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Word frequency modulates the processing of emotional words: Convergent behavioral and electrophysiological data

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ABSTRACT

The processing of high frequency (HF) words is speeded as compared to the processing of low frequency (LF) words, which is known as the word frequency effect. This effect has been suggested to occur at either a lexical access or in a decision processing stage. Previous work has shown that word frequency influenced the processing of emotional content at both neural and behavioral levels. However, the results of these studies lead to discrepant findings because some of the variables that have shown to impact the processing of affective information were not always controlled. In order to make a better characterization of frequency effects on emotional word processing, event related potentials (ERPs) and reaction times to HF and LF negative and neutral nouns were measured as participants performed a lexical decision task. Temporal and spatial component analyses were used to detect and quantify, in a reliable way, those components associated with the interaction between word frequency and emotion. LF negative nouns were recognized faster and more accurately than LF neutral nouns whereas no differences were found in the HF word comparison. Also, LF neutral words elicited reduced amplitudes in a late positive component (P450) as compared to LF negative words. These findings might be reflecting a different involvement of attentional mechanisms during the evaluation of lexical information that benefits the processing of LF negative nouns.

Research on affective neuroscience has shown that the emotional content of words modulates behavioral and electrophysiological measures in lexical decision tasks (LDTs). Participants discriminate words from nonwords faster when they have emotional content [13,17]. The processing of emotional words is associated with enhanced amplitudes of two event-related potential (ERP) components: an early posterior negativity (EPN), which index effortless initial phases of visual attention [12,27] and a late posterior positivity (LPP) that reflects the functional mobilization of attentional resources [5,27]. However, the use of different experimental manipulations, as well as the heterogeneous way of controlling linguistic variables such as word frequency, word length or word category, limits the generalization of these findings.

One lexical variable that especially affects word processing is their frequency of occurrence. Psycholinguistic research has established that high-frequency (HF) words are identified faster than low-frequency (LF) words [20]. Two hypotheses about the locus of the word frequency effects have been proposed [26]. According to the "encoding hypothesis", word frequency effects are thought to reflect the preattentive access to the lexical representation of words [28,30]. In support of this view, greater amplitudes for LF as compared to HF words have been found in early latency ERP components such as the N1 or the P1, which are associated with early lexical processing [11,30]. In contrast, the "decision hypothesis", localizes word frequency effects in decision operations that require limited capacity resources. In particular, LF words require more processing capacity for their evaluation than HF words [2,3,26]. The finding of a differential amplitude modulation by LF and HF words in late latency components, such as the N400 and/or the P300/LPP [11,26], is in agreement with this proposal. These components have been linked to controlled post-lexical and attentional processing, respectively [19,24; but see 15].

The following question arises: do word frequency effects differentially modulate the processing of emotional and neutral words? Three previous studies investigated this question. In an fMRI study, Nakic et al. [21] presented high negative, low negative and neutral words that were either HF or LF words in a LDT. Pseudowords were created by modifying one letter from the target words. No interaction between emotion and word frequency was observed in reaction times (RTs). However, they found that the processing of HF negative as compared to HF neutral words was associated with decreased activity in the inferior frontal gyrus. Kuchinke et al. [18] measured pupillary and behavioral responses to HF and LF negative, positive and neutral words in a LDT. Interactive effects were only evident in RTs. Both positive and negative LF words were discriminated faster than LF neutral words. Also, participants recognized

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Table 1
Means and standard deviations (in parenthesis) of valence (1, negative to 9, positive), arousal (1, calming to 9, arousing), word frequency (per 2 million), concreteness (1, abstract to 9, concrete) and word length (number of syllables). The results of the statistical analyses concerning each of these variables are also shown.

	Valence	Arousal	Frequency	Concreteness	Length
Negative HF words	2.09 (0.56)	7.28 (0.73)	85.84 (47.03)	6.16 (1.27)	2.86 (0.80)
Negative LF words	2.07 (0.56)	7.15 (0.59)	3.72 (2.08)	6.62 (0.91)	3.22 (0.99)
Neutral HF words	5.14 (0.21)	5.21 (0.30)	88.28 (39.35)	6.09 (1.80)	2.97 (0.84)
Neutral LF words	5.06 (0.25)	5.19 (0.48)	4.31 (2.20)	6.17 (1.53)	3.17 (0.85)
ANOVA (2×2)					
Emotion	$F_{1,35} = 1630.2^{***}$	$F_{1,35} = 533.8^{***}$	$F_{1,35} = 0.42^{\text{n.s.}}$	$F_{1,35} = 1.3^{\text{n.s.}}$	$F_{1,35} = 0.02^{\text{n.s.}}$
Frequency	$F_{1,35} = 0.6^{\text{n.s.}}$	$F_{1,35} = 0.7^{\text{n.s.}}$	$F_{1,35} = 144.7^{***}$	$F_{1,35} = 1^{\text{n.s.}}$	$F_{1,35} = 3.4^{\text{n.s.}}$
Emotion × frequency	$F_{1,35} = 0.2^{\text{n.s.}}$	$F_{1,35} = 0.4^{\text{n.s.}}$	$F_{1,35} = 0.2^{\text{n.s.}}$	$F_{1,35} = 0.6^{\text{n.s.}}$	$F_{1,35} = 0.5^{\text{n.s.}}$

HF = high frequency; LF = low frequency; n.s. = non-significant.
*** $p < 0.001$.

faster HF positive than both HF neutral and negative words. Finally, Scott et al. [28] conducted an ERP study with positive, negative and neutral HF and LF words in a LDT. They replicated the behavioral findings of Kuchinke and collaborators [18]. Interactions between word frequency and emotion were also observed at several early latency components. For LF words, neutral words elicited enhanced N1 amplitudes (that extended to the EPN) as compared to negative and positive words whereas HF negative words generated higher N1 amplitudes than both neutral and positive HF words. Also, negative HF words elicited a smaller P1 than the other conditions. The authors interpreted these results as indexing emotional influences on lexical access.

These studies reported interesting data that were divergent in some aspects. Differences in the experimental settings may account for this discrepancy: while arousal has shown to have a great impact in the processing of affective information [23], only Scott et al. [28] took into account this dimension. In contrast, these authors did not control for concreteness, which has been found to influence emotional processing [14]. Also, in Nakic et al. study [21] pseudowords differed in one letter from target words whereas there was no such a constraint in Scott et al. [28] and Kuchinke et al. [18] studies. This is important since lexical decisions are more likely to rely on semantic processing as pseudowords resemble words [4]. Finally, nouns [21], nouns and verbs [18], and nouns, verbs and adjectives [28] were presented as stimuli in these studies. The use of different word categories has some consequences. For instance, verbs differ from nouns by their very direct reference to actions and in several syntactic and semantic aspects [9]. Overall, these inconsistencies suggest that the interaction of emotion and word frequency might be a complex issue that deserves further attention.

In this study we explored word frequency effects on the processing of emotional words by recording ERPs. This measure provides enough temporal resolution to identify the stages of the processing at which this interaction might occur. Since the interaction between word frequency and emotion seems to be especially sensitive to experimental manipulations, we modified some of the parameters used in the Scott et al. [28] study to see if this affects the locus of the interaction: words with extreme arousal values were used with the purpose of maximizing emotional effects; pseudowords were created by exchanging the syllables of the experimental words for enhancing semantic processing; nouns were used as target words, so there were no stimuli belonging to different word categories. Also, a different data analysis approach was followed. In the Scott et al. study [28] component identification was based on visual inspection. In the present study components were detected through temporal (tPCA) and spatial (sPCA) principal component analysis. This procedure is 'data-driven' and identifies components by a systematic approach of the variance in the data, so the overlapping components can be separated at both temporal and spatial levels [8,10]. This allows purer measures of each underlying component.

Based on the previous literature, we hypothesize to find interactions between word frequency and emotion. Behaviorally, we expect either no interactions [21] or faster RTs for negative as compared to neutral LF words [18,28]. At an electrophysiological level, the results of the study by Scot et al. [28] suggest that word frequency effects on the processing of emotional words emerge at a lexical access stage. This should be reflected in modulations of early latency components such as the P1–N1 or the EPN. However, an interaction at a post-lexical level could not be totally ruled out according to the decision hypothesis [2,3]. In this case, word frequency effects on the processing of emotional words should be observed at late latency components such as the N400 and/or the P300.

Thirty native Spanish speakers (22 females; 18–33 years, mean 23 years) that gave their informed consent participated in the study. All participants were right-handed (mean 98%, lateralization quotient 75–100%, measured by the Edinburgh Handedness Scale [22]) and reported normal or corrected-to-normal vision.

Stimuli were 144 Spanish nouns (36 HF negative, 36 HF neutral, 36 LF negative and 36 LF neutral words) selected from a previous pilot study [12]. Participants rated word valence, arousal, and concreteness in a 9-point Likert scale (9 being very positive, very arousing, and very concrete, respectively). Negative nouns were chosen because their arousal ratings are generally high whereas positive nouns show more variability. Word frequency was extracted from Alameda and Cuetos [1]. Nouns were selected according to several criteria that were contrasted with Analyses of Variance (ANOVAs) with two factors: Emotion (negative and neutral) and Frequency (high and low), and post hoc analyses with the Bonferroni correction (alpha < 0.05). Neutral nouns differed from negative words in arousal and valence. HF words differed from LF words in frequency. Negative HF and LF words had similar valence and arousal. Neutral HF and LF were equated in valence and arousal. Negative and neutral HF words had the same frequency. Negative and neutral LF words had similar frequency. All words were matched for length and concreteness. Table 1 summarizes mean ratings in all dimensions and the results of the ANOVAs. 144 Pseudowords were created by transposing the order of the syllables of the target words, which increases the use of semantic strategies [4] and ensures that words and pseudowords are matched for length and syllabic frequency. The list of the stimuli can be seen at http://www.uam.es/carretie/grupo/emotionfrequency.htm.

Participants had to decide if a letter string was a word or a nonword by pressing a two-buttons device. Button assignment was counterbalanced among the participants. Stimuli were displayed on a computer screen with a grey background using the Stim2 software (NeuroScan Inc.). Each stimulus was displayed for 650 ms, followed by a blank screen that lasted 1850 ms. Every stimulus was presented once during an experimental session. They were assigned to one of two blocks. Both blocks contained and equal number of pseudowords (72) and words of each stimulus cate-