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Does emotional valence modulate word recognition? A behavioral study manipulating frequency and arousal

Catarina I. Barriga-Paulino [a,*], Milene Guerreiro [b], Luís Faísca [a], Alexandra Reis [a]

[a] Center for Research in Health Technologies and Information Systems (CINTESIS-UAlg), Universidade do Algarve, Faro, Portugal
[b] Faculdade de Ciências Humanas e Sociais, Departamento de Psicologia e Ciências da Educação, Universidade do Algarve, Faro, Portugal

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ABSTRACT

Effects of emotional valence have been observed in lexical decision tasks, suggesting that valence information modulates early word recognition. However, is still unclear the processing advantage of the different valence categories, and how these advantages might be modulated by word frequency and arousal. To clarify this question, a lexical decision task was designed using emotional words as stimuli. Emotional words were divided into three categories: 60 positive, 60 negative, and 60 neutral words. Word frequency was manipulated into low and high conditions and arousal was controlled among experimental conditions (word valence and frequency). In the first experiment, 54 participants performed the task with a maximum stimuli exposure time of 2000 ms. In a follow-up experiment, 42 participants performed the same task with two shorter fixed time exposures (150 ms and 300 ms). The results were similar between experiments: positive words were recognized faster and negative words were recognized slower than neutral ones. Furthermore, this valence effect was modulated by word frequency, affecting only words that take longer to be recognized (low-frequency words). However, the valence by frequency interaction was attenuated for high-arousal words when the pressure to respond was high (short exposure time - 150 ms). Overall, the results confirm that the emotional status of a word can affect word processing at early stages when automatic processes are taking place.

1. Introduction

Several studies have presented convergent results concerning the processing advantage of emotional over neutral words (*e.g.*, Citron et al., 2013; Palazova et al., 2011; Scott et al., 2009), *i.e.*, response times to negative and positive emotional words seem to be shorter compared to neutral words. Some of these authors have framed these results in emotion theories. For instance, according to Lang et al. (1997), emotion is organized around two motivational systems, one appetitive and one defensive. The appetitive system is activated in contexts that promote survival, motivating behaviors such as ingestion, copulation, and care-giving. The defense system also promotes survival but is primarily activated in contexts involving threat, motivating behaviors built on withdrawal, escape, and attack. Considering the evolutionary adaptive significance of fast responses to motivational relevant stimulus, both negatively and positively valued items will be processed faster due to their relevance to survival and well-being, although for different reasons.

Concerning the experimental studies done with written words, there are some discrepant findings regarding the processing advantage of negative words. For example, while Kousta et al. (2009) found an advantage of negative over neutral words, Estes and Adelman (2008a, 2008b) found that negative stimuli elicit slower response times when compared to neutral. The latter authors justified their results based on the Automatic Vigilance Theory, which postulates the existence of an adaptative psychological mechanism to monitor the environment for potential dangers (*e.g.*, Pratto & John, 1991). According to this theory, stimuli are automatically evaluated as negative or positive to facilitate rapid avoidance or approach behaviors. In particular, the detection and monitoring of negative stimuli are crucial as the failure to avoid them may be fatal. On the other hand, failure to reach a positive stimulus is less likely to be fatal since other opportunities may appear. Hence, after the initial evaluation, the monitoring of negative stimuli grabs attention and makes them disengage more slowly from negative than from neutral or positive stimuli. This extended attention to negative stimuli, termed automatic vigilance, mobilizes cognitive resources and interferes in the ongoing cognitive tasks, leading to slower responses to negative compared to positive or neutral stimuli. When applied to the recognition

* Corresponding author.
E-mail address: cipaulino@ualg.pt (C.I. Barriga-Paulino).

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of written stimulus, the Automatic Vigilance Theory might predict that the negative valence would affect the decisional or response stage in a variety of tasks such as emotional Stroop, lexical decision or word naming tasks, rather than the activation of lexical or semantic representation (Kuperman et al., 2014).

On the other hand, the Density Hypothesis proposed by Unkelbach et al. (2008) tries to explain the faster responses to positive words considering the organizational structure of information in memory instead of the specific survival value of such information. This hypothesis postulates that positive information is more similar and closely related to other positive information in comparison to negative information, an assumption that has been supported by the multidimensional scaling of evaluative stimuli and response latency experiments. Increased density of positive information in memory causes faster activation according to connectionist models of memory, allowing the speed processing of the positive stimulus. Therefore, the Density Hypothesis predicts a faster response to positive words due to similarity-based processing advantage and not to the emotional valence *per se*. In a follow-up study, Unkelbach et al. (2010) suggested that the overall effect of valence on processing speed could be a mixture of genuinely faster processing of positive information due to subjective exposure and similarity, and slower processing of negative information due to interference and attention-capture, as postulated by Pratto and John (1991).

When assessing the impact of emotional valence on word recognition, it is very important to consider all the non-emotional characteristics of words that have long been known to affect word recognition latencies, such as frequency, age of acquisition, or imageability (Cortese & Schock, 2013). These features must be carefully controlled in studies designed to reliably estimate the effect of emotional dimensions on early word processing. Among those psycholinguistic variables, word frequency has been the most studied and typically explains 30% to 40% of the variance in word recognition tasks (Brysbaert et al., 2017). Word frequency effects have been mainly associated with lexical access (Balota et al., 2004): high-frequency words are faster recognized and with higher accuracy than low-frequency words and this advantage has been explained because high-frequency words can be recognized immediately as a whole word whereas low-frequency words may demand additional analysis such as phonological processing. Kuchinke et al. (2007) studied the joint effect of frequency and emotional valence in a lexical decision task and found a significant interaction between these factors: emotional valence affects high-frequency words, with faster responses for positive words compared to neutral and negative ones, whereas the emotional valence effect on the low-frequency words yielded shorter response times to positive and negative words compared to neutral words. Thus, negative valence affected only the processing of low-frequency words, which are in general discussed to be processed more slowly, while positive valence also affected the fast-processed high-frequency words. Being frequency effect considered a marker of lexical access during word recognition, the observed modulation of the frequency effect by word valence suggests that the emotional status of a word can affect the very early stages of word processing.

Additional studies tried to characterize frequency effects on emotional word processing, using event-related potentials (ERPs) and reaction times in lexical decision tasks. Using ERPs, Scott et al. (2009) found a similar significant interaction between valence and frequency: for high-frequency words, positive words were detected faster than both negative and neutral words, while for low-frequency words, both positive and negative words were detected faster than neutral words. This interaction between word frequency and valence was observed at several early latency components. The authors interpreted their results as indexing emotional influences on the lexical access stage. Also, Méndez-Bértolo et al. (2011) studied the frequency (high *vs.* low) effects on emotional word processing (only negative and neutral words), using ERP and reaction times, while participants performed a lexical decision task. The authors found no differences in high-frequency word comparison. However, in low-frequency condition, negative words were faster recognized than neutral words. In addition, low-frequency neutral words elicited reduced amplitudes in a late positive component (P450) as compared to low-frequency negative words. According to Méndez-Bértolo et al. (2011), these findings suggest a different involvement of attentional mechanisms during the evaluation of lexical information that benefits the processing of low-frequency negative nouns. Different findings were obtained by Scott et al. (2012) using an eye-tracking methodology. The authors' focus was to determine whether the emotionality of a word affects early lexical processes within the context of sentence reading. The results showed that fixation times on emotion words (positive or negative) were consistently faster than those on neutral words except for high-frequency negative words, which were read no faster than their neutral counterparts. While Automatic Vigilance Theory may explain the lack of facilitation for high-frequency negative words, the authors had to propose a modification to this theory to account for the observed facilitation in the case of low-frequency negative words: the Automatic Vigilance Theory should be sensitive to word frequency since low-frequency words represent seldom-occurring threats, being thus less threatening and requiring less vigilance. In a follow-up behavioral study, Scott et al. (2014; Experiments 2a and 2b) showed that when explicit categories were employed in a lexical decision task where stimuli were explicitly blocked according to valence ("positive", "negative" and "neutral" words), only positive words retained their relative behavioral advantage over neutral words; responses to negative words (both high- and low-frequency) were no different than their neutral counterparts. The overall pattern of effects indicates that positive words are always facilitated, while the recognition of negative words is less reliable perhaps because the "negative" emotional category is probably a more heterogeneous one. According to the authors, this heterogeneity may explain why some negative words will engage the activation of an avoidance mechanism, while other words (such as those related to the concept of "anger") may often involve approach actions. These results support the notion that emotional word processing may be moderated by distinct systems.

Another variable that should be considered in this context is arousal, the second dimension of emotional experience which refers to the degree of activation elicited by the stimulus, ranging from calming to exciting. The association between emotional valence and arousal has been described as a U-shaped relationship, *i.e.*, the higher is emotional valence (either positive or negative), the higher is the arousal, while neutral stimuli have lower arousal levels (Kuppens et al., 2013). Kuperman et al. (2014) analyzed a sample of 12.658 words from a dataset of affective norms and observed that calming words (low-arousal) are recognized more quickly than arousing words, indicating that arousal slows word processing. This result challenged the authors to explain it; however, as the contribution of arousal to word recognition times was very small (explaining 0.1% of the variance in lexical and naming times for the full dataset), the authors chose not to develop strong theoretical proposals about it. Recently, Kever et al. (2019) also reported a significant arousal effect on word recognition times independently from valence. However, contrary to Kuperman et al. (2014), arousal exerted a medium-sized effect where high-arousing words elicited faster reaction times than low-arousing words. A study conducted by Robinson et al. (2004) analyzed the interaction between valence and arousal during the evaluation of emotional pictures and words in several experiments. The authors found that assessment latencies were consistently faster if a negative stimulus was high in arousal or if a positive stimulus was low in arousal. The first finding suggests a withdrawal tendency because negative high-arousal stimuli represent a possible threat, while the second one suggests an approach tendency because positive low-arousal stimuli are perceived as safe. The authors proposed that these two tendencies are initiated independently at a pre-attentive level and subsequently integrated, onto appraise the stimulus for further action. Thus, positive low-arousal and negative high-arousal stimuli will be easier to process because they elicit congruent tendencies (approach and withdrawal, respectively), whereas positive high-arousal and negative low-arousal stimuli will be more difficult to process because they elicit conflicting approach-withdrawal tendencies. According to this theory, called the Valence-Arousal Conflict Theory, these opposite tendencies are integrated at an implicit processing level before explicit stimulus evaluation.

In agreement with this theory, Hofmann et al. (2009), using a lexical decision task, observed shorter response times for positive (low-arousal) and high-arousal negative words than for neutral (low-arousal) words, whereas low-arousal negative words presented longer response times than neutral words. Therefore, responses for positive words were facilitated despite their lower arousal level; on the other hand, responses for negative words were modulated by the arousal level. In a large-scale study, with careful control for psycholinguistics features, Larsen et al. (2008) also observed a slow-down of the lexical decision speed for negative low-arousal words. However, a similar large-scale study with Spanish words (Rodríguez-Ferreiro & Davies, 2019) did not find an influence of arousal on word recognition not even an interaction between valence and arousal (for similar results see Vinson et al., 2014).

Gianotti et al. (2008) analyzed the temporal dynamics of the brain electric mechanisms that are responsible for the implementation of valence and arousal dimensions during the processing of emotional words and emotional pictures. Their results suggested that arousal is processed at a rather late processing stage compared to valence, which has been reported to be processed in earlier processing stages. The extraction of valence information started at around 100 ms after stimulus onset, while the extraction of the arousal information occurred in a later step (starting at around 300 ms). This finding could suggest that arousal influences allocation of attentional resources and later sustained stimulus evaluation processes, while valence or emotion attributes of stimuli can influence early, initial evaluation of stimuli. This ensures that potentially relevant stimuli are preferentially processed over irrelevant. However, Citron et al. (2013) found a significant interaction of valence and arousal at an early stage of word recognition, due to greater allocation of attention towards positive high-arousal and negative low-arousal words. Also, a marginal interaction at later stages of processing was found, engaging evaluative processes. The authors also performed an fMRI study (Citron et al., 2014) where it was found that words eliciting conflict tendencies (positive high-arousal and negative low-arousal) require more processing resources showing greater neural activation within the right insular cortex than the stimuli that elicit congruent tendencies (positive low-arousal and negative high-arousal words).

Overall, the effects of manipulating valence and arousal on word recognition are difficult to conciliate across studies. This inconsistency is probably explained by the homogeneity, or not, within each emotional category (different degrees of valence; valence considered as categorial or graded; equivalent levels of arousal among valences, *etc.*) and the different experimental paradigms used (lexical decision; Stroop paradigm; emotion decision; word reading). In addition, some results emerge from large-scale data sets (*e.g.*, Kuperman et al., 2014; Rodríguez-Ferreiro & Davies, 2019; Vinson et al., 2014) and others from primary experimental studies.

Lexical decision tasks are one of the best measures to study word recognition since they provide a window into the processes involved in word recognition and, consequently, an opportunity to assess the effects of lexical features of the word (*e.g.*, length in letters, frequency of use, arousal level, *etc.*) that influence lexical decision speed. For that reason, lexical decision tasks have been the most used paradigm to assess the early effects of valence in word recognition; furthermore, valence effects seem to be substantially more prominent in the lexical decision than in other tasks such as naming or emotional Stroop (see, for example, Rodríguez-Ferreiro & Davies, 2019).

So, based on a lexical decision task, our goal was to investigate the processing advantage of positive and negative valence words, and how this advantage is modulated by frequency and arousal. Despite the common idea that emotional stimuli have a processing advantage over neutral words, it is still unclear whether this advantage extended to negative words. If the negative words are processed slower compared to neutral and positive words, the results will support the Automatic Vigilance Theory (Pratto & John, 1991), given that this theory assumes that negative stimuli mobilize cognitive resources due to their dangerous significance in the environment, increasing the response times in lexical decision tasks. On the other hand, if emotional stimuli (both positive and negative) are processed faster, the results will agree with the generic predictions of Lang et al. (1997) theory, which postulates that emotional stimulus has relevance to survival and well-being, promoting faster responses. In addition, we will look at how these advantages are modulated by word frequency and arousal. We hypothesized that if a word's emotional content is activated immediately after visual presentation, then valence will modulate the recognition of both high and low-frequency words. On the other hand, if emotional content is available after frequency exerts its effect, we will expect that valence only modulates the recognition of low-frequency words once high-frequency words would be processed first, regardless of valence. So, if valence effects are contemporaneous of lexical processing, we expect to verify the interaction between frequency and valence on lexical decision times. Furthermore, since arousal is a dimension of emotional stimuli considered to be available at later stages compared to valence, we will expect that arousal effects will modulate only low-frequency word recognition, regardless of valence. To clarify these questions, we will analyze the effects of valence during word recognition and its relationship with frequency and arousal levels.

2. Experiment 1

2.1. Method

2.1.1. Participants

Sixty native Portuguese speakers were recruited from the University Campus and participated in the study. Informed consent was obtained from all participants in compliance with the Helsinki Declaration.

Participants were pre-screened with two reading tests to discard reading difficulties, the Reading History Questionnaire (ARHQ) (Portuguese version by Alves & Castro, 2003), and the adult version of the Reading Age Test (Fernandes et al., 2017). Additionally, the State-Trait Anxiety Inventory (STAI) (Portuguese version by Silva, 2003) was applied to rule out anxious participants who may have problems with negative stimuli. This inventory is composed of two sub-scales, one assessing the anxiety state and the other assessing the anxiety trait.

One of the participants identified himself as dyslexic and five participants scored above the cut-of-point for Portuguese college students in both STAI scales, being excluded from the sample. The mean score for the ARHQ was 37.1 [±8.8], a score slightly below the cutoff point for the adult Portuguese population (40), suggesting the absence of reading difficulties in this sample. The mean number of correct sentences completed by participants in 1 min in the Reading Age Test was 15.6 [±2.7], a similar score to the one obtained in a normative sample of 185 Portuguese college students (Fernandes et al., 2017; mean ± SD = 15.5 ± 3.09). So, according to reading performance, no participant was excluded.

Thus, the final sample was composed of 54 participants (45 female, 2 left-handed) with mean age [±std] = 20.4 [±3.5] years old.

2.1.2. Visual lexical decision task

2.1.2.1. Stimulus material. For the lexical decision task, 60 negative words (*e.g.*, "tristeza" - sadness), 60 positive words (*e.g.*, "alegria" - joy), and 60 neutral words (*e.g.*, "museu" - museum) were selected from the European Portuguese version of the Affective Norms for English Words (ANEW) (Soares et al., 2012). In this database, the word valence is classified on a 9-point rating scale: scores equal to or below 3 were considered negative, scores between 4 and 6 were considered neutral, and scores equal or above 7 were positive. The information about arousal level was also obtained from the ANEW database and classified with the same rating scale. Words were also divided into two groups according to their frequency: low-frequency words (less than 30 occurrences per million) and high-frequency words (more than 40 occurrences per million). The word frequency was obtained from P-PAL database (Soares et al., 2018).

Pseudowords were created from words using three procedures: syllable permutation (*e.g.*, the word "cadáver" was transformed into the pseudoword "daverca"); vowel substitution (*e.g.*, the word "escorbuto" was transformed into the pseudoword "escarbeto"); and consonant substitution (*e.g.*, the word "fétido" was transformed into the pseudoword "néfico"). All pseudowords were pronounceable and followed Portuguese orthographic rules. In total, 360 stimuli were used (180 words and 180 pseudowords). The stimuli list can be consulted in the Appendix.

The balance of stimulus' characteristics across experimental conditions (3 valence levels × 2 frequency levels) was assessed for valence, arousal, frequency, length, and the number of orthographic neighbors (see Table 1). Performing an ANOVA on words' characteristics showed that arousal levels were not balanced across conditions: arousal is lower for neutral words, compared to positive and negative ones; this difference is more evident for high-frequency compare to low-frequency words (interaction Valence × Frequency: $F(2, 174) = 5.0$, $p = 0.007$); for the frequency and valence levels, the expected effects were observed; word length and the number of orthographic neighbors were equivalent across conditions. Since neutral words have intrinsically less arousal than emotional words, a reasonable balance of arousal across experimental conditions was not possible and thus we decide to include this variable as a continuous predictor of word decision.

2.1.3. Experimental procedures

The stimuli were grouped into four randomized blocks and displayed on a computer screen using Presentation software (version 20.1; nbs.neuro-bs.com/presentation). The computer used in the experiment was a laptop Lenovo Ideapad Y700 with a 15.6″ screen. Words and pseudowords were presented all in lower-case ('Arial', font size 30, and black font on white background). Each trial began with a fixation cross presented in the center of the screen for 500 ms, after which the stimulus was presented. The stimulus was displayed for a maximum of 2000 ms but disappeared as soon as the response was given. Participants were instructed to decide as rapidly and accurately as possible, whether the presented letter string corresponded to a real word or not, and to use their indicator fingers to press a designated button on the keyboard. Half of the sample had to respond to words with the left button and pseudowords with the right button (scenario 1) and the other half had to respond *vice-versa* (scenario 2) to balance the putative effects of manual laterality. Accuracy and response times were automatically recorded. Ten practice items were given to familiarize participants with the task.

Table 1
Word stimulus characteristics (means and standard deviations).

	High frequency	Low frequency
Negative	$N = 30$	$N = 30$
	Valence = 2.48 ± 0.35	Valence = 2.54 ± 0.31
	Arousal = 6.17 ± 0.63	Arousal = 5.18 ± 0.93
	Frequency = 95.13 ± 57.60	Frequency = 7.35 ± 9.01
	Orthog. Length = 6.03 ± 1.38	Orthog. Length = 7.23 ± 1.99
	Orthog. Neigh. = 2.27 ± 2.90	Orthog. Neigh. = 1.03 ± 1.63
Neutral	$N = 30$	$N = 30$
	Valence = 5.07 ± 0.59	Valence = 5.06 ± 0.60
	Arousal = 4.90 ± 0.78	Arousal = 4.70 ± 0.98
	Frequency = 96.05 ± 51.96	Frequency = 7.37 ± 8.61
	Orthog. Length = 6.30 ± 2.23	Orthog. Length = 6.73 ± 1.82
	Orthog. Neigh. = 2.27 ± 2.94	Orthog. Neigh. = 1.57 ± 2.21
Positive	$N = 30$	$N = 30$
	Valence = 7.63 ± 0.38	Valence = 7.44 ± 0.34
	Arousal = 5.83 ± 0.74	Arousal = 4.63 ± 1.20
	Frequency = 100.27 ± 67.71	Frequency = 7.22 ± 5.72
	Orthog. Length = 7.10 ± 2.51	Orthog. Length = 6.50 ± 1.63
	Orthog. Neigh. = 1.70 ± 2.86	Orthog. Neigh. = 1.73 ± 2.69

Valence and arousal ratings: 1 (low) to 9 (high); Frequency (occurrences per million); Orthographic Length (Orthog. Length: number of letters); Orthographic Neighborhood (Orthog. Neigh.: number of orthographic neighbors obtained by deleting, adding, or replacing a letter).

2.1.4. Data analysis

Only word trials were considered for the reaction time analyses. Two low-frequency negative valence words were eliminated due to the high number of incorrect responses ("putrefacto" and "fétido", both with a percentage of errors above 50%). From a total of 9572 valid responses, seven trials had RTs less than 250 ms (anticipatory responses) and were excluded from further analysis. For the RTs analyses, only correct responses were considered (9132 trials, 95.4% of the valid data). RTs beyond 2.5 standard deviations above the participants' mean for each condition were additionally excluded (259 trials). These trimming procedures resulted in a data loss percentage per participant ranging from 1.2 to 5.4% of the trials (mean = 3.3%).

A Linear Mixed-effects Model (LMM), an analytic procedure that allows controlling for the variability of items and subjects (Singmann & Kellen, 2019), was implemented using trial-level data. LMM limits the loss of information due to the prior averaging of the traditional by-subject and by-item analyses and has been repeatedly used in the case of RTs and accuracy (Brown, 2021). In all models, the random effect structure was selected based on the experimental design (Barr et al., 2013), following a maximal to minimal-that-converges modeling strategy (Meteyard & Davies, 2020): the complete random effect structure was considered, and high-order interaction terms were successively eliminated until obtaining a model that converged. Thus, both participant and item random intercept and slopes were included to account for participant and item differences. Once established the random effect structure, the fixed effects were added based on the complete factorial design of the study (three valence levels, two frequency levels, and arousal as a continuous covariate). Arousal values were *z*-scored to facilitate interpretation. Nakagawa's pseudo-R^2 coefficients were computed to measure the variation explained by the linear mixed-effects model (Nakagawa & Schielzeth, 2013). Model parameters' significance was tested using *t*-tests with Satterthwaite approximations to degrees of freedom. Analyses were carried out by using R (R Core Team, 2019), with the package *lme4* for fitting the models (Bates et al., 2015), and the package *ggplot2* for the graphics (Wickham, 2009). The package *lmerTest* was used to obtain *p*-values and summary tables for model parameters (Kuznetsova et al., 2017).

2.2. Results

There were no statistically significant differences between both scenarios regarding accuracy ($t(52) = -0.2$; $p = 0.869$) and correct response times ($t(52) = 0.9$; $p = 0.392$), so data were analyzed considering the whole sample.

As expected, a significant difference was found for the mean of correct response times between words and pseudowords ($t(53) = -12.5$; $p < 0.001$): words were responded faster (M ± SD = 592.5 ms ± 84.8) than pseudowords (M ± SD = 717.9 ms ± 127.5). There was also a significant difference in the mean accuracy percentages between words and pseudowords ($t(53) = 3.0$; $p = 0.004$): words showed a higher percentage of correct answers (95.7% ± 2.9) than pseudowords (93.2% ± 6.0).

2.2.1. Reaction times analysis

The LMM with the maximal random structure that was retained included random intercepts for both subject and item factors as well as random slopes for each within-subject experimental factor (valence, frequency, and arousal); however, the inclusion of random slopes for interactions resulted in non-soluble convergence problems and consequently, such effects were not considered in the model. The fixed part of the model included all three experimental factors and their interactions (see note in Table 2). *Conditional-R^2* value (Table 2) indicates that 53% of the variance is explained by the entire model, while only 11% is explained by its fixed component alone (*marginal-R^2* = 0.109).

Overall, lexical decision times were modulated by stimulus valence [F(2, 162.3) = 2.98; p = 0.053] and frequency [F(1, 191.3) = 71.46; p < 0.001] but not by stimulus arousal [F(1, 175.8) = 0.10; p = 0.752]. Positive words were marginally faster than negative ones (573 ms *vs.* 601 ms; p = 0.061) and high-frequency words were responded faster than low-frequency ones (542 ms *vs.* 635 ms; p < 0.001). However, this valence effect was dependent on frequency [Valence by Frequency: F(2, 159.3) = 6.61; p = 0.002]. No other interactions were significant (p < 0.5).

Based on the β unstandardized effect estimates presented in Table 2, we calculated marginal effects considering the average level of arousal across conditions. For low-frequency condition, positive valence words were responded 40 ms faster than neutral valence words (637 *vs.* 597; p = 0.008), while negative valence words were 33 ms longer than neutral (637 *vs.* 670; p = 0.022). On the other hand, for the high-frequency condition, differences between valences are negligible: negative and positive words were as fast as neutral words (respectively, 546 *vs.* 532, p = 0.479; 546 *vs.* 548; p = 0.886). These effects are displayed in Fig. 1.

The analysis of the random effects reveals that the variance in response times attributed to individual differences (participants' random intercepts) is higher than the variance attributed to items. The effect frequency had on response times is more affected by individual differences than the valence effects. Finally, the strong negative correlations between participants' random intercepts and valence random slopes may indicate that the individual tendency to give fast responses may wash out the valence effects on lexical decision times.

Table 2
LMM point and interval estimates of fixed and random effects for lexical decision reaction times in Experiment 1 (maximum time of exposure: 2000 ms). Neutral valence and low-frequency words were considered as baseline categories. Note: V – Valence; F – Frequency; A – Arousal; neg – negative; pos – positive; neu – neutral.

Fixed effects	*Estimates*	*95% CI*	*p*
(Intercept)	637.07	603.80–670.34	<0.001
V (negative *vs.* neutral)	32.94	4.78–61.10	0.022
V (positive *vs.* neutral)	−39.66	−68.85 to −10.48	0.008
F (high *vs.* low)	−91.46	−122.19 to −60.73	<0.001
A	−3.04	−22.75–16.67	0.762
V (neg *vs.* neu) × F (high *vs.* low)	−46.55	−93.35–0.25	0.051
V (pos *vs.* neu) × F (high *vs.* low)	41.85	0.03–83.67	0.050
V (neg *vs.* neu) × A	4.39	−24.71–33.49	0.767
V (pos *vs.* neu) × A	17.28	−7.90–42.47	0.179
F (high *vs.* low) × A	−3.30	−34.54–27.94	0.836
V (neg *vs.* neu) × F (high *vs.* low) × A	11.12	−37.53–59.77	0.654
V (pos *vs.* neu) × F (high *vs.* low) × A	−16.76	−60.19–26.68	0.450

Random effects		*Variance*	*Correlations*			
Residual		10,648.89				
Words	Intercept	2290.92				
Subjects	Intercept	6838.72				
	Slope for V (neg *vs.* neu)	135.13	−0.78			
	Slope for V (pos *vs.* neu)	93.92	−0.94	0.77		
	Slope for F (high *vs.* low)	1677.35	0.14	−0.51	−0.40	
	Slope for A	102.94	0.69	−0.96	−0.62	0.33

ICC	0.47
N Subjects	54
N Words	178
N Observations	8873
Marginal R^2/Conditional R^2	0.109/0.526

Note: Model: RT ~ 1 + V*F*A + (1 + V + F + A|Subjects) + (1|Words).

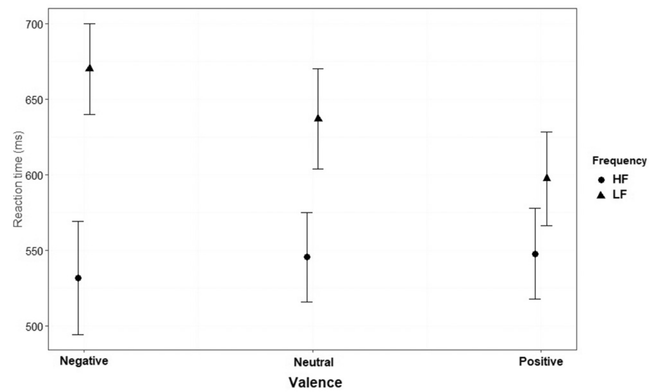

Fig. 1. Emotional valence by frequency interaction effects on lexical decision reaction time (2000 ms exposure time): mean effects ±95% confidence interval. HF and LF: high- and low-frequency.

2.3. Discussion

In this experiment, we aimed to analyze the influence of emotional content (valence and arousal) during word recognition. Our analysis demonstrated that positive words are recognized faster than neutral words, while negative words have slower recognition times compared to neutral ones. However, this valence effect is modulated by word frequency and occurs only for low-frequency words. High-frequency words are recognized earlier and did not present any reliable differences across valence conditions.

Contrary to what was expected, arousal did not show any effect on word decision times. This result is not in agreement with our hypothesis, which assumed that arousal may modulate low-frequency word responses. Arousal effects were described by Robinson et al. (2004), who observed that high-arousal words were recognized faster than low-arousal words. Kuperman et al. (2014) also observed a main arousal effect, but its contribution to lexical decision times was very small (0.1% for the full dataset). Kuperman et al. (2014) also did not find an interaction between valence and arousal. The absence of this interaction confirms that, independently of the arousal level, low-frequency positive words are recognized faster than negative low-frequency words.

In our experiment, the stimulus exposure time was response-dependent and could be long enough (max. 2000 ms) to allow deep word processing beyond lexical access. Thus, a second experiment was set up with shorter and fixed exposure times (150 ms and 300 ms). With this experimental manipulation, we expected to prevent later word processing and to foster more automatic and faster responses.

3. Experiment 2

In Experiment 1, the stimuli exposure time could last until 2000 ms duration, which might have prompted deeper word processing. Thus, to verify if the obtained results reflect or not a later processing stage, where high-level semantic factors may affect the lexical decision response, a second experiment with two shorter and fixed exposure times (150 ms and 300 ms) was designed, using the same stimuli and procedures from Experiment 1.

Previous eye-tracking studies produced a working estimate of the time window within which lexical access may occur, namely around 100–200 ms post-stimulus (see for a review, Sereno & Rayner, 2003). Electroencephalographic studies also showed that the N1 (the earliest electrophysiological marker of word frequency) could become a functional watershed separating early, lexical access from later, post-lexical integration stages of processing (Sereno & Rayner, 2003). So, based on these shreds of evidence, we have decided to use in our second experiment two shorter exposition times to prevent deep word processing: 150 and 300 ms.

3.1. Method

3.1.1. Participants

Forty-four native Portuguese speakers were recruited from the University Campus. However, two participants were excluded because they obtained high scores in the STAI inventory. Thus, the final sample was composed of 42 subjects (31 women, 2 left-handed) with mean age [±std] = 23.0 [±2.7] years old. The Reading History Questionnaire (ARHQ) (Portuguese version by Alves & Castro, 2003), and the Reading Age Test (Fernandes et al., 2017) were applied to discard reading difficulties. The mean score for the ARHQ was 34.4 [±8.0], a score below the cutoff point for the adult Portuguese population (40), suggesting the absence of reading difficulties in this sample. The mean number of correct sentences completed by participants in 1 min in the Reading Age Test was 18.8 [±2.4], a score above the obtained in the normative sample of 185 Portuguese college students (Fernandes et al., 2017; mean ± SD = 15.5 ± 3.09). According to the results on reading tasks, no participants were excluded. Informed consent was obtained from all participants in compliance with the Helsinki Declaration.

3.1.2. Experimental procedures

The procedure was the same as Experiment 1 but the decision lexical task has two different exposure times for stimulus. Twenty-three participants performed the task where the stimuli were displayed during 150 ms and the remaining 19 participants performed the task with a 300 ms exposure time. Identical to Experiment 1, there were also two scenarios regarding key buttons that the participants had to respond to.

3.1.3. Data analysis

Data pre-processing followed the same procedures as Experiment 1. From a total of 7438 valid responses, 15 trials with RTs less than 250 ms were excluded from further analysis. For the RTs analyses, only correct responses were considered (6981 trials, 94.2% of the valid data). RTs beyond 2.5 standard deviations above the participants' mean for each condition were additionally excluded (171 trials). These trimming procedures resulted in a data loss percentage per participant ranging from 0.1 to 6.4% of the trials (mean = 3.1%).

Data were analyzed using LMM modeling and the selection of the random and fixed effect structures followed the same procedures described for Experiment 1, but now including an additional between-subject factor (time exposure condition, 150 ms *vs.* 300 ms).

3.2. Results

There were no statistically significant differences between both scenarios regarding accuracy ($t(40) = 1.1$; $p = 0.295$) and correct response times ($t(40) = -1.1$; $p = 0.279$); therefore, data was analyzed considering the whole sample.

As expected, a significant difference was found for the mean of correct response times between words and pseudowords ($t(41) = -15.9$; $p < 0.001$): words were responded faster (M = 511.7 ms ± 63.9) than pseudowords (M = 609.8 ms ± 77.2). There was also a significant difference in the mean accuracy percentages between words and pseudowords ($t(41) = 4.9$; $p < 0.001$): words showed a higher percentage of correct answers (94.2% ± 4.0) than pseudowords (89.9% ± 7.0).

Furthermore, the overall mean response times for correct words in both experimental conditions (150 ms: 514.2 ± 63.3; 300 ms: 508.6 ± 66.4) were equivalent and significantly shorter than the observed in Experiment 1 (582.5 ± 81.1; $p < 0.001$), suggesting that the time exposure manipulation induced faster lexical decisions, as expected.

The LMM with the maximal random structure that was retained included random intercepts for both subject and item factors as well as random slopes for two within-subject experimental factors (frequency, and arousal) and the random slope for the within-item experimental factor (time exposure); the inclusion of random slopes for valence and within-subject interactions resulted in non-soluble convergence problems and, consequently, such effects were not considered. The fixed part of the model included all four experimental factors and their interactions (see Note in Table 3). *Conditional-*R^2 value (Table 3) indicates that 45% of the variance is explained by the entire model, while only 7% is explained by its fixed component alone (*marginal-*$R^2 = 0.068$).

Overall, lexical decision times were modulated by stimulus valence [$F(2, 157.6) = 5.26$; $p = 0.006$], stimulus frequency [$F(1, 125.6) = 42.47$; $p < 0.001$] but not by stimulus arousal [$F(1, 159.7) = 0.06$; $p = 0.453$] or time exposure condition [$F(1, 40.6) = 0.08$; $p = 0.775$]. Positive words were recognized faster than negative (498 ms *vs.* 524 ms; $p = 0.004$) and neutral ones (498 ms *vs.* 512 ms; $p = 0.079$), while negative words were marginally slower than neutral ones (524 ms *vs.* 512 ms; $p = 0.079$). As expected, high-frequency words were responded faster than low-frequency ones (485 ms *vs.* 537 ms; $p < 0.001$). The valence effect was dependent from frequency [Valence by Frequency: $F(2, 157.6) = 7.15$; $p = 0.001$]. Also, a four-order interaction was significant [Condition by Valence by Frequency by Arousal: $F(2, 148.9) = 4.24$; $p = 0.016$]. No other interactions were significant.

Based on β values represented in Table 3, we calculated the marginal effects for the valence by frequency interaction, considering the average level of arousal across conditions. For the low-frequency condition, words with a positive valence were responded 25 ms faster than words with a neutral valence (510 *vs.* 535; $p = 0.022$), while decision times for negative words were 32 ms longer than for neutral words (567 *vs.* 535; $p = 0.001$). On the other hand, for the high-frequency condition, differences between word valences were negligible: positive and negative words were responded as fast as neutral words (respectively, 486 *vs.* 488, $p = 0.857$; 482 *vs.* 488, $p = 0.708$). The valence by frequency interaction effect is displayed in Fig. 2.

In Fig. 3 (a and b) it is represented the significant interaction between exposure time, valence, frequency, and arousal. Interestingly, this interaction seems to result from the exposure time impact on the response decision latency. When the exposure time is short (150 ms and there is a pressure to give a rapid response) high arousal attenuates the observed interaction between frequency and valence effect: the valence effect weakens for high-arousal low-frequency words – negative words did not differ from the neutral ones (552 *vs.* 536; $p = 0.404$) and are only marginally slower compared to low-frequency positive words (552 *vs.* 519; $p = 0.077$). On the other hand, for low-arousal words, we found the previously described interaction between valence and frequency: negative low-frequency words produce longer response times than neutral low-frequency words (588 *vs.* 553; $p = 0.015$) and positive low-frequency words produce shorter response times than neutral ones (509 *vs.* 553; $p < 0.001$). On the other hand, with longer exposure times (300 ms), this attenuation of the valence by frequency interaction was not evident, both for low and high-arousal levels.

The analysis of the random effects reveals again that the variance in response times attributed to individual differences (participants' random intercepts) is clearly higher than the variance attributed to words. The effect of frequency on response times is more affected by individual differences than the arousal effects.

3.3. Discussion

As Experiment 1 had a long stimuli exposure time, which could allow deeper word processing, a second experiment with shorter exposure times was designed to verify if the obtained results reflected a later word processing where high-level semantic factors may affect the lexical decision response times. Overall, the lexical decision times were shorter in Experiment 2, suggesting that the manipulation of the stimulus exposure effectively pressured the participants to give faster responses.

Table 3
LMM point and interval estimates of fixed and random effects for lexical decision reaction times in Experiment 2 (time of exposure condition: 150 ms *vs.* 300 ms). Neutral valence, low-frequency words, and 150 ms time exposure condition were considered as baseline categories. Note: C – Condition; V – Valence; F – Frequency; A – Arousal; neg – negative; pos – positive; neu – neutral.

Fixed effects	*Estimates*	*95% CI*	*p*
(Intercept)	544.36	509.74–578.98	<0.001
C (300 *vs.* 150)	−19.31	−66.94–28.32	0.427
V (negative *vs.* neutral)	25.49	4.52–46.45	0.017
V (positive *vs.* neutral)	−30.56	−52.31 to −8.81	0.006
F (high *vs.* low)	−54.36	−79.41 to −29.30	<0.001
A	−8.68	−23.34–5.98	0.246
C (300 *vs.* 150) × V (neg *vs.* neu)	12.68	−4.38–29.73	0.145
C (300 *vs.* 150) × V (pos *vs.* neu)	12.43	−4.98–29.84	0.162
C (300 *vs.* 150) × F (high *vs.* low)	15.24	−10.65–41.14	0.249
V (neg *vs.* neu) × F (high *vs.* low)	−36.48	−71.31 to −1.66	0.040
V (pos *vs.* neu) × F (high *vs.* low)	28.82	−2.33–59.97	0.070
C (300 *vs.* 150) × A	0.78	−11.18–12.73	0.899
V (neg *vs.* neu) × A	−9.25	−31.10–12.59	0.406
V (pos *vs.* neu) × A	13.57	−5.30–32.44	0.159
F (high *vs.* low) × arousal	−0.63	−24.00–22.73	0.958
C (300 *vs.* 150) × V (neg *vs.* neu) × F (high *vs.* low)	−3.34	−31.22–24.53	0.814
C (300 *vs.* 150) × V (pos *vs.* neu) × F (high *vs.* low)	−12.56	−37.45–12.33	0.323
C (300 *vs.* 150) × V (neg *vs.* neu) × A	17.23	−1.30–35.76	0.068
C (300 *vs.* 150) × V (pos *vs.* neu) × A	5.07	−10.15–20.29	0.513
C (300 *vs.* 150) × F (high *vs.* low) × A	7.48	−11.22–26.18	0.433
V (neg *vs.* neu) × F (high *vs.* low) × A	30.90	−5.49–67.28	0.096
V (pos *vs.* neu) × F (high *vs.* low) × A	−13.47	−45.64–18.71	0.412
C (300 *vs.* 150) × V (neg *vs.* neu) × F (high *vs.* low) × A	−40.92	−70.46 to −11.37	0.007
C (300 *vs.* 150) × V (pos *vs.* neu) × F (high *vs.* low) × A	−4.01	−29.81–21.79	0.761

Random effects		*Variance*	*Correlations*	
Residual		7970.88		
Words	Intercept	1018.59		
	C (300 *vs.* 150)	55.78	−0.64	
Subjects	Intercept	3612.91		
	F (high *vs.* low)	1018.74	0.28	
	A	2.72	0.63	−0.56

ICC	0.41
N_{Subjects}	42
N_{Words}	178
$N_{\text{Observations}}$	6810
Marginal R^2/Conditional R^2	0.068/0.451

Note: Model: RT ~ 1 + V*F*A + (1 + F + A|Subjects) + (1 + C|Words).

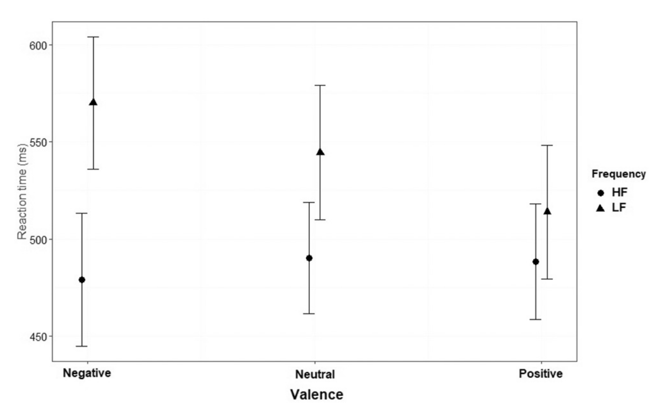

Fig. 2. Emotional valence by frequency interaction effects on lexical decision reaction time (Experiment 2: 150 ms and 300 ms exposure time): mean effects ±95% confidence interval. HF and LF: high- and low-frequency.

Similar to Experiment 1, Experiment 2 showed an advantage of positive words over neutral and negative words, as well as a disadvantage of negative words over neutral ones. As expected, reaction times in the high-frequency condition were faster than in the low-frequency condition. Also, the effect of valence was modulated by word frequency, affecting only low-frequency words. However, this interaction between frequency and valence depends on arousal but only when the stimulus exposure time was short (150 ms). This complex effect seems to result from the fact that high-arousal levels attenuate the valence effect: response times to negative and positive low-frequency words become close to their neutral counterparts.

In sum, the results obtained in Experiment 2 confirm those from Experiment 1, generalizing them to shorter exposure times and giving evidence that the general findings did not depend on late high-level semantic factors which could affect the lexical decision response times. However, the observed valence by frequency interaction seems to be attenuated for high-arousal words when the pressure to respond is high (short exposure time - 150 ms).

4. General discussion

The present study aimed to analyze the effects of emotional valence in isolated written word recognition and to what extent these effects are modulated by word frequency and arousal. To do that, two experiments using a lexical decision task were conducted: one with a stimuli maximum exposure time of 2000 ms and the other with two shorter fixed exposure times (150 and 300 ms), to evaluate whether the processing of emotional information occurs at a shallow phase of the visual word recognition processing.

As found in lexical decision literature, high-frequency words showed faster decision times than low-frequency words, possibly because high-

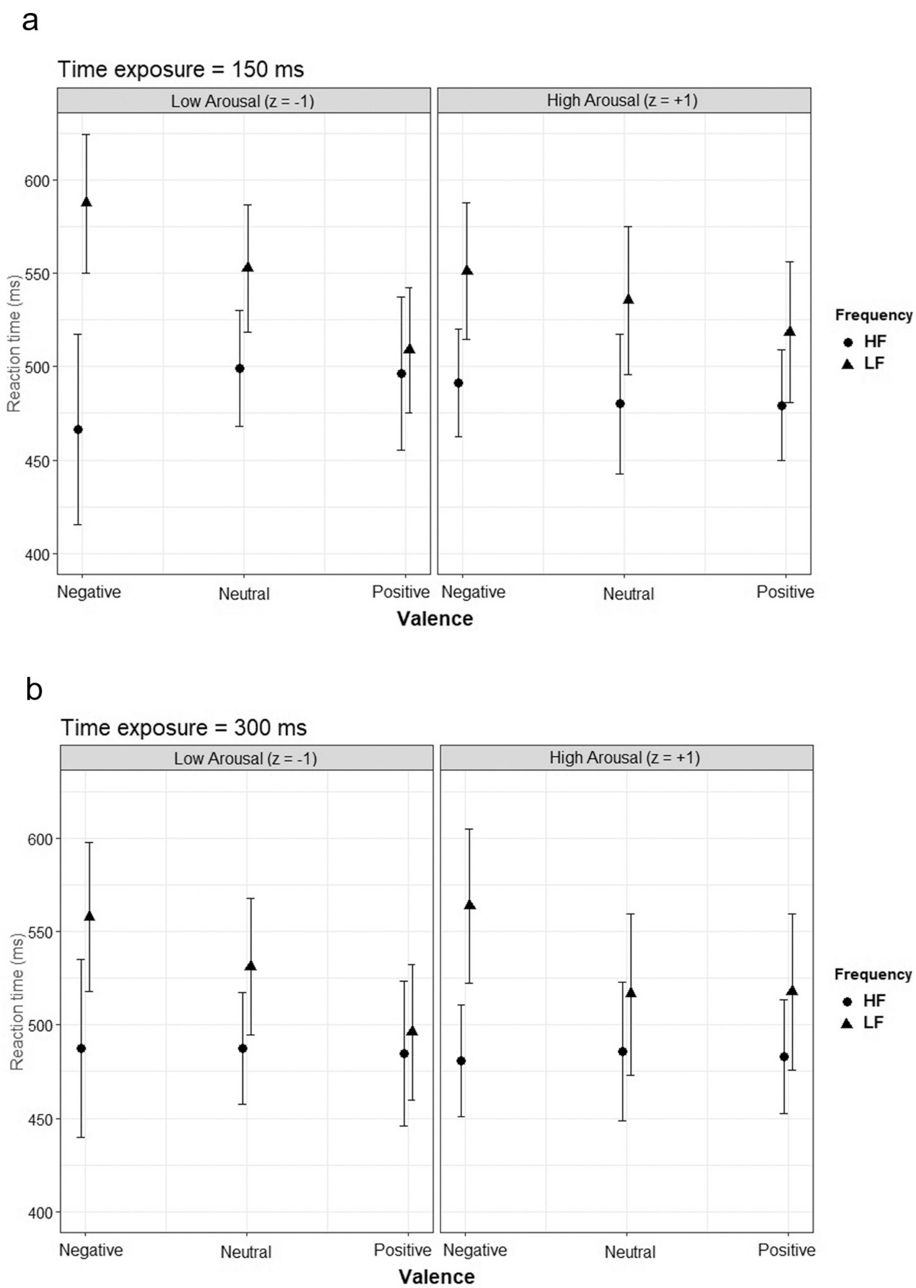

Fig. 3. a. Emotional valence by frequency by arousal interaction effects on lexical decision reaction time (150 ms exposure time): mean effects ±95% confidence interval. HF and LF: high- and low-frequency. b. Emotional valence by frequency by arousal interaction effects on lexical decision reaction time (300 ms exposure time): mean effects ±95% confidence interval. HF and LF: high- and low-frequency.

frequency words could be recognized as a whole word while low-frequency words demand an additional analysis (Balota et al., 2004).

Considering the effect of emotional content on visual word lexical decision, we observed that, when compared to neutral words, positive words were responded faster, while negative ones were responded later. This pattern has not been usually found in the literature. Most studies that include neutral and emotional words described an inverted-U shape effect of valence on response times (see, for example, Kousta et al., 2009; Scott et al., 2009; Vinson et al., 2014). Recio et al. (2014) reported an advantage exclusively for positive words, while negative words were processed as faster as neutral ones. Other studies that reported advantage of positive over negative words (Estes & Adelman, 2008a; Unkelbach et al., 2010; Wentura et al., 2000; Yap & Seow, 2014) did not include neutral stimuli and, therefore, it is not possible to verify whether these results are compatible with the inverted-U pattern or with the "linear" categorical pattern observed in the present study. Only Kuperman et al. (2014) have found a similar effect of valence on word response times after controlling for word frequency. This result cannot be explained exclusively by any of the theories mentioned in the Introduction, but it is partially compatible with either the Automatic Vigilance Theory (Pratto & John, 1991) and the Density Hypothesis (Unkelbach et al., 2008). The delayed decision times for negative words are explained by the Automatic Vigilance Theory, which states that negative stimuli are critical for individuals' survival and consequently it could be more difficult to disengage attention from them due to the threat that they might represent. Although the Automatic Vigilance Theory is not explicit concerning the advantage of positive stimuli, we may additionally assume that positive stimuli elicit faster responses since they are perceived as safe and might represent potentially rewarding events in the environment, prompting approaching tendencies. Alternatively, the specific advantage of positive words might also be caused by the similarity-based processing benefit predicted by the Density Hypothesis (Unkelbach et al., 2008). Thus, the processing of emotional words may be modulated by distinct cognitive and motivational systems (Scott et al., 2014).

However, our main valence effect is small and dependent on the word frequency. For high-frequency words, valence effects are negligible, while for low-frequency words positive valence stimuli induced faster responses than neutral ones, and negative stimuli produced longer responses times than neutral. So, this interaction effect might be a consequence of high-frequency words being recognized before valence exerts its influence, and therefore, the recognition time of these words is independent of their valence. In other words, lexical representations of high-frequency words are quickly activated due to their familiarity, and a lexical decision is made before valence information becomes available. The fact that the decision about low-frequency words is affected by their emotional content suggests that meaningful information about valence is already available even if the word is not yet fully identified and may delay (negative words) or facilitate (positive words) the lexical decision. This is in agreement, for instance, with a Yap and Seow (2014) study that explored the impact of affective valence on the reaction times distribution in a lexical decision task and found that valence influences the reaction time distribution in later, more controlled stages of processing.

Concerning arousal, when participants were pressured to give a rapid response (150 ms time exposure condition), the interaction between valence and frequency smoothed out for high-arousal words. In this specific experimental situation, the processing delay of low-frequency negative words and the advantage of the low-frequency positive words somehow vanish for high-arousal stimuli, and decision times became similar to neutral words; on the contrary, for low-arousal levels, the slowing lexical decision for negative words and the faster responses to positive words were observed both for the 150 ms time exposure condition as well as for the 300 and 2000 ms conditions. Our data suggest that when the arousal is high, its effect overlaps the effect of valence, suggesting that both valence and arousal information are already available when lexical decisions for low-frequency words are being taken. This pattern of results seems to be predicted by the Valence-Arousal Conflict Theory (Robinson et al., 2004), which states that stimuli eliciting congruent tendencies (high-arousal negative words and low-arousal positive ones) are easier to process. However, the Valence-Arousal Conflict Theory was not specifically developed for word recognition processes and consequently does not consider the frequency effect. When this theory is applied to the specific context of word recognition, the facilitatory and inhibitory effects predicted seem only to manifest in low-frequency words. Since this theory requires the simultaneous contribution of information about arousal and valence, the results seem to suggest that this information is only available at a later stage of lexical access, when words that take longer to be recognized (the more unfamiliar, low-frequency words) are being processed.

What is interesting in our findings is that arousal modulates the recognition of low-frequency words only when time exposure of the stimulus is short. So, it seems that when the participants are compelled to make faster decisions on emotional words they are not so much familiar with, the valence-arousal congruency might be a shortcut that enhances word recognition. Time pressure to respond may result in the incremented usage of lexical fast guess mechanisms that may temporarily suspend or attenuate the Automatic Vigilance, delaying effects on low-frequency negative words. The fact that this pattern of results was only observed for short exposure times (150 ms) deserves further investigation.

In sum, regardless of the exposure times of the stimuli, the results about the emotional valence words effect went in the same direction in both Experiments, confirming the internal validation of the study. The outcomes are suggestive that the valence effect only emerges when words take longer to be recognized, enhancing positive word recognition compared to negative ones. Since emotional words cannot be distinguished from neutral ones based solely on orthographic information conveyed by the visual word form, it is possible that, immediately after a minimal lexical activation, bi-directional interactions with the amygdala could enhance the processing of a word identified as having emotional significance (Kissler et al., 2009). However, this effect seems to be attenuated when participants are required to provide fast lexical decisions to high-arousal words.

Like in previous studies, the present results show that early and automatic cognitive processes such as word recognition may be open to the influence of the emotional connotation of the stimulus, at least before a behavioral lexical decision response is given. Despite the heterogeneity of the findings that may appear published in the literature, it is still an open issue how the threat or appetitive meaning of a word, presumably accessible only after the word has been recognized, may affect its recognition. To explain this, we must assume that rudimentary emotional information must be available simultaneously together with the orthographic features required for a lexical decision or immediately after minimal lexical information has been accessed. Palazova (2014) summarized two main hypotheses: 1) emotional valence is possibly the first semantic feature to be retrieved during word recognition; or 2) affective information is already a component of the lexical linguistic representation, being early available during word recognition. So, empirical evidence that the emotional connotation of a word (both valence and arousal) impacts the early stages of word recognition is pinpointing future challenges for models of visual word recognition.

One limitation of this study was the difficulty to control arousal across the three valence conditions, without diminishing the contrast between emotional and neutral words. This fact could have affected the arousal-related results. Thus, in future studies, it is crucial to balance very well all linguistic variables to minimize possible confounding.

Despite the evidence already available in the literature, it is still unclear what is the time locus of emotional effects during lexical access. Behavior response parameters are difficult to translate into the temporal course of word processing. Clearly, the mechanism underlying the early valence effects on isolated word recognition requires further specifications that are not accessible through an exclusively behavioral approach.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2021.103484.

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