Valence of auditory words enhances subsequent recognition and facilitates processing of written words: ERP and behavioral evidence.

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Abstract

The present study combined behavioral measures and EEG to investigate the impact of emotional valence on both auditory and written word processing. Participants were first presented with a series of auditory words with varying emotional valence (positive, neutral and negative) produced in neutral tone, which they rated according to valence level. Subsequently they performed a surprise recognition task with written stimuli (half being foils). Our results revealed a significant valence/arousal effect on word recognition; written words with high-arousal and either positive or negative valence were recognized with higher accuracy compared to low-arousal neutral ones. EEG analyses revealed an effect of valence only for words presented in written format; no effects were found for auditory words. For written words, both positive and negative valence elicited a larger P2 response in comparison to neutral valence, indicating allocation of attentional resources. Critically, a reduced N400 was observed only for negative words, suggesting facilitated processing of unpleasant information perhaps due to better encoding during the auditory presentation. Overall, our study provides valuable insights into the cognitive mechanisms involved in integrating emotional information presented in distinct modalities, shedding light on the influence of valence on word recognition.

VALENCE FACILITATES ENCODING AND LEXCIAL ACCESS

Valence of Auditory Words Enhances Subsequent Recognition

and Facilitates Processing of Written Words:

ERP and Behavioral Evidence

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INTRODUCTION

Individuals tend to remember speech addressing emotional experiences, perhaps due to the use of emotionally-charged words (Kensinger & Corkin, 2003). The emotion that a word elicits has been frequently measured and contrasted by vector models, suggesting that each emotion can be described in terms of two main dimensions: valence and arousal (Rubin & Talarico, 2009). Valence refers to the degree to which an emotion is positive or negative; for instance, words like "paradise" have high, positive valence, while those such as "earthquake" have low, negative valence. Arousal refers to the intensity that an emotion activates – a word such as "death" evokes a high level of arousal, whereas a more neutral word such as "carousel" is associated with low arousal ratings. In vector models, words with higher arousal tend to be located at the two extreme ends of valence scale, while words with lower arousal are rated in the middle of valence scale. Additionally, negatively valenced words generally show a stronger correlation with arousal than positively valenced words. This arousal bias to negative words as well as the u-shaped distribution along arousal and valence dimensions have been observed across several European languages (Warriner et al. 2013; Söderholm et al. 2013; Monnier & Syssau 2014; Stadthagen-Gonzalez et al. 2017) as well as in Mandarin (Yu et al. 2015). These findings reflect a universal pattern of emotion classification, as revealed by questionnaires where participants evaluate their perception of a word's arousal and valence on a numeric scale.

The impact of emotional valence on word processing has been investigated through several physiological measures, such as heart rate (Iffland et al. 2020), skin conductance (Jankowiak et al. 2018) or facial muscle activity (Niedenthal et al. 2009). Number of studies using electroencephalography (EEG) have demonstrated specific ERP signatures evoked by the processing of valenced words presented in written format, both at initial as well as at later stages (for a review of early studies, see Citron, 2012). Two early ERP components, the P2 and the Early Posterior Negativity (EPN), have been frequently observed in response to these stimuli. The P2 component, peaking at approximately 150 - 300 ms over centro-frontal sites, is characterized by more positive amplitudes for highly arousing stimuli compared to less arousing stimuli, reflecting the automatic allocation of attentional resources to words that elicit emotion (Hajcak et al. 2012). The EPN response is similar to the P2 in terms of its sensitivity to emotional content of verbal stimuli and the time window. The two, however, have distinct polarity and scalp distribution. Specifically, EPN shows larger negative-going amplitudes for emotionally-valenced words compared to neutral words, observed mostly over occipito-temporal sites. In contrast, the ERP components elicited by emotional words during the later stages of processing, notably the N400 and Late Positivity Component (LPC) tend to be influenced by task demands. Some studies have reported reduced N400 effects for valenced words compared to neutral words when participants performed a lexical decision task (Kanske & Kotz, 2007; Schacht & Sommer, 2009; Pauligk et al., 2019), an emotion-color stroop task (Sass et al., 2010) or a gender decision task (Kanske & Kotz, 2011). These findings thus suggest facilitated lexical or semantic processing of emotional stimuli. The LPC is a positive deflection that occurs at a latency of around 500-800 msec post stimulus onset over parietal regions. Emotionally valenced (positive and/or negative) words generally elicit a greater response than neutral words (Carretie et al. 2008; Citron et al., 2013; Herbert et al., 2008; Hinojosa et al., 2010; Hofmann et al., 2009; Palazova et al., 2011), reflecting the sustained attention towards a more in-depth evaluation of the emotional features of a stimulus.

The auditory processing of valenced words has been less widely documented in comparison to written words. In a seminal study, Mittermeier and colleagues (2011) reported an early modulation, in the P2 time window, for valenced words in comparison to simple tones. Using the same materials as Mittermeier et al (2011) in a combined fMRI/ERP design, Jaspers-Fayer and colleagues (2012) reported a similar early modulation of the P2 component, which was coupled with early activation of the anterior and orbito-frontal cortex specifically for emotionally laden auditory words. Importantly however, in both studies, these effects were obtained by contrasting auditory words with negative or positive valence to either simple tones or meaningless syllables. In contrast to these results, studies that compared the auditory processing of valenced words to neutral words rather than to non-linguistic stimuli, found no evidence of such early modulations. Grass and colleagues (2016) reported effects of valence 370-530 msec post-stimulus onset, evidenced by an increased frontal positivity and parieto-occipital negativity, which the authors suggested to be a mix of an N400 response and the auditory equivalent of the visual EPN. They did not find that the modulation of these later components, linked to lexical-semantic processing, was affected by modulations of the physical characteristics of the auditory words (volume), which affected the N1-P2 complex. Grass et al. (2016) argued that the auditory response evoked by the emotional content of words is thus distinct from early auditory evoked potentials. It is important to note that none of the above studies manipulated the prosodic contours of the auditory words, which were produced in a neutral manner. Indeed, the emotion conveyed by spoken words can be transmitted by both semantic content and by the speaker's prosody, and the latter can affect earlier components such as the P2 (cf. Kotz & Paulmann, 2007). Hatzidaki and colleagues (2015) reported that valenced words evoked an increased late positivity, coming in after the offset of auditory stimuli, which resembled an LPC. Rohr and Rahman (2015), in contrast, did not find a reliable effect of valence on EEG signatures of auditory word processing at either early or later stages in pre-defined time windows or electrode sites. Post hoc exploratory analyses revealed a small but reliable increase in negativity at central ROI in response to negatively-valenced words from 300-400 msec. To further explore how valence and arousal may affect processing in the auditory domain, Kanske and Kotz (2011) compared the cortical response for negatively valenced compared to neutral auditory words in a task that involved response conflict. Both the ERP and fMRI results showed an interaction between response conflict and emotion, with an increased positivity at anterior sites between 420 and 550 msec and increased activation in the ventral anterior cingulate cortex when processing conflict in an emotional context compared to neutral context. Taken together, these studies suggest that the processing of isolated auditory words pronounced in neutral tone has shown a rather wide range of cortical response, with none of the reported effects occurring earlier than 300 msec.

Valence not only has an immediate impact on processing, as indexed by changes of neural activity, but its longer-lasting effects on our cognitive functions, especially memory, have also been studied with behavioral measures (for a review, see Kensinger & Schacter, 2008) and ERPs. Indeed, people tend to remember more visual stimuli that have high arousal, emotional valence than that have low arousal, neutral valence, including images (Jaeger et al., 2022), faces (Johansson et al., 2004), sentence contexts (Maratos et al., 2001) or isolated words (Leclerc & Kensinger, 2011). Several ERP studies were also conducted to understand the neural underpinning of how recognition memory is modulated by emotional valence. A common experimental design is the "study-test" paradigm, in which participants are first presented with a set of stimuli they are instructed to memorize, followed by a test phase during which they are asked to indicate whether items are old or new. Windmann and Kutas (2001) used this paradigm under the hypothesis that valence would bias participants' recognition memory, leading them to both correctly identify and falsely recognize more negatively-valenced words as old, which would in turn impact the ERP response. Their hypothesis bore out behaviorally (see Inaba et al., 2005 for similar behavioral evidence). In contrast, valence produced no effect on ERPs prior to 450 msec and only a limited effect on the LPC. Using a similar design, Inaba and colleagues (2005) reported an "increased positivity" starting at 150 msec and continuing through 700 msec for correctly identified negative and positive words (new and old) compared to neutral words. The difference across the two studies lies thus in the ERP signature, which showed an early effect of valence, most likely related to the N400, in Inaba et al. (2005) but only a late effect, linked to the LPC, in Windmann and Kutas (2001). Santaniello and colleauges (2018) employed a short and long lag repetition priming paradigm to examine the influence of valence both behaviorally and on ERPs. They demonstrated that, compared to neutral and positive words, repeated negative words elicited a reduced N400 in central-posterior regions, suggesting a stronger episodic trace for these words. Critically, the facilitation was short-lived as the reduced N400 was significant only for very short lag repetition. Auditory stimuli, both linguistic (Schirmer, 2010) and non-linguistic (Alonso et al. 2015), have also been used in behavioral research to investigate the effects of valence on recognition memory. Schirmer (2010) showed that emotional prosody of auditory neutral words modulated the subsequent valence ratings of written words, but did not increase their recognition accuracy. In sum, previous ERP research on the effect of valence on the recognition of printed words has produced inconsistent results. The present study aimed to further address this question.

To our knowledge, no research to date has tested whether the valence of auditory words enhanced the subsequent recognition of written words, nor how such may impact the underlying neural mechanisms. To address these questions, we conducted an ERP experiment where participants were presented with positive, negative and neutral words in auditory format, and were later tested for their recognition of these words in written format. Based on previous literature, we hypothesized that participants would show enhanced behavioral recognition for valenced words, compared to neutral words. In relation to ERPs, previous research on auditory processing of valenced words has produced mixed results such that no clear hypotheses can be made. For written words, we predicted that valenced stimuli would induce an increased early attention, as indexed by the P2 or EPN. We also predicted facilitated processing to valenced words, based on not only pre-existing valence norms but also the ratings of individual participants.

EXPERIMENT 1

The first experiment had three main objectives. The first was to expose participants to the set of stimuli, presented as individual spoken words in Mandarin. The second was to reexamine the effect of valence and arousal on the cortical processing of spoken words as evidenced by ERPs. Only valance and arousal were manipulated; prosody was neutral for all stimuli. The third aim was to provide a cross-linguistic validation of the valence of the auditory stimuli, originally rated in English, by asking participants to rate each item on a 5 point scale, from negative to positive, in Mandarin.

2.1 Method

Participants. Twenty-five Mandarin native speakers (12 women) residing in Aix-Marseille-Provence metropolis, aged 19 to 34 years (M = 25.8, SD = 4.2), were recruited. They reported living in a Mandarin-speaking country until the age of 18 with an average length of stay in France of 2.5 years (range: 0.5-7 years, SD=2.0). All participants had normal or corrected-to-normal vision, were right-handed (Oldfield, 1971), and none presented hearing impairment or psychiatric disorders. All participants gave written consent prior to participation and received a gift card after the experiment.

Materials. Target words were chosen from Affective Norms for English Words (ANEW) and (Bradly & Lang, 1999), based on mean valence from 1 (negative) to 9 (positive), and arousal scores from 1 (low) to 9 (high). The pool of items was initially selected following the criteria: (1) valence values were greater than 6.5 for positive words, less than 3.5 for negative words and between 4.5-5.5 for neutral words; (2) arousal values were greater than 5 for both positive and negative items and less than 4.5 for neutral words. The set of words did not contain taboo words. All selected items were translated into Mandarin and French, and the printed frequency was obtained from Sinica Corpus for Mandarin and from Lexique 3 for French. A further selection was performed based on the printed frequency of selected items in both languages. Twenty-five items were retained for each of the three emotion categories. All Mandarin words were disyllabic and contained 2 characters. An overlap of character was avoided so that no minimal pairs were included in the pool of words. LME models with Item as a random effect and the fixed effect of Emotion Category (CAT) were performed to examine differences in lexical properties, arousal and valence (**cf. Table 1**). None of the differences in either printed frequency or number of phonemes was significant across categories. Number of strokes did not differ between negative and positive items, whereas both tended to differ from neutral items. Arousal ratings did not differ between negative and positive target words, whereas both differed from neutral words. Valence ratings differed significantly between all 3 categories; negative words were rated lower than both positive and neutral words, and the latter were rated lower than positive words.

Target items were recorded in a professional sound booth and sampled at 48 kHz with a format of 32-bit float during a single session by a female Mandarin native speaker who did not participate in the main experiment. They were subsequently segmented and annotated automatically into individual tracks with SPASS(Bigi, 2021) and manually verified in PRAAT(Boersma et al.). LME models revealed no significant difference in auditory word duration between any of two Emotion categories (cf.**Table 1**). Altogether, there were 75 trials divided into 3 blocks, with an even distribution of Valence category and Mandarin printed frequency across blocks; block order was counterbalanced across participants.

Procedure. Participants were seated 70 cm from the computer monitor in a dimly lit, sound-attenuated room. Each trial began with a fixation cross, concurrent with an auditory target word in Mandarin. Participants were asked to rate each word according to its valence from 1 to 5 on a Likert scale (1: very negative, 2:

somewhat negative, 3: neutral, 4: somewhat positive, 5: very positive) manually on an external response box upon the presentation of a visual response prompt. Subsequent to the response, a blink prompt was displayed for 1 second prior to the onset of the next trial. A practice block of 5 trials initiated participants to the task requirements. Participants could take a short break between the blocks.

Electroencephalographic (EEG) activity was recorded continuously from 64 scalp locations using BioSemi Active Two system AD box over frontal, temporal, central, posterior temporal, parietal and occipital areas of the left and right hemispheres and midline. EEG data were sampled online at 512 Hz and impedance for individual electrodes was kept below 20µV. Electrodes were placed beneath and at the outer canthus of the left eye to monitor blinks and horizontal eye-movements, and over the left and right mastoids. Offline analysis was referenced to the electrode placed on the left mastoid. EEG continuous signal was segmented offline starting from 100 msec prior to stimulus onset, which served as reference point for the pre-stimulus baseline correction, to 1100 msec post stimulus onset All channels were filtered offline with a high frequency filter of 30 Hz. Automated routines were applied to exclude trials contaminated by ocular-motor or muscular artifacts.

2.2 Results

Behavioral measures. Valence ratings of all Mandarin target words by all participants categorized by emotion type are illustrated in**Figure 1** . Neutral words (mean=3.2, SD=0.6) were rated lower than positive words (mean=4.3, SD=0.9 ; $\beta = 1.05$, se = 0.1229, t = 8.5, $p<.001$), and higher than negative words (mean=1.6, SD=0.8; $\beta = 1.58$, se = 0.1275, t = 12.38, $p<.001$). The re-leveled model with "negative" as intercept revealed a significant difference between negative and positive words ($\beta = 2.63$, se = 0.1499, t = 17.54, $p<.001$). We also calculated the percentage of items that were rated per participant within the expected range for their predesignated category: negative (1 or 2), neutral (3) or positive (4 or 5). This included 80.9% of items across all participants, with less Neutral words (M=73.8%, sd=17.4%) than Positive words (M=83.0%, sd=10.5%; β =.092, se =.039, t = 2.321, $p<.05$) or Negative words (M=85.9%, sd=13.6%; β =.121, se =.039, t = 3.041, $p<.001$), while no difference was found between Positive and Negative words (β =-.028, se =.039, t = -0.720, p=.475).

ERP analyses. Analyses included all trails free from artefact, for items that were rated within the expected range for their predesignated category: negative (1 or 2), neutral (3) or positive (4 or 5). The percentage of trials lost due to artefact was 16% for the Neutral words, 14% for the Positive words and 16% for Negative words, and to ascertain whether the valence of target words induced differences in the ERP trace, we conducted a two-tailed permutation t-test (1000 random partitions) between Neutral and Negative target words, and between Neutral and Positive target words for all selected electrodes (midline: Fz, FCz, Cz, CPz, Pz, frontal central : FC1, FC3, FC5, FC2, FC4, FC6, central-parietal: C1, C3, C5, C2, C4, C6, CP1, CP3, CP5, CP2, CP4, CP6, and parietal: P1, P3, P5, P2, P4, P6), with time points of 5 ms across the entire epoch (0 to 1200 ms after stimulus onset). Only differences that persisted for 10 ms or more were considered statistically significant. The results revealed no significant differences between Neutral and Positive, or between Neutral and Negative target words at any selected electrode. **Figure 2** shows the average response across all 20 participants for 9 central partiel cites; none of the permutation tests are revealed due to there being no significant effects.

To further examine possible differences induced by Valence, we modeled the data using linear mixed effect regression, with the LmerTest package (Kuznetsova & Christensen, 2017) in R (R Core Team, 2017). The models, summarized in **Table 2** , included the treatment coded fixed factor Valence (Neutral, Negative, Positive), with random intercept for Item and Participant. A random slope of Valence for Participant was included. Models were performed independently at 3 ROIs for the mean voltage amplitude at the four time windows post stimulus onset, associated with the P200 (150-300 msec), N400 (300-500 msec), LPC (500-800 msec) and later component (800-1200 msec). No significant differences were found in any ROI, at any time window (cf. **Table 2**).

2.3 Discussion

Our results did not show any evidence of early ERP components linked to the processing of spoken emotionally laden words. Notably, we did not find that negatively or positively valenced words evoked an EPN compared to neutral words. This result is in line with several previous studies, which only showed effects starting at 370 ms (Grass et al. 2016; Kanske & Kotz, 2011; Rohr & Rahman, 2015) or substantially later, only after word offset (Hatzidaki et al., 2015). In contrast, Mittermeier and colleagues (2011) reported increased early negativity, on the P2 component, for auditory words with both negative and positive connotations, but only in comparison to neutral tones (and only reported for Pz). The very early effects reported by Mettermeier (2011), replicated by Jaspers-Fayer and colleagues (2012), may nonetheless be linked to their design, which included only ten auditory words that were repeated numerous times. This may have allowed participants to anticipate the words and access meaning from their onset. In addition, as no neutral words were included, it is difficult to ascertain whether the reported effect was due to the valence of the linguistic stimuli or to differences in task demands, i.e. the ease of discriminating between two tones vs. identifying linguistic content. In line with this, previous results have shown that the N1-P2 complex is modulated by the physical characteristics of auditory stimuli but not by their linguistic (emotional) content (Grass et al., 2016). The lack of early effects in present study may be linked to the characteristics of our auditory stimuli in particular and to auditory processing of words in general, which is incremental in nature. The Mandarin words we presented were disyllabic and full lexical access was not possible until participants heard the second syllable, which on average occurred at roughly 400 msec. No stimulus was repeated such that participants could not anticipate words. Our results differ from Grass's study (2016), which reported an enhanced frontal positivity and parieto-occipital negativity for valenced words between 370-540 msec post-stimulus, likely due to the differences in task requirement: While our study used a valence judgement task, Grass's study employed a one-back task that encouraged participants to recall previous stimuli, leading to increased priming effect through contextual association. Valenced words have been shown to exhibit stronger inter-item associations and higher semantic relatedness (Buchanan et al., 2006), suggesting that valenced words may prime each other more effectively. This superior priming among valenced words could result in facilitated processing for valenced words during the one-back task. Instead, our findings align more closely with Hatzidaki's (2015) study, which also used a valence judgement task and reported a late LPC between 600-950 msec post-stimulus. Although the mean amplitudes of ERPs for our Negative or Positive words were numerically larger than for Neutral words in later time windows (500-800 msec and 800-1100 msec), this pattern did not reach statistical significance.

In relation to the behavioral classification of the auditory words, our results showed that participants' valence ratings of Mandarin words generally corresponded to the English norms, with some discrepancies. Previous studies of emotion lexicons have shown cultural differences of emotion concept, including appraisal. That is, while an emotion word may have equivalent translations in two languages, speakers of those languages may still have different evaluations of associated events or consequences with positive or negative connotation (for a review, see Pavlenko, 2008). Noting that our experimental words were translated from English to Mandarin and categorized into one of three given valence types based on an affective database of English words, our behavioral data is thus consistent with this account, reflecting that Mandarin speakers and English speakers did not always appraise lexical items that carry emotional connotations identically.

EXPERIMENT 2

As outlined in the general introduction, people tend to show enhanced recall and recognition of emotional stimuli compared to neutral ones (for a review, see Tyng et al., 2017). Such "emotion-memory" effects are less widely documented for auditory than visually presented stimuli. We capitalized on our participants having taken part in the first, auditory experiment to further examine this question. In the following experiment, stimuli were presented in written format and participants were required to identify those words that they had heard in the immediately prior experiment among an equal number of foils with positive, negative or neutral valence ratings. Participants were not informed of the second experiment prior to the completion of the first. The second experiment thus provided us with a means to examine the impact of valence and arousal on memory encoding as well as allowing a direct comparison of the electrophysiological response to emotionally laden words across auditory and written format. To our knowledge, while numerous studies have examined the ERP response to emotion words in either written or auditory format, only one study (Rohr & Rahman, 2015) to date has directly compared the two for the same set of words. Distinct patterns were reported as a function of presentation, with an enhanced negativity, specifically for negative compared to neutral words for printed words, while no reliable valence effect, but an unexpected negativity over central ROI for negative words compared to neutral words in auditory presentation.

3.1 Method

Participants. The same 25 Mandarin native speakers participated in the experiment 1.

Materials. A total of 150 Mandarin words were visually presented. Half of the stimuli were the target stimuli presented aurally in Experiment 1. The other half were foils, selected from the ANEW database following the identical selection criteria as the targets. Twenty-five filler words were selected per valence category, and then translated into Mandarin. All words comprised two characters. Across target and foil words, both Valence and Arousal ratings were equated for each emotion category, including Negative words (mean target and foil valence 2.68 vs 2.45, $\beta = 0.264$, se = 0.155, t = 1.70, ns; mean target and foil arousal 5.85 vs 5.89, $\beta = -0.073$, se = 0.131, t= -0.56, ns), Positive words (mean target and foil valence 7.53 vs. 7.55, $\beta = -0{,}019$, se = 0.154, t = -0.13, ns; mean target and foil arousal 5.73 vs. 5.72, $\beta = 0.014$, se = 0.164, t= 0.09, ns) and Negative words (mean target and foil valence 5.11 vs. 5.09, $\beta = 0.026$, se = 0.081, t = 0.32, ns; mean target and foil arousal 3.75 vs. 3.86, $\beta = -0.117$, se = 0.128, t= -0.92, ns).

Procedure. Participants were comfortably seated, facing a computer screen situated at a distance of 70 cm in a dimly lit, sound-attenuated room wearing a 64 channel Biosemi electrocap. Each trial began with a fixation cross, followed by a written Mandarin word. Participants were asked to determine whether they had heard the word in the previous experiment and press the corresponding button (*yes* or *no*) on an external response box. Subsequent to the response, a blink prompt was displayed for 1 second prior to the onset of the next trial. A practice block of 5 trials initiated participants to the task requirements. EEG was recorded throughout the session, in identical fashion to that of the first experiment.

3.2 Results

Behavioral measures. Recognition accuracy was analyzed in a logit glmer model that included the treatment coded fixed factor Valence (Negative, Neutral and Positive) with random intercepts for Participants and Items. The slope for Valence was not included due to non-convergence of the model when included. The first model with "Neutral" as intercept revealed that neutral words (M=69.4%, sd=18%) significantly differed from both Positive words (M=85.9%, sd=9% ; $\beta = 4.12$, se = 0.7321, t = 5.63, $p<.001$) and Negative words (M=81.3%, sd=14%; $\beta = 2.96$, se = 0.7321, t = 4.04, $p<.001$). The re-leveled model with "Negative" as intercept did not reveal a significant difference between negative and positive words ($\beta = 1.16$, se = 0.7321, t = 1.58, p=.119). This pattern of results confirmed that recognition accuracy was higher for emotionally laden target words (whether positive or negative) than neutral words. (cf. **Figure 3**)

ERP analyses. To probe the effect of Valence on the processing of printed Mandarin words, a two-tailed permutation t-test (1000 random partitions) was conducted to assess significant differences in ERP amplitude between Neutral and Negative target words, and between Neutral and Positive target words for all selected electrodes (midline: Fz, FCz, Cz, CPz, Pz, frontal central : FC1, FC3, FC5, FC2, FC4, FC6, central-parietal: C1, C3, C5, C2, C4, C6, CP1, CP3, CP5, CP2, CP4, CP6, and parietal: P1, P3, P5, P2, P4, P6), with time points of 5 msec across the entire epoch (0 to 1200 msec after stimulus onset). Only differences that persisted for 10 msec or more were considered statistically significant. **Figure 4** demonstrates the results of these tests for 9 representative electrodes.

Based on the results of the permutation tests, the mean voltage amplitude of two time windows, 220-300 msec and 300-500 msec, were chosen. These windows are also in line with the P2 and the N400 components in the literature. Data were modeled using linear mixed effect regression, with the LmerTest package (Kuznetsova & Christensen, 2017) in R program (R Core Team, 2017). Models were performed independently over 3 regions of interest : mid-line sites (Fz, FCz, Cz, CPz, Pz), frontal-central sites (FC1, FC3, FC5, FC2, FC4, FC6, C1, C3, C5, C2, C4, C6) and centro-parietal sites (CP1, CP3, CP5, CP2, CP4, CP6, P1, P3, P5, P2, P4, P6). The first models, summarized in **Table 3** , included the treatment coded fixed factor Valence (Neutral, Negative, Positive), with random intercept for Item and Participant. A random slope of Valence for Participant was included. Independent models were performed at all 3 ROIs for the mean voltage amplitude in the 220-300 and 300-500 msec time window. The models revealed significant differences between Negative and Neutral target words at all 3 ROIs in the 220-300 msec time window, and at frontal-central sites in the 300-500 msec time window). The comparison of Positive and Neutral target words revealed a significant difference only at frontal-central sites in the 220 - 300 msec time window.

3.3 Discussion

Our results showed modulation of the P2 in response to emotionally-laden visually presented words, but not an EPN response in contrast to earlier studies (cf Citron, 2012 for a review) which considered the EPN to be a robust EEG signature. Indeed, several recent studies failed to demonstrate a negative deflection at posterior sites during early time windows for emotionally valenced words (Pauligk et al, 2019; Ku et al. 2020; Imbir et al. 2021). In addition, unlike previous research showing larger P2 amplitude to either only positive words (Schapkin et al.,2000) or only negative words (Huang & Luo, 2006), our results demonstrated an enhancement of positive amplitude across the 220-300ms time window for both positively and negatively-valenced words, compared to neutral words. However, the effect was more widespread for negatively valenced than positively valenced words. The P2 component is assumed to reflect the early, automatic allocation of attentional regardless of task-relevance of emotional context (González-Villa et al., 2014). Our findings thus indicate that more attentional resources were allocated to emotion stimuli during the recognition task, undoubtedly due to the inherent importance of such stimuli. Our results add to literature on the P2 effect for positive as well as for negative valence words (Herbert et al.,2006). As noted above, this early effect was widespread for negative words, whereas positive words elicited a larger P2 amplitude only over frontal-central sites. According to the automatic vigilance model of emotion, humans have learned to avoid adverse situations for survival in threatening environments. In contrast, leaving a positive reward unattended would not incur a cost. The mechanism that quickly detects undesirable messages thus developed, leading to an attentional bias to negatively-valenced information (Estes & Adelman, 2008). It is thus possible that such "negativity bias" of emotion processing may have increased the P2 effect, extending to a boarder cortical response to negative than positive words. The concept of "negative bias" is in line with Rohr and Rahman's (2015) results. Although these authors reported an EPN, which exhibits a distinct distribution and opposite polarity to our P2, they observed an EPN for negative words, but not for positive words, suggesting that the processing of negative words is prioritized over positive words at an early perceptual stage.

In addition, our results showed reduced N400 amplitude with a frontal-central distribution to words that carried negative connotations in relation to neutral words. Interestingly, in roughly the same time window, Grass et al. (2016) found that negatively connotated spoken words elicited a greater anterior positivity compared to neutral words. Recent, Leynes and Upadhyay (2022) suggested that distinct scalp distribution of N400 can be associated with either relative or absolute familiarity. They suggested that N400 detected at posterior sites reflects integrating process to accumulated semantic knowledge based on lifetime experience, while the frontally-distributed N400 (FN400) is hypothesized to be sensitive to the exposure of current content, with an attenuated negative wave to old relative to new items, indicating ease of processing for words that were recently presented, for example during a recognition task. Taken together, our results support the hypothesis that valenced words were processed more easily than neutral words due to the higher level of relative familiarity from previous auditory exposure, as indexed by a reduced FN400.

In contrast, our positive stimuli failed to elicit a reduced FN400, suggesting negligible facilitated processing during the recognition task. This result could be explained by the "negativity bias" of recognition memory in younger adults (Carstensen & DeLiema, 2018). That is, while aging brains are prone to positive content, younger adults tend to remember more negative than positive information. Taking this into account, less priming resources of positive words were maintained during initial encoding, leading to little or non-existent processing facilitation for positive words. This pattern of EEG results does not, however, match that for our behavioral data, which did not showed a “negative bias” where both negative and positive words were recognized better than neutral words. We can note that participants were not required to respond within a given time frame, such that the conscious retrieval of words may have overridden the facilitation often observed for negative words.

GENERAL DISCUSSION

The aim of the current study was twofold. First, we explored how the valence of auditory words, presented in an immediately prior experiment, influenced the subsequent recognition of printed words. Second, this design allowed us to directly compare the ERP response to the same stimuli across auditory and visual format. In relation to the first question, our results demonstrate a clear effect of valence/arousal of auditory stimuli on the subsequent recognition of these stimuli presented in written format. This was borne out by both behavioral and ERP data. Our behavioral results revealed increased recognition for both positive and negative valenced words compared to neutral ones, in agreement with the existing literature (Kensinger & Corkin, 2003). The neural response associated with the recognition of visually-presented valenced words was revealed by two different components, which varied according to polarity of words. We observed an increase in the P2 component, for both negative and positive words, although the effect was more widespread for negative words. In contrast, we observed a reduced N400 only for negative words in relation to neutral words. Overall, the results suggest that more attentional resources were allocated to negative words during recognition. It is possible that the relatively young age of our participants contributed to the “negative bias” that we observed in the ERP record (Carstensen & DeLiema, 2018).

Our ERP results align with those reported by Maratos and colleagues (2000) for valenced words. They demonstrated reduced N400 amplitudes to words with negative connotations compared to neutral words during a surprise memory task, with a maximum amplitude at frontal sites. However, the FN400 effect was found not only at the recognition phase but also during the prior encoding phase. As such their results do not support our claim that the effect arises from facilitated processing during recognition. Indeed, the FN400 effect has been reported in prior ERP studies including negative and positive words in diverse tasks. For instance, in a lexical decision task, Kanske and Kotz (2007) reported a reduction of N400 amplitude for concrete valenced words, relative to neutral words, and the effect was stronger over anterior than posterior sites. In an emotion-color Stroop task, valenced words elicited a reduced N400 compared to neutral words, with a frontal distribution (Sass et al., 2010). Together, these results indicate that the facilitated processing of valenced words per se, as indexed by reduced FN400, is likely due to higher-level inter-item association among valenced words. Otherwise stated, words with emotional connotations tend to prime one another due to their higher degree of semantic relatedness (Buchanan et al. 2006). However, our results diverge from the above-mentioned studies, in that we only found a reduced fN400 for negative items. If said effect was only due to semantic relatedness among stimuli, we would expect to observe a similar effect for positive words, which we did not. Therefore, it is less likely that the FN400 effect found for our negative words stems from inter-item association.

Kaestner and Polich (2011) reported a similar pattern of “negative bias” for facilitated processing during recognition in an ERP study using pictorial stimuli. Participants were instructed to memorize a series of pictures with high or low arousing, negative or positive valence, and then asked to indicate if the image had been presented previously. Behavioral results showed that d-prime (hit minus false alarm) was higher for negative than positive stimuli, suggesting that negative pictures were more salient and easier to detect than positive pictures. EEG results showed different patterns across the first, passive viewing task and the subsequent recognition task. During the recognition phase, compared to positive pictures, negative pictures showed larger effects of arousal, including enhanced positivity 200-400 msec and reduced negativity 450-650 msec post-stimulus. This effect, however, was not found during the passive viewing task. Instead, they reported a larger positivity 500-900 msec post-stimulus in response to negative pictures with high-arousal level, compared to low arousal level, reflecting a sustained allocation of attentional resources. Their results suggest that the effects of emotional valence is dependent on task demands and, critically, these findings support the idea that stimuli with negative content may have a privileged status in memory processing. Our results join this account and further demonstrate that the negativity bias in recognition memory extends to lexical items. In relation to the second question, we found clear differences in the neural response to valenced words as a function of presentation format. In line with the vast majority of studies, we did not find any evidence of early ERP effects for auditory presentation, in contrast to written words. As concerns later components, we again only found modulations, in the N400 time window, for written words, with no reliable effects for words presented auditorily. This question remains to be explored. Indeed, whereas early effects are quite rare, previous work has shown a modulation of the LPC (Hatzidaki et al., 2015) although it can be noted that their results were limited to processing in specific contexts. Overall, our results provide a compelling and complete picture of the effect of valence on the immediate processing and subsequent recognition of words as a function of presentation format. Our study provides valuable, cross-linguistic evidence to the existing body of literature and calls for further studies to examine how memory is affected by the emotional content of words.

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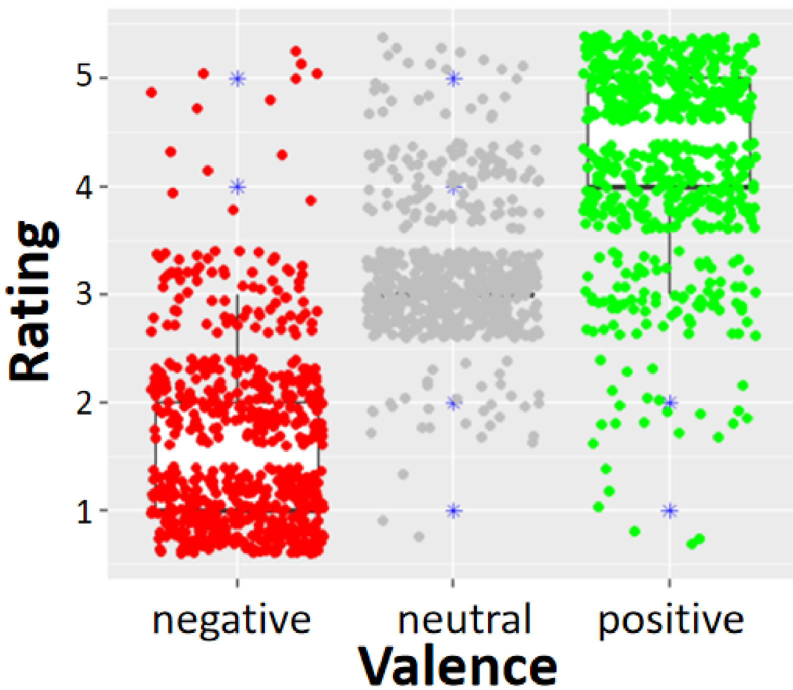

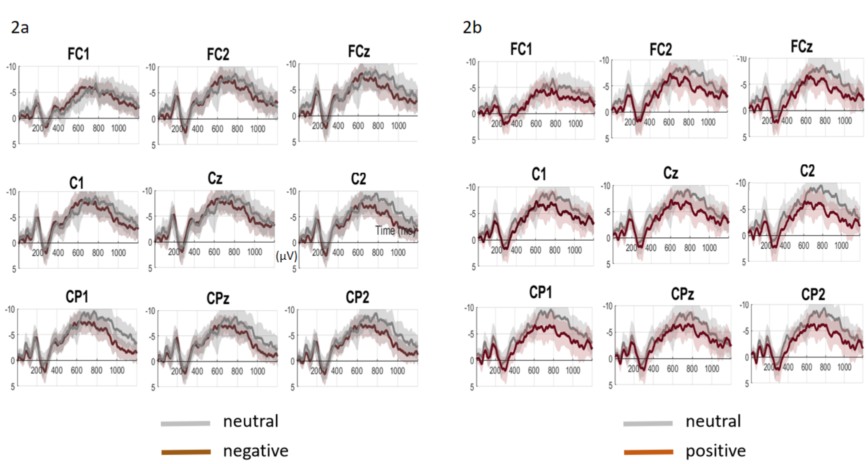

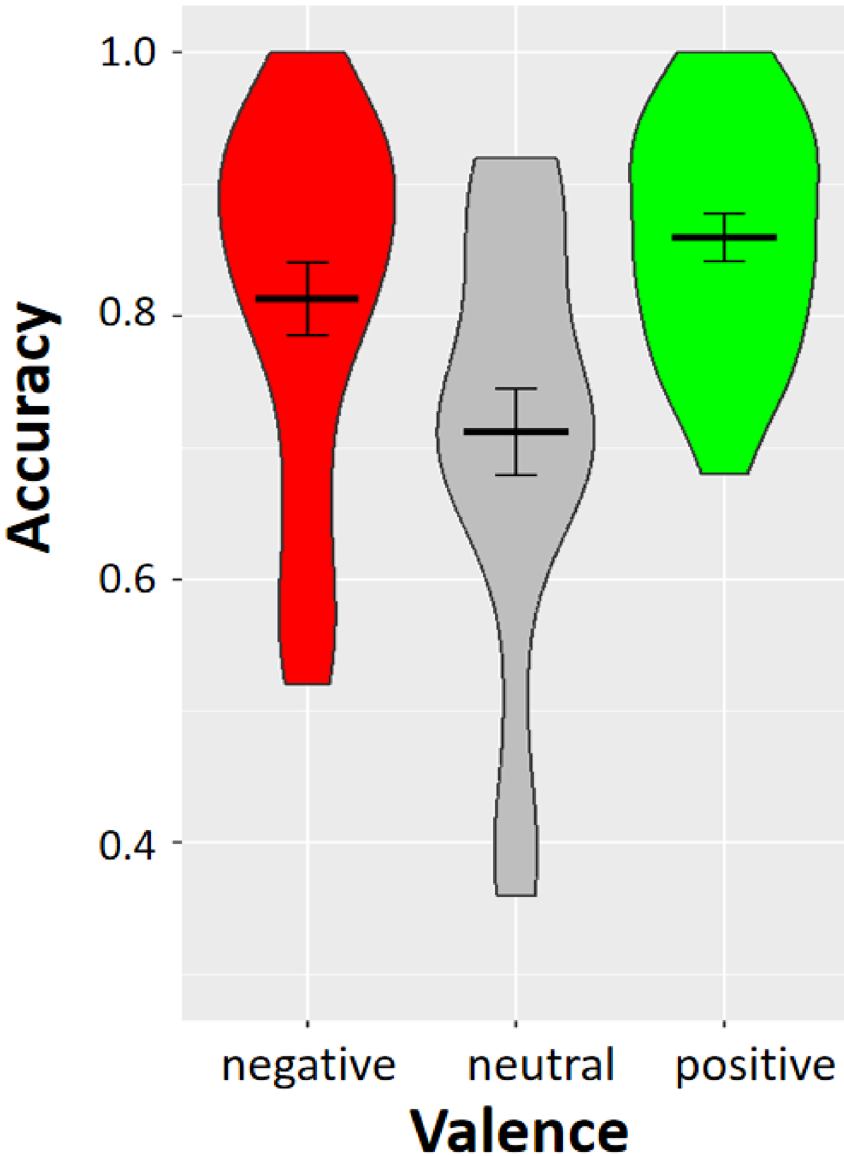
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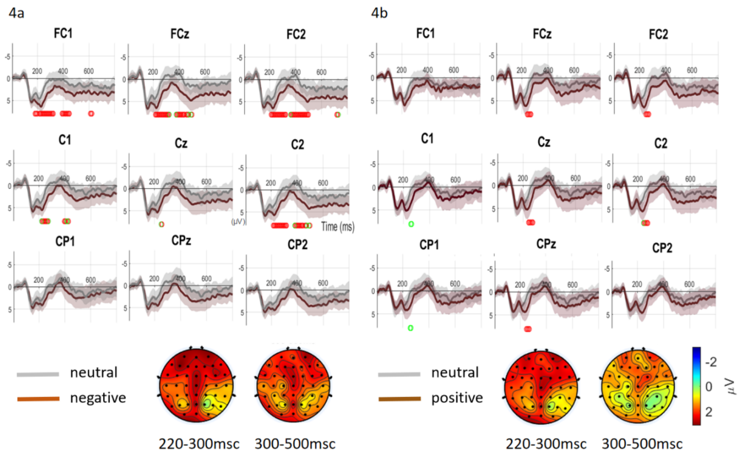

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