



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.

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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 indexes 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	$F_{1,35} = 1630.2^{***}$	$F_{1,35} = 533.8^{***}$	$F_{1,35} = 0.42^{n.s.}$	$F_{1,35} = 1.3^{n.s.}$	$F_{1,35} = 0.02^{n.s.}$
Frequency	$F_{1,35} = 0.6^{n.s.}$	$F_{1,35} = 0.7^{n.s.}$	$F_{1,35} = 144.7^{***}$	$F_{1,35} = 1^{n.s.}$	$F_{1,35} = 3.4^{n.s.}$
Emotion × frequency	$F_{1,35} = 0.2^{n.s.}$	$F_{1,35} = 0.4^{n.s.}$	$F_{1,35} = 0.2^{n.s.}$	$F_{1,35} = 0.6^{n.s.}$	$F_{1,35} = 0.5^{n.s.}$

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 Scott 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 non-word 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 an equal number of pseudowords (72) and words of each stimulus cate-

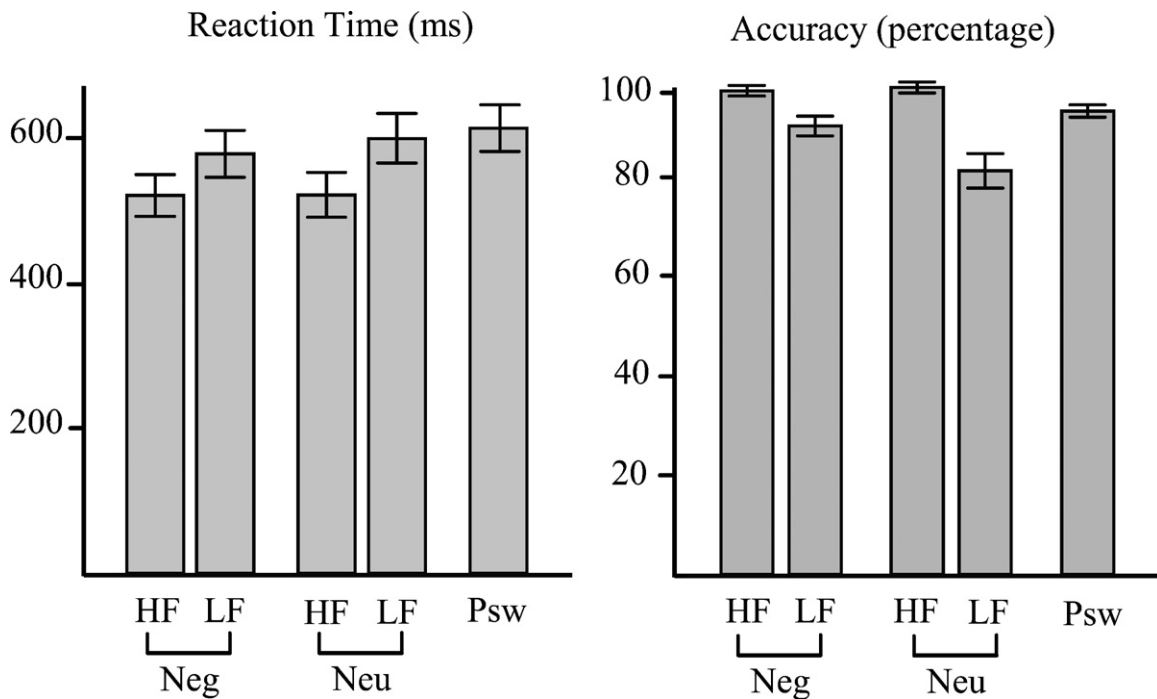


Fig. 1. Behavioral performance for negative HF and LF words, neutral HF and LF words and pseudowords. Neg = negative; Neu = neutral; HF = high frequency; LF = low frequency; Psw = pseudoword.

gory (18 for each of the four experimental categories). Stimuli were arranged in a pseudorandomized fashion. No more than three words or pseudowords were allowed to appear consecutively. Block order was counterbalanced across participants.

Electroencephalographic activity was recorded using an electrode cap with 56 Ag–Ag Cl electrodes that were referenced to the linked mastoids. Bipolar horizontal and vertical electrooculogram was recorded. Electrode impedances were kept below 3 k Ω . The signals were recorded continuously with a band-pass from 0.1 to 50 Hz and a digitization sampling rate of 250 Hz. Trials with RTs shorter than 200 ms or longer than 1500 ms and trials with incorrect responses were excluded from the analyses. Average ERPs from –200 to 800 ms after the presentation of every type of stimulus were computed separately. Muscle artifacts, drifts and amplifier blockings were removed by visual inspection before offline correction. Eye movement artifacts were corrected using the method described by Semlitsch et al. [29].

Components explaining most ERP variance were detected and quantified through a covariance-matrix-based tPCA. This methodology has been repeatedly recommended, since the exclusive use of traditional visual inspection of grand averages may lead to several types of misinterpretation (see Ref. [8,10] for a review on this issue and for a description of tPCA advantages). Components were extracted according to the Scree test that is based on finding the place where the smooth decrease of eigen values appears to level off. Everything to the right of this point is not further considered [6]. Thereafter, factors were submitted to Promax rotation, which in comparison to other rotation procedures such as Varimax, allows factors to be correlated. This removes a possible source of distortion in the factor results (see [8] for more details). Repeated-measures ANOVAs were carried out on each temporal factor's (TF) scores involving Electrode (56 levels), Emotion (two levels) and Frequency (two levels). The Greenhouse–Geiser epsilon correction was applied to adjust the degrees of freedom of the *F*-ratios where necessary.

Signal overlapping may also occur at the space domain. At any given time-point, several neural processes may occur, so the

recording at any scalp location at that moment is the electrical balance of these different neural processes. Spatial PCA separates ERP components along space, each spatial factor (SF) ideally reflecting one of the concurrent neural processes underlying each temporal factor. Additionally, sPCA provides a reliable division of the scalp into different recording regions, an advisable strategy prior to statistical contrasts, since ERP components frequently show a different behavior in some scalp areas than in others. Again, the number of factors to select was based on the Scree test, and extracted factors were submitted to promax rotation. Repeated-measures ANOVAs on the SFs with respect to Emotion and Frequency were carried out. Again, the Greenhouse–Geiser epsilon correction was applied, and follow-up planned comparisons with the Bonferroni correction ($\alpha < 0.05$) were made.

RTs and errors were analyzed using repeated-measures ANOVAs with the factors Emotion (two levels: negative and neutral) and Frequency (two levels: high and low) and planned comparisons with the Bonferroni correction ($\alpha < 0.05$). Mean RTs and errors are represented in Fig. 1. The ANOVA for RTs revealed significant effects of Emotion ($F_{1,29} = 9.60$, $p < 0.005$) and Frequency ($F_{1,29} = 279.2$, $p < 0.001$), as well as the interaction between Emotion and Frequency ($F_{1,29} = 16.3$, $p < 0.001$). Planned comparisons showed that negative and HF words were processes faster than neutral and LF words, respectively. Moreover, neutral LF words were recognized slower than negative LF words, whereas there were no differences between negative and neutral HF words. The ANOVA for errors showed a main effect of Emotion ($F_{1,29} = 19.2$, $p < 0.001$), Frequency ($F_{1,29} = 109.3$, $p < 0.001$), and the interaction between Emotion and Frequency ($F_{1,29} = 27.8$, $p < 0.001$). Planned comparisons replicated the pattern of results observed in RTs.

A selection of the grand average ERP waveforms to all target word categories is represented in Fig. 2A. The tPCA extracted seven components (Fig. 2B). Since our aim was to study word frequency effects on the processing of emotional words, only the factors showing significant interactions between Emotion and Frequency were further considered. A significant effect of Electrode \times Emotion \times Frequency interaction ($F_{55,1595} = 3.19$, $p < 0.05$)

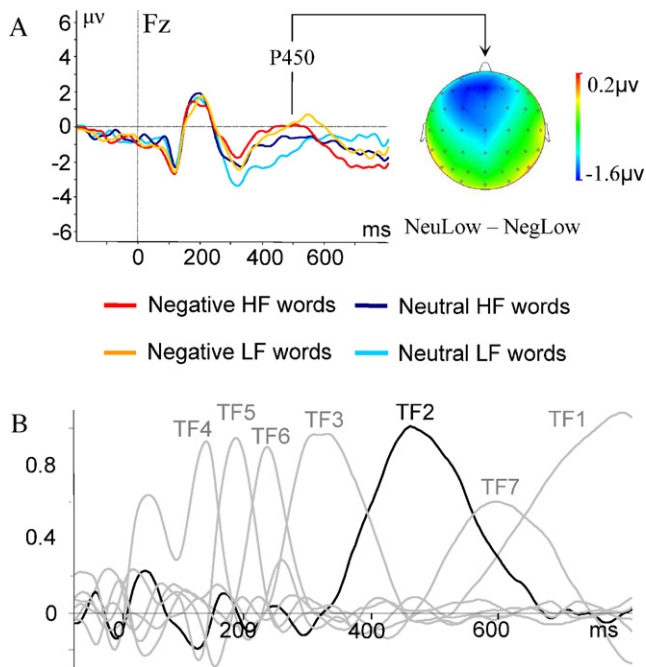


Fig. 2. (A) Grand averaged ERPs elicited by negative HF and LF words, and neutral HF and LF words. The topographic distribution of the spatial factor 2 is also shown, after subtracting the activity of negative LF words from that elicited by neutral LF words. (B) Factor loadings after promax rotation for the tPCA. Temporal factor 2 is drawn in black.

was only observed in TF2. Scalp topography (parieto-occipital distribution) and temporal characteristics (peak latency around 448 ms) associated TF2 to the P300/LPP wave. Hereafter and to make the results easier to understand, this component will be labeled P450.

The sPCA subsequently applied to temporal factor scores extracted four SFs for the P450. Repeated-measures ANOVAs performed on each SF revealed a significant Emotion \times Frequency interaction ($F_{1,29} = 4.7, p < 0.05$) – as well as main effects of Emotion ($F_{1,29} = 18.8, p < 0.001$) – on SF2, which showed a frontal distribution. Planned comparisons revealed that LF neutral words elicited lower amplitudes than LF negative words, whereas no differences were reported in the comparison between HF negative and neutral nouns.

In the current study we explored whether word frequency modulates affective processing in a LDT. Replicating previous findings, we found that negative and HF words were recognized as words faster than neutral and LF words, respectively [17,20]. The interaction between emotion and word frequency was reflected in the slower RTs and more errors elicited by the neutral LF as compared to the negative LF words. A similar processing advantage for negative as compared to neutral LF words was found in some studies [18,28] and was interpreted to indicate a benefit in some of the cognitive components involved in LDT such as lexical access, lexical selection, post-lexical processing or even motor planning and execution [18,28].

The analysis of the ERPs might be helpful while attempting to delineate a better characterization of the processing stages at which this interaction occurs. Word frequency effects on the processing of emotional content were only evident by the time of the P450 component. Paralleling behavioral data, LF neutral nouns elicited reduced amplitudes as compared to LF negative words. Previous research with LDT attributed frequency effects on late positivities to the involvement of attentional factors during the evaluation of words lexical information since the amplitude of these components is especially sensitive to processing capacity demands [24].

Interestingly, it has been reported that the additional capacity required for performing simultaneous secondary tasks decreases P300 amplitude [16]. In line with this finding, Polich and Donchin [25] reported reduced P300 amplitudes for LF as compared to HF words that were thought to index the additional search engaged in determining that LF words are actual words. Therefore, our finding could be interpreted as a benefit for the processing of LF negative words as compared to LF neutral words. The time course of this effect suggests that this facilitated processing seems to operate at the level proposed by the “decision hypothesis” due to the involvement of limited capacity attentional resources in word evaluation as reflected by the P450.

In the current study negative content did not affect the processing of HF words. The lack of differences between negative and neutral HF words replicates previous findings [18,21,28]. Moreover, the processing advantage observed for negative words disappeared in some studies when only HF words were examined [18]. Discrepancies in the impact of negative content on LF and HF words might be attributed in part to the differences in the strength of their neural representations. Thus, since the representation of LF words is rather weak, the presence of high levels of arousal might speed their processing. However, these benefits seem to be less useful in the case of HF words that are quickly processed in general due to their higher salience.

It should be noted that the interaction between word frequency and emotion was found at a lexical access stage in Scott et al. study [28], as reflected in modulations of the P1–N1 amplitude. Despite of the existence of differences in the experimental parameters such as the use of different grammatical categories, this discrepant result might be explained in part by the proposal of Balota and Chumbley [3]. These authors suggested that in making word/non-word discriminations, participants could find it more difficult to respond to LF than to HF words because the former are more similar to the pseudowords on a familiarity dimension. Thus, LDT effects to LF words would reflect discrimination difficulty and not differences in lexical access. In our study, pseudowords were created by transposing the order of the syllables of the words used as stimuli. Therefore, the interaction between word frequency and emotion that we observed at a post-lexical attentional stage might be reflecting the increased difficulty in discriminating words from pseudowords. In contrast, pseudowords stimuli were not made from experimental words in Scott et al. [28] study. Discriminating words from pseudowords could be easier in that study, so the interaction was evident as soon as at the lexical access level. In support of this argument, it took 511 ms to recognize LF words to the participants in the Scott et al. study whereas subjects employed 528 ms to discriminate LF words from pseudowords in the present study.

Finally, the topography of our differences should be considered. Although the P450 showed the typical largest amplitude at parieto-occipital scalp locations, differences between neutral and negative LF words were evident at frontal electrodes. Amplitude variations in late positivities at frontal sites have been observed with pictures as a function of emotional variables [7]. This might be attributed to the contribution of frontal regions to P300 generation [24]. Also, our results could be tentatively related to the word frequency by emotion interaction previously found within the inferior frontal cortex [21]. Interestingly, frontal and prefrontal structures have been involved in the processing of negative words in LDT [17]. Nevertheless, the relation between the present and previous fMRI findings remains speculative. It should be noted that ERPs recorded at frontal electrodes do not necessarily reflect the activity of underlying frontal cortices.

In conclusion, it has been proposed that LF words require more processing capacity for their evaluation than HF words [2,3,26]. Our results suggest that negative content might overcome to some

extend such limitations. It appears that the presence of negative information mobilizes limited capacity attentional resources that operate at a post-lexical level, which facilitates the processing of negative as compared to neutral LF words.

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References

- [1] J.R. Alameda, F. Cuetos, Diccionario de frecuencias de las unidades lingüísticas del castellano, Universidad de Oviedo, Oviedo, 1995.
- [2] D.A. Balota, J.I. Chumbley, Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage, *J. Exp. Psychol. Hum. Percept. Perform.* 10 (1984) 340–357.
- [3] D.A. Balota, J.I. Chumbley, The locus of word-frequency effects in the pronunciation task: lexical access and/or production? *J. Mem. Lang.* 24 (1985) 89–106.
- [4] J.R. Binder, K.A. McKiernan, M.E. Parsons, C.F. Westbury, E.T. Possing, J.N. Kaufman, L. Buchanan, Neural correlates of lexical access during visual word recognition, *J. Cogn. Neurosci.* 15 (2003) 372–393.
- [5] L. Carretié, J.A. Hinojosa, J. Albert, S. López-Martín, B.S. De La Gándara, J.M. Igoa, M. Sotillo, Modulation of ongoing cognitive processes by emotionally intense words, *Psychophysiology* 45 (2008) 188–196.
- [6] N. Cliff, *Analyzing Multivariate Data*, Harcourt Brace Jovanovich, San Diego, 1987.
- [7] S. Delplanque, M.E. Lavoie, P. Hot, L. Silvert, H. Sequeira, Modulation of cognitive processing by emotional valence studied through event-related potentials in humans, *Neurosci. Lett.* 356 (2004) 1–4.
- [8] J. Dien, Evaluating two-step PCA of ERP data with Geomin, Infomax, Oblimin, Promax, and Varimax rotations, *Psychophysiology* 47 (2010) 170–183.
- [9] K.D. Federmeier, J.B. Segal, T. Lombrozo, M. Kutas, Brain responses to nouns, verbs and class-ambiguous words in context, *Brain* 123 (2000) 2552–2566.
- [10] D. Foti, G. Hajcak, J. Dien, Differentiating neural responses to emotional pictures: evidence from temporal-spatial PCA, *Psychophysiology* 46 (2009) 521–530.
- [11] O. Hauk, F. Pulvermüller, Effects of word length and frequency on the human event-related potential, *Clin. Neurophysiol.* 115 (2004) 1090–1103.
- [12] J.A. Hinojosa, C. Méndez-Bértolo, M.A. Pozo, Looking at emotional words is not the same as reading emotional words: behavioral and neural correlates, *Psychophysiology* 47 (2010) 748–757.
- [13] M.J. Hofmann, L. Kuchinke, S. Tamm, M.L. Vö, A.M. Jacobs, Affective processing within 1/10th of a second: high arousal is necessary for early facilitative processing of negative but not positive words, *Cogn. Affect. Behav. Neurosci.* 4 (2009) 389–397.
- [14] P. Kanske, S.A. Kotz, Concreteness in emotional words: ERP evidence from a hemifield study, *Brain Res.* 1148 (2007) 138–148.
- [15] M. Kiefer, The N400 is modulated by unconsciously perceived masked words: further evidence for a spreading activation account of N400 priming effects, *Cogn. Brain Res.* 13 (2002) 27–39.
- [16] A.F. Kramer, C.D. Wickens, E. Donchin, Processing of stimulus properties: evidence for dual-task integrality, *J. Exp. Psychol. Hum. Percept. Perform.* 11 (1985) 393–408.
- [17] L. Kuchinke, A.M. Jacobs, C. Grubich, M.L. Vö, M. Conrad, M. Herrmann, Incidental effects of emotional valence in single word processing: an fMRI study, *Neuroimage* 28 (2005) 1022–1032.
- [18] L. Kuchinke, M.L. Vö, M. Hofmann, A.M. Jacobs, Pupillary responses during lexical decisions vary with word frequency but not emotional valence, *Int. J. Psychophysiol.* 65 (2007) 132–140.
- [19] M. Kutas, K.D. Federmeier, Electrophysiology reveals semantic memory use in language comprehension, *Trends Cogn. Sci.* 4 (2000) 463–470.
- [20] J. Morton, Interaction of information and word recognition, *Psychol. Rev.* 76 (1969) 165–178.
- [21] M. Naki, B.W. Smith, S. Busis, M. Vythilingam, R.J. Blair, The impact of affect and frequency on lexical decision: the role of the amygdala and inferior frontal cortex, *Neuroimage* 31 (2006) 1752–1761.
- [22] R.C. Oldfield, The assessment and analysis of handedness: the Edinburgh inventory, *Neuropsychologia* 9 (1971) 9–97.
- [23] J.K. Olofsson, S. Nordin, H. Sequeira, J. Polich, Affective picture processing: an integrative review of ERP findings, *Biol. Psychol.* 77 (2008) 247–265.
- [24] J. Polich, Updating P300: an integrative review of P300a and P300b, *Clin. Neurophysiol.* 118 (2007) 2128–2148.
- [25] J. Polich, E. Donchin, P300 and the word frequency effect, *Electroencephalogr. Clin. Neurophysiol.* 70 (1988) 33–45.
- [26] R.W. Remington, R.S. McCann, The locus of word frequency effects revealed by patterns of dual-task interference, Paper presented at the Annual Meeting of the Psychonomic Society, Washington, DC, 1993.
- [27] A. Schacht, W. Sommer, Time course and task dependence of emotion effects in word processing, *Cogn. Affect. Behav. Neurosci.* 9 (2009) 28–43.
- [28] G.G. Scott, P.J. O'Donnell, H. Leuthold, S.C. Sereno, Early emotion word processing: evidence from event-related potentials, *Biol. Psychol.* 80 (2009) 95–104.
- [29] H.V. Semlitsch, P. Anderer, P. Schuster, O. Preelich, A solution for reliable and valid reduction of ocular artifacts applied to the P300 ERP, *Psychophysiology* 23 (1986) 695–703.
- [30] S.C. Sereno, K. Rayner, Measuring word recognition in reading: eye movements and event-related potentials, *Trends Cogn. Sci.* 7 (2003) 489–493.