paradigm. Using words, Xie, Jiang, and Zhang (2018) found that F-cues elicited a great positivity between 100 and 150 ms over posterior areas (P1 component) in individuals with depressive tendencies. They argued that the P1 results indicate that the F-cues attracted earlier attention. Another analyzed component is P2. Gao et al. (2016) and Schindler and Kissler (2018) found that R-cues elicited more positivity than F-cues over anterior sites. This effect has been interpreted as the reflection of greater attention allocation to R-cues (Schindler & Kissler, 2018) or withdrawal of attention to F-cues (Gao et al., 2016).

One question of great interest is whether information with emotional content is more resistant to forgetting than information with neutral content. Negative stimuli are preferentially processed because of their importance to our survival (Lazarus, 1991; LeDoux, 1996). This preferential processing is associated with an increase in attention and enhanced emotional memory encoding (Hamann, 2001). This effect is known as negativity bias and refers to the tendency to prioritize negative information (Grühn, Smith, & Baltes, 2005). Because of the specialized processing of negative stimuli, it is possible that negative information is expected to be more resistant to forgetting than neutral information. However, the behavioral results are not conclusive. While some studies using pictorial stimuli have reported a reduced or no DF effect for negative stimuli (Hauswald et al., 2011), others have reported a normal DF effect for both types of negative and neutral pictures (Yang et al., 2012). When verbal stimuli have been used, Gal-

lant and Dyson (2016) found a reduced DF effect for negative compared with neutral words. However, Brandt et al. (2013) found a DF effect for negative and neutral words, with the former showing the greater effect. Therefore, there is no conclusive evidence on ability to intentionally forget negative information.

In relation to the ERP correlates of emotional information, several studies have observed a late positive potential on posterior areas elicited by negative pictures rather than neutral ones (Hauswald et al., 2011; Yang et al., 2012). However, the results are less clear when verbal stimuli have been used. Whereas some studies found larger ERPs elicited by negative stimuli at centro-parietal sites from 400 ms onward (Bailey & Chapman, 2012; Gallant & Dyson, 2016), others found greater positivity elicited by negative words than by neutral ones at anterior sites (Brandt et al., 2013). Overall, these results have been interpreted as the electrophysiological correlate of negativity bias. Thus, forgetting negative emotional items is more difficult because such items automatically invite specialized processing before any memory instruction is given. One result that supports this hypothesis was reported by Yang et al. (2012) who found greater negativity evoked by F-cues in the N2 component for negative than for neutral pictures at anterior areas. The authors interpreted this result as forgetting negative material requiring greater inhibitory effort. Xie et al. (2018) found that participants with depressive tendencies showed larger negative-going N2 amplitude for F-cues with negative words than for those with neutral words. In an fMRI study, Yang, Lei, and Anderson (2015) found that directed forgetting of neutral words elicited more activations in the right frontal area compared to incidental forgetting. However, this result was not observed in negative words. The authors interpreted it as being due to an attentional bias in the processing of negative words that interferes with the deployment of inhibitory control (Yang et al., 2015). However, using words, Patrick et al. (2015) and Gallant and Dyson (2016) found no differences in the ERPs associated with F-cues between negative and neutral words.

Therefore, the current evidence is unclear as to whether forgetting negative emotional stimuli is more difficult and requires greater inhibitory effort than does forgetting neutral ones. A complementary way to analyze this issue is to evaluate the demand or cognitive effort, as well as its electrophysiological correlate associated with R vs F instructions. Fawcett and Taylor (2008) designed a procedure which consists of introducing a visual detection task after the presentation of R vs F instructions. The aim was to measure the cognitive effort associated with both instructions. These authors found longer reaction times (RTs) at the visual detection task when it was preceded by the F-cue (post-F probes) than when it was preceded by the R-cue (post-R probes). They interpreted these results as forgetting is more demanding than remembering. To date, we have only found one study that analyzes the ERP correlates of cognitive demand associated with R vs F instruction. Cheng, Liu, Lee, Hung, and Tzeng (2012) combined a semantic priming task into the item-method directed forgetting. Participants had to perform a lexical decision task on target, presented after R vs F instruction. The ERP deflection of P2 elicited by the targets was used to index the amount of cognitive resources occupied by the TBR and TBF items. The authors found lesser P2 amplitudes for targets after F instructions than targets after R instructions. They interpreted these results as F instructions were more demanding and consumed more resources than R instructions. Therefore, there are less available resources for lexical decision tasks on targets preceding F instructions. Surprisingly, RTs to post-F targets were shorter than RTs to post-R targets. If there are less available resources after F instructions than R instructions then longer RTs after post-F targets would be expected (Fawcett & Taylor, 2008). However, these discrepancies between the behavioral results of Cheng et al. (2012) and Fawcett and Taylor (2008) could be due to procedural differences. Therefore, in the pre-

sent study, we have combined RT and ERP measures in a visual detection task embedded in the DF procedure like the original paradigm elaborated by Fawcett and Taylor (2008). As ERPs provide a continuous measure of processing and allocation of attention to stimuli (Luck, Woodman, & Vogel, 2000), they can be very useful for analyzing the time course of attention allocation to a visual detection task after processing R vs F instructions.

The main aim of this study was to analyze cognitive effort in a visual detection task and the electrophysiological correlates associated with remembering vs forgetting neutral and negative words. Additionally, the ERPs associated with the processing of the instruction itself, R vs F, were recorded. For this purpose, the following hypotheses are proposed: First, if forgetting is more demanding than remembering, then we should find longer post-F than post-R RTs on visual detection probes, replicating the results obtained by Fawcett and Taylor (2008, 2010). Further, this should also be reflected in the ERPs associated with probe detection following the R- and F-cues. A P2 wave elicited by the probe was used to index the cognitive resources demanded by R and F instructions (Cheng et al., 2012). If F-cues are more demanding than R-cues, then there would be less available resources to post-F probes detection than to post-R probes detection. Thus, we expected smaller P2 for post-F probes than post-R probes. Second, if negative words are more resistant to forgetting, then post-F probe RTs should be longer for negative words than for neutral ones. We would also expect the ERPs associated with probe detection to be affected by emotion in its interaction with instruction; P2 component should be smaller to post-F negative probes than post-F neutral ones. Third, in relation to the processing of the R vs F instruction, and taking into account the results of previous studies (Bailey & Chapman, 2012; Brandt et al., 2013; Gao et al., 2016; Schindler & Kissler, 2018), we should find greater ERPs associated with R-cues over anterior sites between 200 and 300 ms (P2 component) and posterior sites between 300 and 500 ms (P3 component). This would indicate greater attention allocation to R-cues and the elaborative rehearsal of TBR items. With regard to the ERPs evoked by F-cues, previous research suggests that two effects, both interpreted in the literature as the action of inhibitory mechanisms, might be found: on the one hand greater negativity associated with F-cues around 200–300 ms (Patrick et al., 2015), and on the other hand greater positivity associated with F-cues from 350 ms onward (e.g., Gallant & Dyson, 2016), both over anterior areas. In addition, if negative content does attract more attention than neutral content, this should influence the ERPs associated with the processing of instruction R vs F so that we would expect to find an instruction-by-emotion interaction. Finally, in relation to word-processing, we expected to find more positive ERPs associated with negative than with neutral words, due to the preferential processing of negative stimuli. On a subsequent performance recognition test, we expected to replicate a global DF effect. Moreover, if negative words have an enhanced memory due to their preferential processing, then it would be more difficult to forget negative than neutral words. This will be reflected in the DF effect, so we expected to find a reduced DF effect for negative words.

2. Materials and method

2.1. Participants

Thirty-three students between 21 and 30 years of age ($M = 22.2$, $SD = 2.7$), 27 female and 6 male, participated in this study. All were students at the University of Oviedo, all had normal vision, and none had any history of psychiatric or neurological illness. Furthermore, none of the participants had any prior experience with this type of task. All participants gave their informed consent.

2.2. Stimuli

A set of 240 words was used (120 neutral, 120 negative). The words were selected from the Spanish adaptation of International Affective Normative English Words -ANEW- (Redondo, Fraga, & Padrón, 2007). Mean valence for neutral words was 5.28 ($SD = 0.5$) and mean arousal was 3.87 ($SD = 0.6$). For negative words mean valence was 2.24 ($SD = 0.63$) and mean arousal was 6.1 ($SD = 0.96$). Negative words differed significantly from neutral words in both valence ($t = -39.9$, $p < 0.001$, $d = 5.5$) and arousal ($t = 21.6$, $p < 0.001$, $d = 2.9$). Negative and neutral words were not matched in arousal because this dimension is intrinsically related to emotion; therefore, when we attempted to select neutral and negative words with the same level of arousal, the selection was too unnatural, as has been observed in other studies (Hauswald et al., 2011; Bailey & Chapman, 2012). There were no differences between negative and neutral words in written frequency ($t = -0.08$, $p = 0.9$), neither in number of letters ($t = 0.61$, $p = 0.54$) nor number of syllables ($t = -0.1$, $p = 0.9$) (see Table 1). The stimuli were divided into two sets with 120 words. Each set contained 60 negative and 60 neutral words. Assignment of the memory instruction (R vs F) to each word was counterbalanced. Both sets were used in the study and in the test phase and were randomly assigned to participants.

2.3. Procedure

The experiment was divided in two parts: the encoding and the recognition phase (see Fig. 1). In the encoding phase, participants were presented with 120 words: half were followed by the R-cue, the other half by the F-cue. Each trial began with the option to blink (˘) for 1000 ms. If participants needed to blink, they could do so at this point. This was followed by the presentation of a word for 2000 ms. After the word, a “forget” (OOO in Spanish) or “remember” (RRR in Spanish) instruction was displayed for 1000 ms. Participants were instructed to memorize the words followed by the R-cue and to forget those followed by the F-cue. Trials were pseudo-random—a constraint was introduced to the effect that no more than three consecutive trials with the same type of instruction could appear in the sequence. A visual probe “+” was presented 1800 ms after the disappearance of each memory instruction. We chose this interval because Fawcett and Taylor (2008) had found maximum differences between F and R memory instructions in the detection of visual probes at this time. The visual probe appeared on the screen for 500 ms. When participants saw it, they had to press the spacebar as soon as possible. The probe appeared on 80% of trials distributed proportionately throughout the different conditions; the probe did not appear in the remaining 20% in order to prevent habituation in participants. Five sets of each version of the experiment were created so that all the words would appear in both the probe and no-probe condition. The experiment began with five test trials to make sure that participants understood the experimental task. Once the test trials were done correctly, the experimental task began. Words were presented in three blocks of 40, with a small break of 10 s

Table 1

Means (\bar{x}) and standard deviations (SD) of negative and neutral words on frequency, number of letters and number of syllables.

	Negative		Neutral	
	\bar{x}	SD	\bar{x}	SD
Frequency	29.5	21.3	29.8	19.8
Number of letters	6.22	1.3	6.12	1.2
Number of syllables	2.6	0.65	2.6	0.62

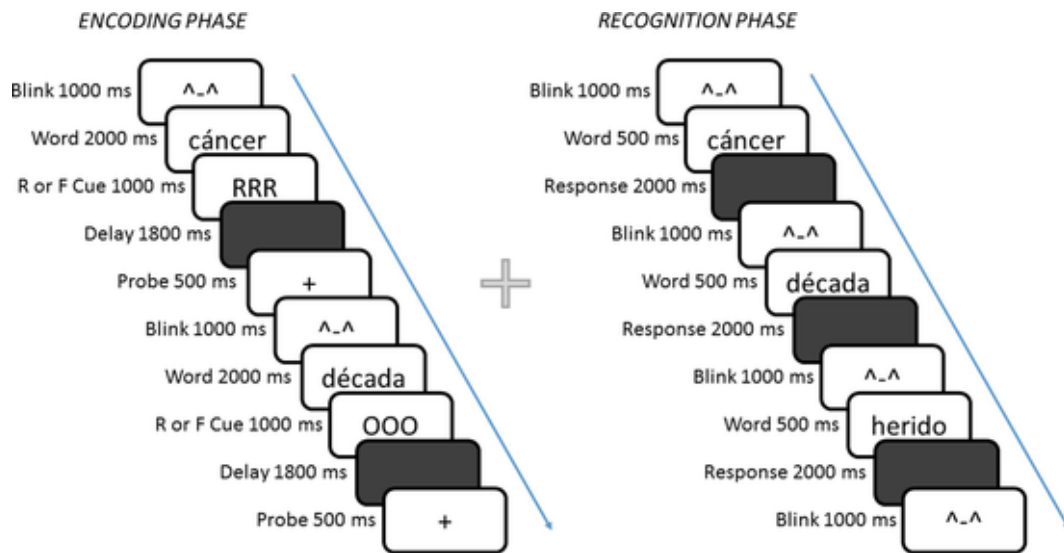


Fig. 1. Display of the procedure. Trials sequence of the encoding and recognition phases.

between each block. After the encoding phase, the participants performed a distractor task for 5 min.

In the recognition phase, words that had been presented in the first phase as well as new words were displayed for 500 ms each. Participants had to decide whether the word was new or had appeared during the first part of the experiment, regardless of the R–F instruction that had accompanied them. They were instructed to respond as quickly and accurately as possible (see Fig. 1). Participants were situated in a quiet room and tested individually. They sat in a comfortable chair at 80 cm viewing distance from the monitor. This study was approved by the Ethical Committee in Research of the University of Oviedo.

2.4. EEG recording

Brain electrical activity was recorded using an elastic cap with 39 channels. Vertical and horizontal electro-oculograms were recorded. The vertical electro-oculogram (EOG) was recorded with an electrode placed below the left eye; the horizontal electro-oculogram was recorded with an electrode placed lateral to the right eye. Additional electrodes were attached to the left and right mastoids as a reference. Impedance was kept below 5 K Ω .

EEG and EOG signals were amplified by a Medicid Neuronic poligraph of 39 channels (I.C. Neuronic S.L.) and filtered between 0.5 and 30 Hz. An additional notch filter for 50 Hz was also used. EEG and EOG were continuously digitized at 200 Hz per channel and stored on an HP Compaq dc 5800 (Intel $\text{\textcircled{R}}$ CoreTM 2 Duo CPU, 3.00 GHz). Data were segmented in epochs from 100 ms pre-stimulus onset until 1000 ms post-stimulus onset. Trials with EOG artifacts (blinks and saccades) or excessive EOG and muscular activity were excluded from further analyses. Automatic artifact detection was used for trials exceeding a threshold of 80 μ V.

2.5. Data analysis

2.5.1. Behavioral data

RTs and the percentage of correct detection responses on the visual detection task were analyzed using repeated measures ANOVAS, with emotion (negative, neutral) and instruction (R, F) as within-subject factors. In the recognition test, hit rates, false alarms, and RTs were recorded. The data were analyzed using repeated measures ANOVAS, with emotion (negative, neutral) and instruction (R, F) as within-subject factors.

2.5.2. ERP data

The EEG data was pre-processed using EP Workstation (I.C. Neuronic S.L.). For word, cues, and probe analysis, 100 ms preceding stimulus onset was used for baseline correction. Mean amplitudes were selected from F1/2, F5/6, F7/8, P1/2, P5/6, P7/8, Fz, and Pz electrodes for word, cues and probe analyses. In order to provide more spatial information, mean amplitudes were calculated based on caudality and laterality: left anterior (F7, F5), medial anterior (F1/2, Fz), right anterior (F8, F6), left posterior (P7, P5), medial posterior (P1/2, Pz) and right posterior (P8, P6).

2.5.2.1. Word presentation After visual inspection of the ERPs, and in accordance with previous studies (Brandt et al., 2013), the 300–500 ms time window was chosen for the analysis after stimulus onset. The mean valid number of ERP trials of the negative and neutral words were 52.3 (SD = 4.9, range 41–60), and 51.7 (SD = 5.4, range 40–60), respectively. No significant differences in mean valid trial numbers were found between the two types of words ($t = -0.98$, $p = 0.33$).

2.5.2.2. Cue presentation Visual inspection of the ERP waveforms revealed that the P2 component displayed a peak at around 200 ms, the N2 component at around 300 ms, and the P3 component at around 400 ms. For this reason, we chose a 200–250 ms time window for analysis of the P2 component, a 250–300 ms time window for analysis of the N2 component, and a 400–500 ms time window for analysis of the P3 component. In addition, cue-related differences were also observed between 100–200, 500–700, and 700–900 ms time windows, as a result of which these periods were also analyzed. The mean valid ERP trials of the F-cues following neutral words were 24.9 (SD = 4.49, range 17–30), for the F-cues following negative words were 24.7 (SD = 3.9, range 19–30), for the R-cues following neutral words were 24.7 (SD = 4.6, range 17–30), for the R-cues following negative words were 25.1 (SD = 4.2, range 16–30). No significant differences in mean valid trial numbers were found as a function either of instruction [$F(1, 32) = 0.06$, $p = 0.81$, $\eta^2_p = 0.002$], or emotion [$F(1, 32) = 0.03$, $p = 0.85$, $\eta^2_p = 0.001$]; nor did these two factors interact [$F(1, 32) = 0.67$, $p = 0.42$, $\eta^2_p = 0.02$].

2.5.2.3. Probe Detection Two time-window periods were chosen for the analysis following Cheng et al. (2012) and after visual inspection of the ERP waveforms: 100–350 ms and 350–550 ms after stimulus onset. The mean valid number of ERP trials of the post-F probes following neutral words was 19.1 (SD = 2.9, range 14–24), of the post-F probes following negative words 19.1 (SD = 3.2, range 14–24), of the post-R probes following neutral

words 18.8 (SD = 2.6, range 14–24), and of the post-R probes following negative words 19.3 (SD = 2.7, range 14–24). No significant differences in mean valid trial numbers were found as a function either of instruction [$F(1, 29) = 0.01, p = 0.91, \eta_p^2 = 0.000$], or emotion [$F(1, 29) = 0.84, p = 0.37, \eta_p^2 = 0.028$]; nor did these two factors interact [$F(1, 29) = 0.44, p = 0.51, \eta_p^2 = 0.015$]. Pearson correlation analyses were performed to better understand the functional significance of ERP effects and subsequent memory performance. To this end, mean ERP amplitudes were correlated with recognition rates: (i) frontal ERPs elicited by negative words were correlated with recognition of negative items in the 300–500 ms period; (ii) posterior ERPs elicited by R-cues were correlated with recognition of TBR items in the 400–500 ms period; (iii) frontal ERPs elicited by F-cues were correlated with recognition of TBF items in the 500–700 ms period. Statistical data were adjusted according to the Greenhouse-Geisser correction if necessary. Bonferroni-corrected method was used to adjust pairwise comparisons of interactions. The IBM SPSS 24 was used for all data analyses.

3. Results

3.1. Behavioural results

3.1.1. Visual detection task

For the analysis were considered responses executed between 100 and 1500 ms after its onset. All other responses were considered errors. The percentage of correct detection responses was 98.8% (SD = 0.01). This did not differ as a function either of instruction [$F(1, 29) = 0.2, p = 0.65, \eta_p^2 = 0.007$], or emotion [$F(1, 29) = 0.21, p = 0.7, \eta_p^2 = 0.007$]; nor did these two factors interact [$F(1, 29) = 0.02, p = 0.9, \eta_p^2 = 0.001$]. The percentage of false alarms was 0.99% (SD = 0.07). Mean probe RTs for correct trials were analyzed using a 2 (emotion: neutral, negative) \times 2 (instruction: R, F) repeated-measures ANOVA. A main effect of instruction was observed [$F(1, 32) = 5.25, p < 0.005, \eta_p^2 = 0.14$], revealing that probe RTs were significantly longer following F than following R instructions. No effects of emotion or interaction with instruction were found (see Table 2).

3.1.2. Recognition task

The accuracy and reaction times results are shown in Table 3. Hit rates for TBR and TBF words were entered into a 2 (emotion: neutral, negative) \times 2 (instruction: R, F) repeated-measures ANOVA. The analysis revealed a significant main effect of instruction [$F(1, 32) = 104.31, p \leq 0.001, \eta_p^2 = 0.76$], indicating that hits were higher for TBR than for TBF words. A significant effect of emotion [$F(1, 32) = 13.93, p = 0.001, \eta_p^2 = 0.30$] was also found, whereby the hit rate for negative words was greater than that for neutral words. Also, a significant interaction between instruction and emotion was found [$F(1, 32) = 9.46, p < 0.005, \eta_p^2 = 0.23$]. A paired t -test showed the higher hit rate for TBF negative words than for TBF neutral words, $t(32) = -4.45, p \leq 0.001, d = 0.74$. No differences were found between TBR negative and TBR neutral words, $t(32) = -1.27, p = 0.21$. Furthermore, the directed forgetting effect (TBR minus TBF words) was smaller in negative words (0.19) than in neutral ones (0.27), $t(32) = 3.07, p = 0.004, d = 0.5$.

Table 2

Mean reaction time measures of correct detection responses at visual detection task in the encoding phase. Note: Standard deviations in parentheses.

VISUAL DETECTION TASK		
	TBR	TBF
<i>Reaction Times</i>		
Negative	589 (113)	611 (122)
Neutral	583 (117)	604 (121)

Table 3

Top of the table: Mean proportion of TBR and TBF words recognized as old, as well as false alarms. Bottom of the table: Mean reaction times measures for correct responses to TBR and TBF words in the recognition test. Note: Standard deviations in parentheses.

RECOGNITION TASK				
	TBR	TBF	OLD	F.A.
<i>Accuracy</i>				
Negative	0.76 (0.14)	0.57 (0.14)	0.66 (0.12)	0.28 (0.13)
Neutral	0.73 (0.15)	0.46 (0.14)	0.59 (0.12)	0.19 (0.14)
<i>Reaction Times</i>				
Negative	873 (121)	903 (140)		
Neutral	857 (98)	906 (137)		

Regarding overall performance on the recognition test, old (TBR and TBF words) and new words were considered. More false alarms occurred for negative than for neutral words $t(32) = 5.05, p \leq 0.001, d = 0.88$. To obtain an overall measure of recognition sensitivity and bias, d' and C criterion values were calculated for each emotion category (Macmillan & Creelman, 1991). A paired sample t -test revealed higher discrimination for neutral ($M = 1.28; SD = 0.62$) than for negative ($M = 1.09; SD = 0.42$) words $t(32) = 2.89, p = 0.007, d = 0.48$. When recognition bias was calculated, a paired sample t -test revealed a more conservative response bias for neutral ($M = 0.10; SD = 0.32$) than for negative ($M = 0.38; SD = 0.35$) words $t(32) = -5.21, p \leq 0.001, d = 0.9$.

Another 2 (emotion: neutral, negative) \times 2 (instruction: R, F) repeated measures ANOVA was performed on the RTs for correct responses. This revealed a main effect of instruction [$F(1, 32) = 11.04, p < 0.005, \eta_p^2 = 0.26$], whereby RTs on the TBF items were longer than those on the TBR items. There was no other significant main effect or interaction.

3.2. Electrophysiological results.

3.2.1. ERPs evoked by words

Repeated measures ANOVAs with emotion (neutral, negative), caudality (anterior, posterior) and laterality (left, medial, right) as within-subject factors were performed on mean amplitudes. The effects of caudality and laterality are only reported in interaction with the emotion factor. There was a significant interaction of emotion \times caudality [$F(1, 32) = 9.23, p = 0.005, \eta_p^2 = 0.22$]. On the one hand, analyses of simple effects showed that more positive ERPs were evoked for negative than for neutral words in anterior regions ($p = 0.02$). On the other hand, when the stimuli were analyzed according to caudality, more positive ERPs were evoked for negative words in frontal than in posterior regions ($p = 0.02$) (see Figs. 2 and 3).

3.2.2. ERPs evoked by cues

Repeated measures ANOVAs with emotion (neutral, negative), instruction (R, F), caudality (anterior, posterior) and laterality (left, medial, right) as within-subject factors were performed on mean amplitudes. The effects of caudality and laterality are only reported in interaction with the other two factors.

In the 100–200 ms time window, there was a significant instruction \times caudality interaction [$F(1, 32) = 22.1, p \leq 0.001, \eta_p^2 = 0.41$; Fig. 4]. Analyses of simple effects showed marginal differences, with more positive ERPs being evoked by R- than by F-cues over anterior sites ($p = 0.06$); however, more positive ERPs were evoked by F- than R-cues over posterior sites ($p = 0.02$).

In the 200–250 ms time window, there was a main effect of instruction [$F(1, 32) = 9.2, p = 0.005, \eta_p^2 = 0.22$; Fig. 4], as more positive ERPs were elicited by R than F cues. Moreover, a significant interaction

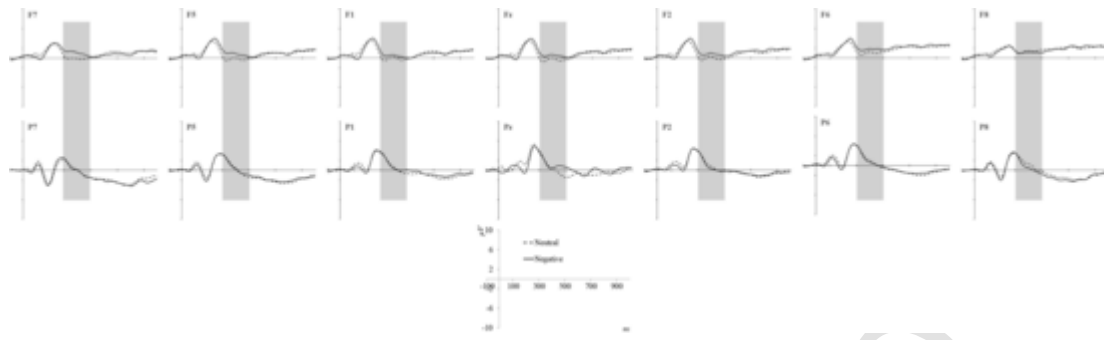


Fig. 2. Grand average ERPs elicited by neutral and negative words. The box depicts the significant effect in the 300–500 ms time window.

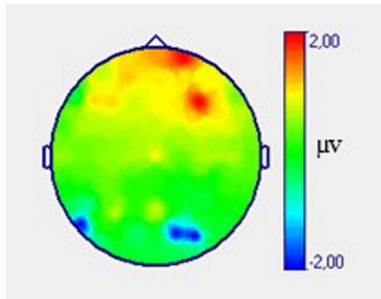


Fig. 3. Topographic map of the differences between negative and neutral words between 300 and 500 ms.

of instruction \times caudality was found [$F(1, 32) = 24.7, p \leq 0.001, \eta^2_p = 0.44$; Figs. 4 and 5]. Analyses of simple effects showed that more positive ERPs were evoked by R than by F-cues over anterior sites ($p \leq 0.001$). However, no significant differences were found between R- and F-cues over posterior sites ($p = 0.87$). In addition, a significant interaction instruction \times laterality was found [$F(1.57, 50.17) = 6.8, p = 0.002, \eta^2_p = 0.18$; Figs. 4 and 5]. Analyses of simple effects showed that more positive ERPs were evoked by R- than by F-cues over medial ($p = 0.001$) and right sites ($p = 0.001$).

In the 250–300 ms time window, there was a main effect of instruction [$F(1, 32) = 17.73, p \leq 0.001, \eta^2_p = 0.36$; Fig. 4], with more positive ERPs being evoked by R- than by F-cues. A significant instruction \times laterality interaction was also obtained [$F(1.98, 63.59) = 5.61, p = 0.006, \eta^2_p = 0.15$]. However, analyses of simple effects showed

that more positive ERPs were evoked by R- than by F-cues over left, medial, and right sites (all $p_s \leq 0.004$). When the instruction were analysed according to laterality, more positive ERPs were evoked for R-cues in left than in medial sites ($p = 0.002$).

In the 400–500 ms period, a instruction \times caudality \times laterality interaction was obtained [$F(1.97, 62.95) = 4.7, p = 0.013, \eta^2_p = 0.13$; Figs. 4 and 6]. Analyses of simple effects showed that R-cues evoked more positive ERPs than F-cues over medial posterior sites ($p = 0.04$). Although the instruction \times emotion \times caudality \times laterality interaction did not show significant effects [$F(1.55, 49.80) = 1.94, p = 0.15, \eta^2_p = 0.06$], exploratory analyses of simple effects showed there was a clear tendency whereby R-cues evoked more positive ERPs than F-cues on negative words ($p = 0.03$). Thus, the posterior sites were selected to explore effects of emotion on memory instruction. A repeated measures ANOVA with emotion (neutral, negative) and instruction (R, F) as within-subject factors was performed on mean amplitudes. There was a significant instruction \times emotion interaction [$F(1, 32) = 5.23, p = 0.03, \eta^2_p = 0.14$; see Figs. 4 and 6 (topographic maps)]. Analyses of simple effects revealed that R-cues elicited greater positivity than F-cues did for negative words ($p = 0.04$) but not for neutral ones ($p = 0.91$). Additionally, more positive ERPs were evoked by R-cues for negative than for neutral words ($p = 0.014$), however there was no differences between negative and neutral words for ERPs evoked by F-cues ($p = 0.59$).

In the 500–700 ms period, there was a significant interaction of instruction \times emotion [$F(1, 32) = 4.2, p = 0.05, \eta^2_p = 0.11$]. Analyses of simple effects showed marginal differences, as more positive ERPs were evoked by F- than by R-cues for neutral words ($p = 0.08$). How-

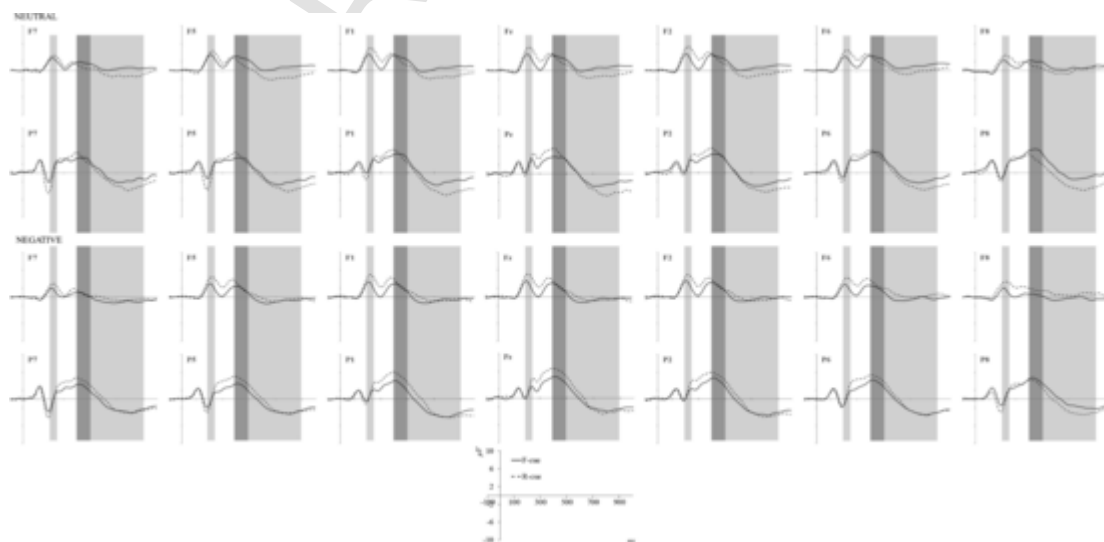


Fig. 4. Grand average ERPs elicited by F-cues and R-cues of neutral and negative words. The boxes depict the significant effects in the 200–250, 400–500 and 500–900 ms time windows.

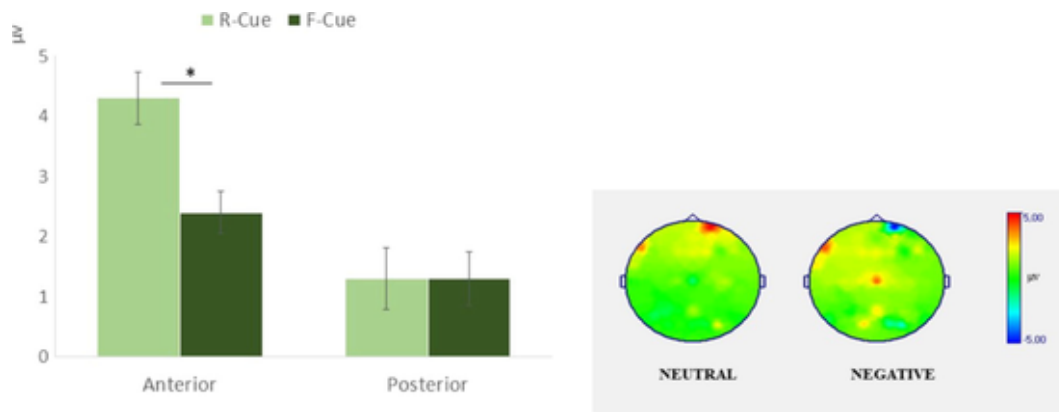


Fig. 5. On the left, mean cue-related amplitudes in the 200–250 ms time window. The bars represent the microvolts evoked by R and F cues based on caudality * $p < 0.05$. On the right, topographic maps of the differences between R and F cues in neutral and negative words between 200 and 250 ms.

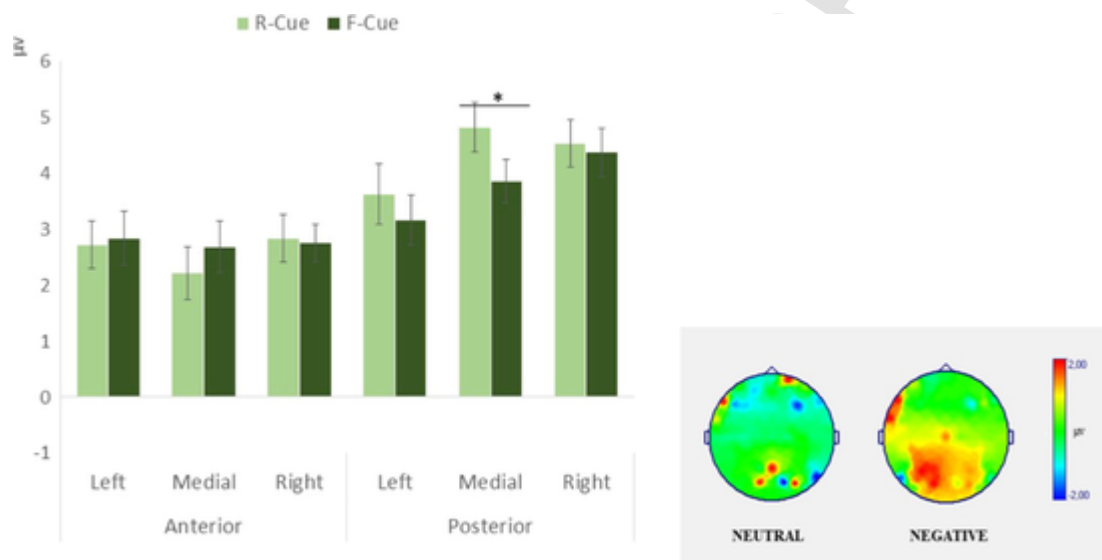


Fig. 6. On the left, mean cue-related amplitudes in the 400–500 ms time window. The bars represent the microvolts evoked by R and F cues based on caudality and laterality. * $p < 0.05$. On the right, topographic maps of the differences between R and F cues in neutral and negative words between 400 and 500 ms.

ever, no significant differences were found between R- and F-cues for negative words ($p = 0.25$), see Figs. 4 and 7). In addition, a significant interaction of instruction \times laterality was found [$F(1.40, 44.98) = 4.11, p = 0.04, \eta^2_p = 0.11$]. Although ERP mean amplitudes were larger in F-cue than in R-cue over right sites, this difference was not significant ($p = 0.14$).

In the 700–900 ms period, there was a main effect of instruction [$F(1, 32) = 7.44, p = 0.01, \eta^2_p = 0.2$], with more positive ERPs being evoked by F- than by R-cues. Moreover, there was a marginally significant interaction of instruction \times emotion [$F(1, 32) = 3.7, p = 0.06, \eta^2_p = 0.10$; see Figs. 4 and 8]. Analyses of simple effects showed that more positive ERPs were evoked by F- than by R-cues for neutral words

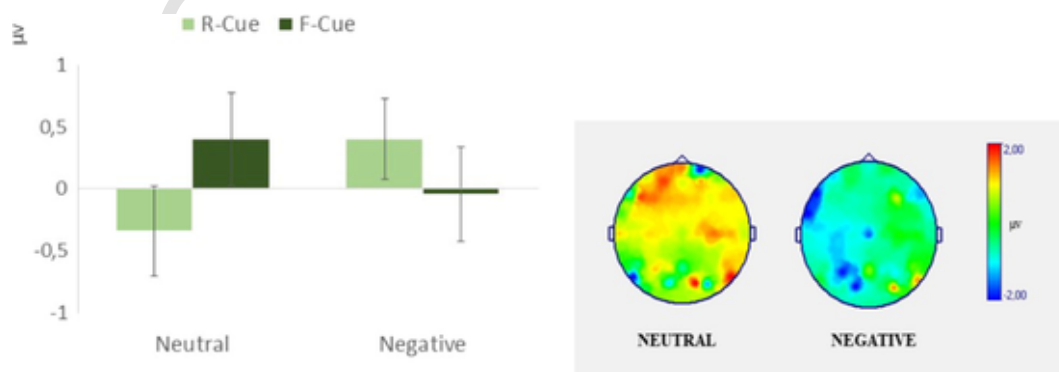


Fig. 7. On the left, mean cue-related amplitudes in the 500–700 ms time window. The bars represent the microvolts evoked by R and F cues based on emotional content of words. On the right, topographic map of the differences between R and F cues in neutral and negative words between 500 and 700 ms.

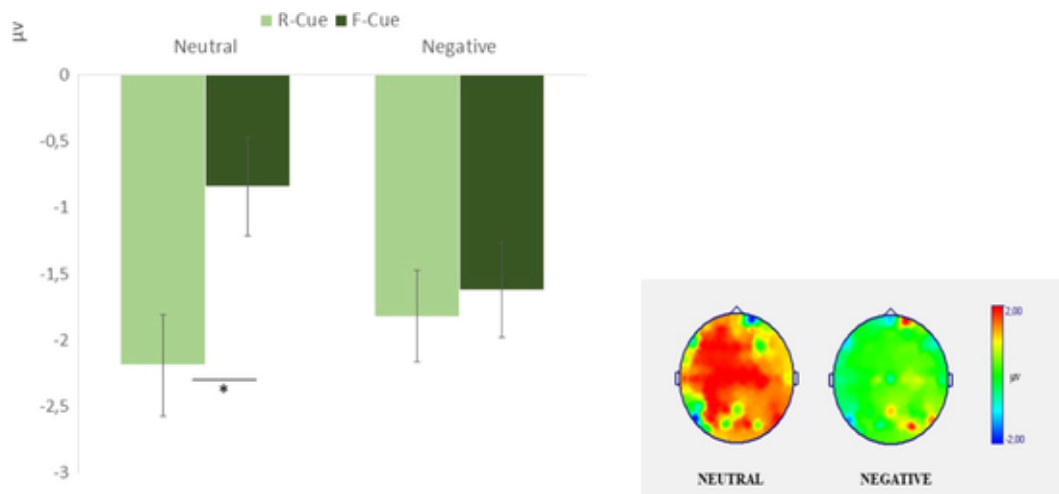


Fig. 8. On the left, mean cue-related amplitudes in the 700–900 ms time window. The bars represent the microvolts evoked by R and F cues based on emotional content of words. * $p < 0.05$. On the right topographic maps of the differences between R and F cues in neutral and negative words between 700 and 900 ms.

($p = 0.003$). However, no significant differences were found between R- and F-cues for negative words ($p = 0.61$).

3.2.3. ERPs evoked by visual detection task

Repeated measures ANOVAs with emotion (neutral, negative), instruction (R, F) caudality (anterior, posterior) and laterality (left, medial, right) as within-subject factors were performed on mean amplitudes in 150–350 ms and 350–550 ms time windows. Three participants were excluded from the analysis due to excessive noise in the electroencephalography (EEG).

In the 150–350 ms time window, there was a significant interaction of instruction \times emotion [$F(1, 29) = 4.59, p = 0.04, \eta^2_p = 0.14$; Figs. 9 and 10]. Analyses of simple effects showed marginally significant differences when the instruction factor was analysed, with more positive ERPs evoked by post-F probes than by post-R probes for negative words ($p = 0.07$). Additionally, more positive ERPs were evoked by post-F probes following negative words than those following neutral ones ($p = 0.07$).

In the 350–550 ms time window, a significant main effect of instruction was found [$F(1, 29) = 8.06, p = 0.008, \eta^2_p = 0.22$], as post-F probes elicited greater positivity than did post-R probes. Moreover,

an instruction \times caudality \times laterality interaction was found [$F(1.95, 56.55) = 3.83, p = 0.03, \eta^2_p = 0.12$]. Analyses of simple effects revealed that more positive ERPs were elicited by post-F than by post-R probes on right anterior sites ($p = 0.01$) and on left ($p = 0.008$) and medial ($p = 0.002$) posterior sites (see Figs. 9 and 11).

3.2.3.1. Correlational analyses Marginally significant correlations were found between left posterior ERP amplitudes associated with R-cues in 400–500 ms period and recognition of TBR items in neutral [$r(33) = 0.32, p = 0.07$] and negative [$r(33) = 0.31, p = 0.08$] words, in both cases two-tailed test. No significant correlations were found between right frontal ERP amplitudes in 500–700 ms associated with F-cues and recognition of neutral TBF words [$r(33) = -0.27, p = 0.13$] and negative TBF words [$r(33) = 0.26, p = 0.13$], in both cases two-tailed test. The correlation between the ERP amplitudes associated with negative words in the encoding phase and recognition performance was not significant either [$r(33) = 0.21, p = 0.24$], two-tailed test.

4. Discussion

The present study sought to examine whether forgetting words with negative emotional content is more effortful than forgetting neutral

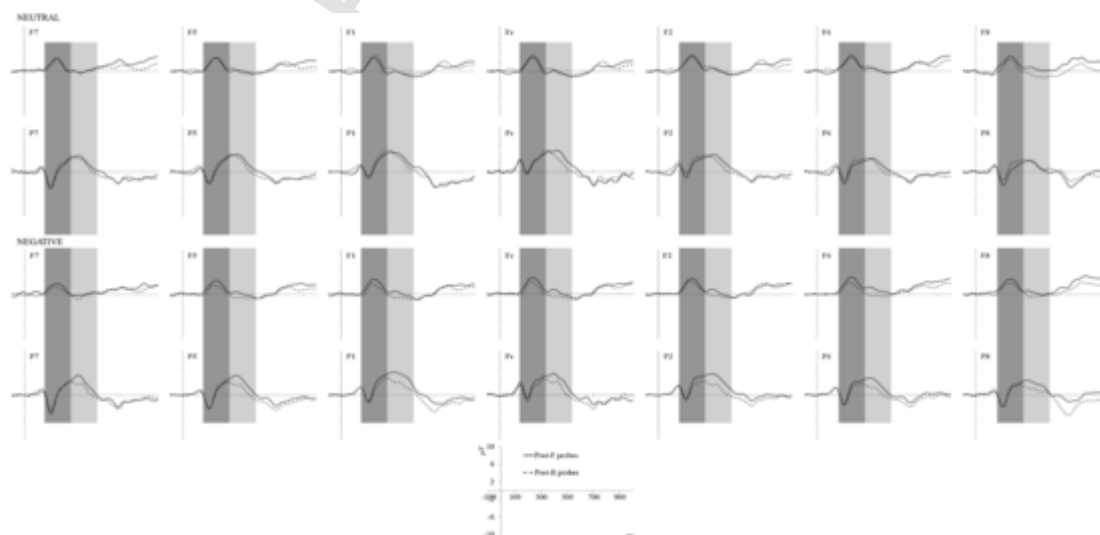


Fig. 9. Grand average ERPs elicited by Post-F probes and Post-R probes for neutral and negative words. The boxes depict the significant effects in the 150–350 and 350–550 ms time windows.

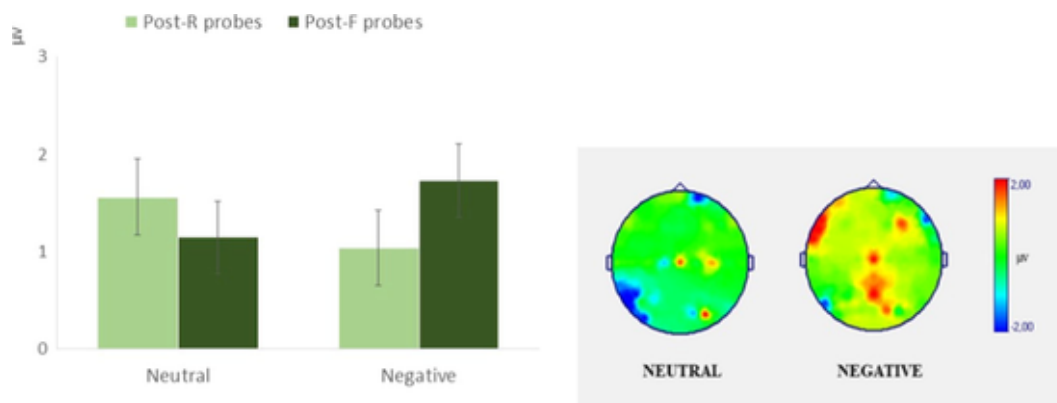


Fig. 10. On the left, mean cue-related amplitudes in the 150–350 ms time window. The bars represent the microvolts evoked by post-F and post-R probes based on emotional content of words. On the right, topographic maps of the differences between post-F and post-R probes in neutral and negative words between 150 and 350 ms.

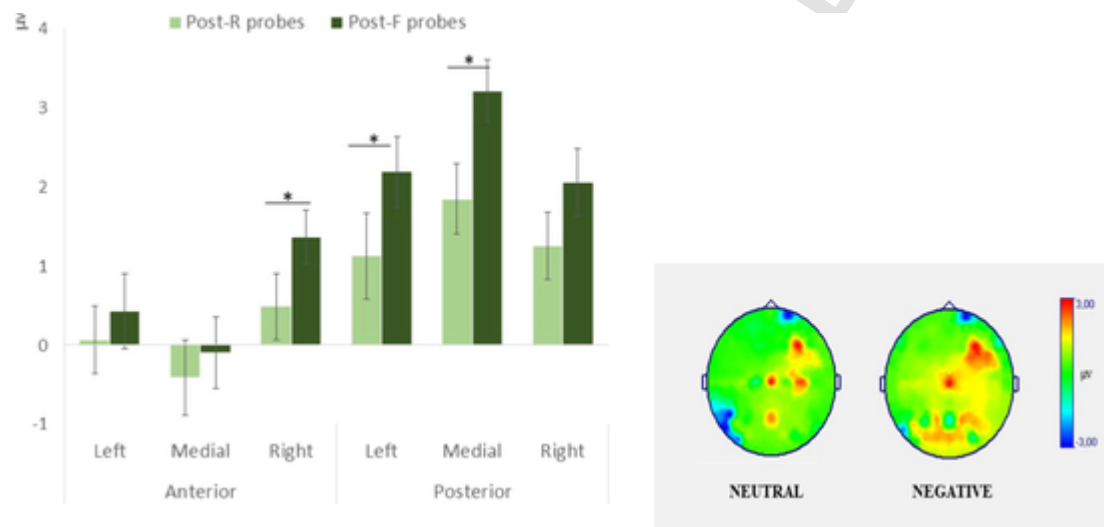


Fig. 11. On the left mean cue-related amplitudes in the 350–550 ms time window. The bars represent the microvolts evoked by post-F and post-R probes based on caudality and laterality *p < 0.05. On the right topographic maps of the differences between post-F and post-R probes in neutral and negative words between 350 and 550 ms.

ones. For this purpose, a visual detection task was performed following presentation of a memory instruction and the ERPs associated with the processing of the instructions and the detection of a visual probe were recorded.

4.1. Behavioural results

The results of the visual detection task showed longer RTs for post-F probes than for post-R probes. These results are consistent with those obtained in other investigations and suggest that forgetting information is more cognitively demanding than remembering it is (Fawcett & Taylor, 2008; Fawcett, Taylor, & Nadel, 2013). Although we expected to find an influence of emotional content, we did not find post-F visual detection probe RTs to be longer for negative words than for neutral ones. A similar result was obtained by Lee and Hsu (2013) in their study of emotional and neutral events, where they found longer RTs for post-F probes than for post-R probes but no instruction × emotion interaction. Therefore, the behavioral results obtained with the visual detection task do not support the hypothesis that negative words require more effort than neutral words in order to be forgotten. As Lee and Hsu (2013) propose, it is possible that implementing the F instruction is so demanding that it overcomes the emotional content of the previous item, eliminating its possible effect.

In the subsequent recognition test, an emotion × instruction interaction was found for hit rates, reflecting a weaker DF effect for nega-

tive words than for neutral ones. This smaller DF effect was due to better recognition of negative words in the TBF condition. These results are consistent with Bailey and Chapman (2012), Gallant and Dyson (2016) and Lee and Hsu (2013). Both Bailey and Chapman (2012) and Gallant and Dyson (2016) found that the proportion of correctly recognized TBF words was higher for negative words than neutral ones. Similarly, Lee and Hsu (2013) found a reduced DF effect for negative events in a cue-recall test, due to better recall of F-negative than of F-neutral events. Taken together, these results suggest that negative words are more resistant than neutral ones to forgetting.

The absence of the emotion-by-instruction interaction in the visual detection task and its presence in the recognition of TBR and TBF words could be due to different reasons. RTs in the visual detection task are a measurement of the cognitive demand for R and F instruction processing. However, recognition memory judgements at test are influenced both encoding and retrieval processes and by decision processes (i.e., bias) that operate on memory representations. When recognition accuracy was calculated, higher discrimination for neutral than for negative words was found. In addition, more liberal response bias was found with negative than with neutral words. Similar results have been reported by Bailey and Chapman (2012) and Patrick et al. (2015). Both of these studies also found that recognition sensitivity was significantly greater for neutral than for negative words with a more liberal criterion used for negative stimuli. Kapucu, Rotello, Ready, and Seidl (2008), in a remember-know paradigm with words

having emotional content, found a more liberal response bias for negative words. Therefore, the negative TBF words were better recognized than the neutral words, possibly because there is a tendency to recognize negative stimuli more than neutral stimuli and this gives rise to more false alarms. However, this only partially explains the results, because the response bias should also enhance the negative TBR words; however, there was no better recognition of TBR negative than of TBR neutral words. Therefore, this seems to indicate that it is a specific effect associated with TBF words. TBF negative words were recognized to a greater extent than neutral words, not only because negative words were biased causing more false alarms, but also because TBF negative words were not inhibited or were not effectively rejected in the encoding phase, which made it more accessible than neutral TBF words in the recognition task.

In relation to RTs, only an effect of instruction was found; no effects of emotion or interaction were obtained. These results are in line with previous studies (Brandt et al., 2013).

4.2. Electrophysiological results

4.2.1. Word effects

Negative words elicited greater positivity compared with neutral ones between 300 and 500 ms over anterior areas. This greater positivity is associated with the preferential processing of negative stimuli (Brandt et al., 2013). While other studies have found greater positivity associated with negative words in posterior areas (Bailey & Chapman, 2012; Gallant & Dyson, 2016; Patrick et al., 2015), our results corroborate those obtained by Brandt et al. (2013) who found more positive ERPs evoked by negative words over frontal sites between 300 and 600 ms. fMRI studies have also found larger activations in inferior frontal gyrus and superior parietal lobe in contrast with neutral words (Yang et al., 2015). These findings support the view that negative stimuli are preferentially processed and produce an increase in attention and enhanced emotional memory encoding (Hamann, 2001).

4.2.2. Cue effects

In relation to R-cues, we found the P2 component over anterior sites between 200 and 250 ms and the classical P3 component over posterior areas between 400 and 500 ms. Together, these two effects may reflect greater attentional allocation to R-cues (Gao et al., 2016; Schindler & Kissler, 2018) and the selective rehearsal of TBR items (Brandt et al., 2013; Gallant & Dyson, 2016; Hauswald et al., 2011; Patrick et al., 2015). It was also found that the effect in P2 component was lateralized in the right hemisphere since ERP differences between R and F instruction was greater with respect to the left hemisphere. Furthermore, ERP mean amplitudes of the left posterior area evoked by R instruction in P300 component were positively associated with the recognition of negative and neutral TBR words. Although these correlations were marginally significant, they are in line with other studies in which a relationship between parietal activity and recognition of TBR items has been observed (Hauswald et al., 2011). Moreover, an exploratory analysis of the effects of emotion on memory instruction in the posterior sites revealed that more positive ERPs were found for R-cue than F-cue in negative words, but not neutral ones. This result is in line with results obtained by other studies in which greater positivity, elicited by R-cues for negative words on posterior sites, was also found (Brandt et al., 2013; Patrick et al., 2015). Further, it could suggest stronger elaborative rehearsal of negative words compared with neutral ones (Brandt et al., 2013; Patrick et al., 2015), as it would be easier to rehearse TBR negative words because they receive more attention given their preferential processing.

In relation to F-cues, we found three effects distributed over different time periods. The first, more positive, ERPs were evoked by F-cues

on posterior sites between 100 and 200 ms. Some authors associate this effect with the P1 component, which "is sensitive to variations in stimulus parameters" (see Luck, 2014, p.75). This effect has also been found by Xie et al. (2018), who found greater positivity associated with F-cues between 115 and 155 ms in posterior areas. They interpreted these results as F-cues attracting earlier attention than R-cues in this time period. Our results are in line with Xie et al. (2018) but it is possible that the greater positivity evoked by F-cues could also reflect early attention based on the physical characteristics of the stimuli (Luck, 2014). The second, lower, positivity associated with F-cues was observed in the 250–300 ms time window. This result has been interpreted as reflecting the action of inhibitory mechanisms (Gao et al., 2016; Patrick et al., 2015; Schindler & Kissler, 2018; Yang et al., 2012). However, in our study this effect was not specific to anterior areas; thus, we believe that it does not necessarily reflect the action of inhibitory mechanisms but rather the continuation of the previous effect. Furthermore, F-cue did not interact with emotion, as has been observed in other studies (Xie et al., 2018; Yang et al., 2012). Finally, the third effect was found in the 700–900 ms period, widely distributed throughout the scalp, where F-cues evoked greater positivity (or less negativity) than did R-cues. This result has also been found in other studies in frontal area with an earlier latency (Gallant & Dyson, 2016; Hauswald et al., 2011; Paz-Caballero et al., 2004; Schindler & Kissler, 2018). The interpretation of this effect is unclear. Some authors have interpreted it as reflecting inhibitory processes (Gallant & Dyson, 2016; Hauswald et al., 2011; Paz-Caballero et al., 2004). However, Schindler and Kissler (2018) argue "the frontal positivity does not index successful inhibition per se, but rather control attempts or even cue-prompted retrieval of the original item" (p.10). In our study, we found no indication that this finding might reflect the retrieval of original items, because no significant correlations were found between the frontal positivity evoked by F-cues and the TBF words in the recognition test. Instead, we found marginally significant effects in the instruction \times emotion interaction in 500–900 period. F-cues evoked more positive ERPs than R-cues did for neutral words but not negative ones. This result has not been found in previous ERP studies and it could reflect the implementation of inhibitory processes on neutral words, but not on the negative ones. Gallant and Dyson (2016) and Hauswald et al. (2011) found an effect of instruction no modulated by emotion, with more positive ERPs evoked by F- than by R-cues. In addition, Hauswald et al. (2011) also found an effect of emotion whereby neutral pictures elicited more positive ERPs than did negative ones. According to the interpretation of Hauswald et al. (2011), our results may reflect the fact that neutral words are easier than negative ones to inhibit because the latter are encoded preferentially; by attracting more attention they leave fewer resources available, thereby making inhibitory mechanisms less efficient. Furthermore, a stronger DF effect for neutral rather than negative words was found in the recognition test. Yang et al. (2015) came to a similar conclusion in a fMRI study in which directed forgetting of neutral words elicited more activations in the right frontal area compared to negative words.

4.2.3. Visual detection probes effects

In relation to the ERPs for visual detection probes, we had hypothesized that the P2 component should be smaller for post-F probes than post-R ones and it should also be smaller to post-F negative probes than post-F neutral ones. Thus, a significant instruction-by-emotion interaction was obtained in the 150–350 ms period compatible with P2 component. However, the effects did not occur in the expected direction. Although simple effects were marginally significant, more positive ERPs were evoked by post-F negative probes than by post-F neutral ones. In addition, ERPs associated with post-F probes were more positive than the ERPs associated with post-R probes for negative words

only. P2 component has been related in the literature to attentional recruitment in visual detection tasks (Bourisly & Shuaib, 2018). In our study, this would indicate that post-F negative probes require more attention recruitment than post-F neutral ones do, it being more effortful to withdraw attention after an F-cue associated with negative words. Similarly, post-F negative probes would require more attention recruitment than would post-R negative probes. In the subsequent 350–550 ms period, the main effect of instruction remained, with ERPs associated with post-F probes more positive than ERPs associated with post-R probes; furthermore, this effect was more evident in the left medial parietal region and in the right frontal region. Other studies examining ERP correlates with visual detection and discrimination tasks have also found this positive potential in the same time window in posterior areas, associating it with the P3 component (Donchin & Coles, 1988; Kutas, Iragui, & Hillyard, 1994). In the context of our task, this effect could be reflecting greater resource allocation to probe detection following F-rather than R-cues. Our ERP and RT measurements in the visual detection task followed a similar pattern. More positive ERPs and longer RTs for the post-F probe than for the post-R probe were found. Given that the visual detection task indexes the relative cognitive demand associated with withdrawal of attention after the presentation of an F-cue, then the longer RTs and the larger ERP amplitudes after post-F probes than after post-R probes indicate that it is more effortful to forget than to remember. However, the greater ERPs associated with post-F negative than post-F neutral probes in 150–350 ms period were not observed on RTs. It is possible that this early ERP effect vanishes before the participant makes the behavioral response not affecting the RTs.

This study has several limitations. First, as noted above, the stimuli did not match on the dimension of arousal. Various studies have shown that the arousal dimension may be relevant to understanding the effects of emotion on the DF effect (Gallant & Yang, 2014; Gallant, Pun, & Yang, 2018; Yang et al., 2012). However, we found the selection to be too unnatural, as has been observed in other studies (Hauswald et al., 2011). Second, it would have been desirable to add an additional condition that could have served as a baseline in the visual detection task, i.e., where the visual probes appeared without instructions. However, this would have greatly increased the number of trials, making the task too long and tedious for participants. Finally, the design used in this study cannot completely rule out the influence of motor response on the ERP results observed in the visual detection task. This issue could be explored in the future experiments modifying the experimental task for controlling effects of motor response.

5. Conclusions

The results of this study indicate that negative words are processed preferentially by recruiting more attentional resources than those recruited by neutral words. This appears to reduce the resources available for the action of inhibition on the F instruction. Such reduction of resources had consequences for the subsequent visual detection task, increasing RTs on post-F probes and the evoking of more positive ERPs by post-F negative probes than by post-F neutral ones. Therefore, when we are required to forget negative information, it is more difficult to withdraw attention from these stimuli as a result of their preferential processing, resulting in the higher recognition of negative words.

Funding

This work was supported by Ministry of Education and Science (Spain). Project SEJ 2007–61596 granted to Julio Menor.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

- Bailey, K., & Chapman, P. (2012). When can we choose to forget? An ERP study into item-method directed forgetting of emotional words. *Brain and Cognition*, 78(2), 133–147. doi:10.1016/j.bandc.2011.11.004.
- Barnier, A.J., Conway, M.A., Mayoh, L., Speyer, J., Avizmil, O., & Harris, C.B. (2007). Directed forgetting of recently recalled autobiographical memories. *Journal of Experimental Psychology: General*, 136, 301–322. doi:10.1037/0096-3445.136.2.301.
- Basden, B.H., Basden, D.R., & Gargano, G.J. (1993). Directed forgetting in implicit and explicit memory tests: A comparison of methods. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 19, 603–616. doi:10.1037/0278-7393.19.3.603.
- Bjork, R.A. (1972). Theoretical implications of directed forgetting. In Melton, A.W., & Martin, E. (Eds.), *Coding processes in human memory* (pp. 217–235). Washington, DC: Winston.
- Bjork, R.A. (1989). Retrieval inhibition as an adaptive mechanism in human memory. In Roediger, H.L., & Craik, F.I.M. (Eds.), *Varieties of memory and consciousness: Essays in honour of Endel Tulving* (pp. 309–330). Hillsdale, NJ: Erlbaum.
- Bourisly, A.K., & Shuaib, A. (2018). Neurophysiological effects of aging: A P200 ERP study. *Translational Neuroscience*, 9(1), 61–66. doi:10.1515/tnci-2018-0011.
- Brandt, K.R., Nielsen, M.K., & Holmes, A. (2013). Forgetting emotional and neutral words: An ERP study. *Brain Research*, 150, 21–31. doi:10.1016/j.brainres.2013.01.019.
- Cheng, S.-K., Liu, I.C., Lee, J.R., Hung, D.L., & Tzeng, O.-J.-L. (2012). Intentional forgetting might be more effortful than remembering: An ERP study of item-method directed forgetting. *Biological Psychology*, 89, 283–292. doi:10.1016/j.biopsycho.2011.10.019.
- Donchin, E., & Coles, M.G. (1988). Is the P300 component a manifestation of context updating? *Behavioral and Brain Sciences*, 11(3), 357–427. doi:10.1017/S0140525X00058027.
- 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.
- Fawcett, J.M., & Taylor, T.L. (2010). Directed forgetting shares mechanisms with attentional withdrawal but not with stop-signal inhibition. *Memory & Cognition*, 38(6), 797–808. doi:10.3758/MC.38.6.797.
- Fawcett, J.M., Taylor, T.L., & Nadel, L. (2013). Event-method directed forgetting: Forgetting a video segment is more effortful than remembering it. *Acta Psychologica*, 144(2), 332–343. doi:10.1016/j.actpsy.2013.07.005.
- Folstein, J.R., & Van Petten, C. (2008). Influence of cognitive control and mismatch on the N2 component of the ERP: A review. *Psychophysiology*, 45, 152–170. doi:10.1111/j.1469-8986.2007.00602.x.
- Fuster, J.M. (2013). Cognitive functions of the prefrontal cortex. *Frontiers in Human Neuroscience*, 4, 11–22.
- 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: Cognitive*, 5, 1–8. doi:10.3389/fpsyg.2014.01334.
- Gallant, S.N., & Dyson, B.J. (2016). Neural modulation of directed forgetting by valence and arousal: An event-related potential study. *Brain Research*, 1648(Part A), 306–316. doi:10.1016/j.brainres.2016.08.009.
- Gallant, S.N., Pun, C., & Yang, L. (2018). Age differences in the neural correlates underlying control of emotional memory: An event-related potential study. *Brain Research*, 1697, 83–92. doi:10.1016/j.brainres.2018.06.019.
- Gao, H., Cao, B., Qi, M., Wang, J., Zhang, Q., & Li, F. (2016). Two stages of directed forgetting: Electrophysiological evidence from a short-term memory task. *Psychophysiology*, 53(6), 806–813. doi:10.1111/psyp.12628.
- Gottlob, L.R., Golding, J.M., & Hauselt, W.J. (2006). Directed forgetting of a single item. *The Journal of General Psychology*, 133(1), 67–80. doi:10.3200/GENP.133.1.67-80.
- Grühn, D., Smith, J., & Baltes, P.B. (2005). No aging bias favoring memory for positive material: Evidence from a heterogeneity-homogeneity list paradigm using emotionally toned words. *Psychology and Aging*, 20(4), 579–588. doi:10.1037/0882-7974.20.4.579.
- Hamann, S. (2001). Cognitive and neural mechanisms of emotional memory. *Trends in Cognitive Sciences*, 5(9), 394–400. doi:10.1016/S1364-6613(00)01707-1.
- Hauswald, A., Schulz, H., Iordanov, T., & Kissler, J. (2011). 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.
- Johnson, H.M. (1994). Processes of successful intentional forgetting. *Psychological Bulletin*, 116(2), 274–292. doi:10.1037/0033-2909.116.2.274.
- Joslyn, S.L., & Oakes, M.A. (2005). Directed forgetting of autobiographical events. *Memory & Cognition*, 33(4), 577–587. doi:10.3758/BF03195325.
- Kapucu, A., Rotello, C.M., Ready, R.E., & Seidl, K.N. (2008). Response bias in “remembering” emotional stimuli: A new perspective on age differences. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34(3), 703–711. doi:10.1037/0278-7393.34.3.703.
- Kutas, M., Iragui, V., & Hillyard, S.A. (1994). Effects of aging on event-related brain potentials (ERPs) in a visual detection task. *Electroencephalography and Clinical Neurophysiology*, 92(2), 126–139. doi:10.1016/0168-5597(94)90053-1.
- Lazarus, R.S. (1991). *Emotion and adaptation*. New York, NY, US: Oxford University Press.
- LeDoux, J.E. (1996). *The emotional brain: The mysterious underpinnings of emotional life*. New York: Simon & Schuster.
- Lee, Y., & Hsu, Y. (2013). How do we forget negative events? The role of attentional, cognitive, and metacognitive control. *Cognition and Emotion*, 27, 401–415. doi:10.1080/02699931.2012.713326.
- Luck, S.J. (2014). *An introduction to the event-related potential technique*. MIT Press.

- Luck, S.J., Woodman, G.F., & Vogel, E.K. (2000). Event-related potential studies of attention. *Trends in Cognitive Sciences*, 4, 432–440.
- MacLeod, C.M. (1998). Directed forgetting. In Golding, J.M., & MacLeod, C.M. (Eds.), *Intentional forgetting interdisciplinary approaches* (pp. 1–57). Mahwah, NJ: Erlbaum.
- Macmillan, N.A., & Creelman, C.D. (1991). *Detection theory: A user's guide*. Cambridge University Press.
- 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.
- 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*, 98, 612–623. doi:10.1016/j.ijpsycho.2015.01.006.
- Paz-Caballero, M.D., & Menor, J. (1999). ERP correlates of directed forgetting effects in direct and indirect memory tests. *European Journal of Cognitive Psychology*, 11(2), 239–260.
- Paz-Caballero, M.D., Menor, J., & Jimenez, J.M. (2004). Predictive validity of event-related potentials (ERPs) in relation to the directed forgetting effects. *Clinical Neurophysiology*, 115(2), 369–377. doi:10.1016/j.clinph.2003.09.011.
- Redondo, J., Fraga, I., & Padrón, I., et al. (2007). The Spanish adaptation of ANEW. *Behavior Research Methods*, 39, 600–605. doi:10.3758/BF03193031.
- Rizio, A.A., & Dennis, N.A. (2013). The neural correlates of cognitive control: Successful remembering and intentional forgetting. *Journal of Cognitive Neuroscience*, 25, 297–312. doi:10.1162/jocn_a_00310.
- Schindler, S., & Kissler, J. (2018). Too hard to forget? ERPs to remember, forget, and uninformative cues in the encoding phase of item- method directed forgetting. *Psychophysiology*, 55, e13207. doi:10.1111/psyp.13207.
- 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.
- Xie, H., Jiang, D., & Zhang, D. (2018). Individuals with depressive tendencies experience difficulty in forgetting negative material: Two mechanisms revealed by ERP data in the directed forgetting paradigm. *Scientific Reports*, 8(1), 1113. doi:10.1038/s41598-018-19570-0.
- Yang, T., Lei, X., & Anderson, M. (2015). Decreased inhibitory control of negative information in directed forgetting. *International Journal of Psychophysiology*. doi:10.1016/j.ijpsycho.2015.09.007.
- Yang, W., Liu, P., Xiao, X., Li, X., Zeng, C., & Qiu, J., et al. (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.
- Zacks, R.T., Radvansky, G., & Hasher, L. (1996). Studies of directed forgetting in older adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 22, 143–156. doi:10.1037/0278-7393.22.1.143.