Associated valence impacts early visual processing of linguistic stimuli: Evidence from ERPs in a cross-modal learning paradigm

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Emotion effects in event-related potentials (ERPs) during reading have been observed at very short latencies of around 100 to 200 ms after word onset. The nature of these effects remains a matter of debate: First, it is possible that they reflect semantic access, which might thus occur much faster than proposed by most reading models. Second, it is possible that associative learning of a word's shape might contribute to the emergence of emotion effects during visual processing. The present study addressed this question by employing an associative learning paradigm on pseudowords. In a learning session, pseudowords were associated with positive, neutral or negative valence by means of monetary gain, loss or zero-outcome. Crucially, half of the pseudowords were learned in the visual modality, while the other half was presented acoustically, allowing for experimental separation of associated valence and physical percept. In a test session 1 to 2 days later, acquired pseudowords were presented in an old/new decision task while we recorded event-related potentials. Behavioural data showed an advantage for gain-associated pseudowords both during learning and in a delayed old/new task. In the visual test session, early emotion effects in ERPs were limited to visually acquired pseudowords, but absent for acoustically acquired pseudowords. These results imply that associative learning of a word's visual features might play an important role in the emergence of emotion effects at the stage of perceptual processing.

Keywords: event-related brain potentials (ERPs), associative learning, emotion, word recognition

Introduction

Emotional salience has been shown to impact visual perception, directing attention in service of preferential processing (Pourtois, Schettino, & Vuilleumier, 2013; Vuilleumier, 2015). In event-related potentials (ERPs), the preferential processing of emotional stimuli is visible already at the stage of perceptual encoding: Emotional content increases activation in the extrastriate visual cortex, resulting in modulations of the P1 component as demonstrated for affective pictures (e.g., Delplanque, Lavoie, Hot, Silvert, & Sequeira, 2004) and facial expressions of emotion (Hammerschmidt, Sennhenn-Reulen, & Schacht, 2017; Rellecke, Palazova, Sommer, & Schacht, 2011; Rellecke, Sommer, & Schacht, 2012). Modulations in the time range of the P1, that is around 100-150 ms, have also been reported for written words (Bayer, Sommer, & Schacht, 2012; Hofmann, Kuchinke, Tamm, Võ, & Jacobs, 2009;

Kuchinke, Krause, Fritsch, & Briesemeister, 2014; Rellecke et al., 2011; Scott, O'Donnell, Leuthold, & Sereno, 2009).

In the case of written language, emotion effects within 200 ms after stimulus onset deserve special attention: Pictorial stimuli, including affective pictures (e.g., of a spider) or emotional facial expressions, convey their emotional content by means of their physical shape. Increased attention towards these stimulus features has often been related to biological preparedness (Öhman & Mineka, 2001) and survival-relevance (Lang & Bradley, 2010). Written words, however, consist of arbitrary symbols, which require the translation into meaningful contexts. Most reading models assume that initial orthographic analyses takes around 200 ms, and is only then followed by the processing of lexico-semantic features, as, for example, visible in the N400 component of ERPs (for review, see Barber & Kutas, 2007). In line with these assumptions, previous research has localized the lexicality effect, i.e. the difference in ERPs between existing words and (orthographically legal) pseudowords, at around 200 to 400 ms after word onset (Palazova, Mantwill, Sommer, & Schacht, 2011; Schacht & Sommer, 2009). Importantly, these studies consistently reported effects of emotional content to coincide or even follow the ERP differences between legal words and pseudowords. In the light of these findings and accounts, emotion effects at approximately 100 ms after word onset for written words are remarkable and seem to allow for two possible explanations: First, it might be possible that lexico-semantic access occurs faster than assumed by serial reading models, and that later ERP effects (like the N400) reflect recurrent processing instead of initial lexico-semantic activations. Evidence for this assumption is provided by a number of studies showing effects of (non-emotional) lexico-semantic variables within 200 ms after stimulus onset, including word frequency, but also semantic knowledge (Hauk, Pulvermüller, Ford, Marslen-Wilson, & Davis, 2009; Pulvermüller, Shtyrov, & Hauk, 2009; Rabovsky, Sommer, & Abdel Rahman, 2012; Sereno & Rayner, 2003).

Second, it seems possible that early emotion effects in response to written words do not reflect lexico-semantic processing, but are rather based on associative learning of stimulus valence, which might become tagged to a word's shape. There is accumulating evidence outside of the language domain suggesting that associative learning of perceptual features can impact the early stages of visual perception: In a study by Schacht and co-workers (Schacht, Adler, Chen, Guo, & Sommer, 2012), formerly unfamiliar Chinese characters were associated with positive, neutral or negative monetary outcome by means of associative learning. In a test session 1-2 days later, characters associated with monetary gain elicited an increased posterior positivity at around 150 ms after stimulus onset. Using a similar associative learning paradigm and peripherally presented textures, Rossi and colleagues (Rossi et al., 2017) showed that associative learning of perceptual features can impact even earlier stages of stimulus processing in the primary visual cortex as indexed by the C1 component peaking at around 75 ms after stimulus onset. In two studies using an emotional conditioning paradigm (Fritsch & Kuchinke, 2013; Kuchinke, Fritsch, & Müller, 2015), pseudowords were paired with emotional pictures and subsequently elicited effects of conditioned valence around 100 to 150 ms. Since pseudowords do not have a pre-existing meaning, these studies demonstrate that also meaningless letter strings can be tagged with conditioned valence. Finally, associative learning of stimulus valence has recently also been demonstrated for biologically relevant stimuli: Neutral faces that were previously associated with monetary reward elicited increased ampli-

tudes of the P1 component (Hammerschmidt et al., 2017).

Taken together, previous literature provides evidence for both fast semantic access and associative-learning accounts. However, both mechanisms are not necessarily mutually exclusive, but might even interact. Crucially, there is no way of distinguishing between the two options using existing words as stimulus materials, because emotional valence and perceptual features are pre-determined and cannot be established experimentally. Therefore, the present study used pseudowords and a cross-domain design in order to manipulate both valence associations and perceptual experience with the pseudowords. In a learning session, pseudowords were associated with positive, negative or neutral valence by means of monetary gain, loss, or neutral outcome. They were presented again in a test session 1-2 days later, while EEG was recorded. Importantly, half of the pseudowords were acquired in the visual domain, while the other half was acquired in the auditory domain. In the test session, all words were presented in the visual domain. As a result, participants gained experience with perceptual features (the word shape) only for pseudowords they had acquired in the visual domain, while they acquired the same semantic, i.e. valence, information for both groups.

In accordance with previous literature (Hammerschmidt et al., 2017; Schacht et al., 2012), we expected effects of associated valence in visual event-related potentials within the first 200 ms after stimulus onset. In case these effects would be based on fast access to semantic information, i.e. the valence category of a pseudoword, these effects should occur irrespective of learning modality. If, however, associative learning would be based on a word's perceptual features, early ERP effects should be limited to pseudowords acquired in the visual domain. In contrast, these effects should be absent for pseudowords learned in the acoustic modality, since participants had no experience with their visual features. Concerning the direction of early effects of associated/conditioned valence, previous literature is inconsistent, showing both increased amplitudes for positive associated valence (Hammerschmidt et al., 2017; Schacht et al., 2012) and for negative associated valence (Rossi et al., 2017), as well as decreased amplitudes for negative associated valence (Fritsch & Kuchinke, 2013). Therefore, we did not specify hypotheses about the direction of early effects of associated valence.

While our main focus was on investigating early effects of associated valence in the visual domain, we additionally collected data from an auditory test session from a subset of participants, i.e. pseudowords were presented in the auditory domain via loudspeakers. This data allows comparing the role of perceptual features in valence associations between modalities. In accordance to the rationale described above, participants had acquired experience with the perceptual features (i.e., the sound) only for pseudowords acquired in the auditory domain, but not in the visual domain.

Methods

Participants

Data were collected from 73 participants; 1 dataset had to be discarded due to excessive EEG artefacts. All remaining 72 participants (56 women, mean age = 24.9 years, SD = 3.7 years, 4 left-handed) were native speakers of German, had normal hearing and normal or corrected-to-normal vision. Data from the auditory test session was collected from a subset of 36 participants, of which one dataset was excluded (all remaining participants were female, mean age = 24.9 years, SD = 4.1 years, 2 left-handed). Participants were compensated with course credit

or 8 Euros per hour; additionally, participants received the money they had earned during the learning session (mean final balance = 14.4 Euro, SD = 3.5 Euro, including a base pay of 3 Euro).

Stimuli

Target stimuli consisted of 24 disyllabic pseudowords following the phonological form consonant – vowel – consonant – vowel (e.g., foti, metu, bano). They were constructed in accordance with phonological rules of German and followed phoneme-grapheme correspondence. Pseudowords were distributed in 3 *valence groups* of 8 words each. Within each valence group, four words were presented in their written form in the learning session, while the remaining four words were learned in the auditory domain. Analyses of control variables were referred both to valence groups and to valence x domain subgroups. All groups were controlled with regard to sublexical bigram frequency (character bigram frequency, obtained from the dlex-database accessible at www.dlexdb.de; Heister et al., 2011), all Fs(5,18) < 1; see Table 1. For auditory presentation, stimuli were spoken by a male speaker in neutral prosody and stressed on the first syllable in order to achieve a natural German pronunciation. Acoustic control variables included word duration, mean and peak amplitude, and mean fundamental frequency (F0); all Fs(5,18) < 1.

Table 1. *Descriptive statistics (means and standard deviations) of linguistic and auditory stimulus variables. Bigram frequency was obtained from the dlex-database. Word duration, amplitude and F0 are indicated in milliseconds, decibel and Hertz, respectively, measured with Praat (Boersma & Weenik, 2009). Amplitude values are only relevant for comparisons between experimental categories, but do not reflect actual presentation levels, which were individually adjusted to a comfortable volume level.*

	Bigram frequency	**Word duration**	**Amplitude (mean)**	**Amplitude (peak)**	**F0**
Targets	89558.5 (38875.9)	632.7 (74.2)	72.6 (2.5)	80.1 (1.3)	145.7 (49.0)
Distractors	99154.1 (75376.1)	644.8 (65.6)	72.5 (2.5)	80.1 (1.2)	150.1 (44.8)

The assignment of valence groups and valence x domain subgroups was counterbalanced across participants in a way that each word was assigned to each valence category and learning modality for an equal number of participants. For the test session, 288 distractor pseudowords that followed the same structure as the target pseudowords were constructed by computer algorithm, excluding orthographic neighbours to target pseudowords. Analyses of all control variables listed above revealed no significant differences between target pseudowords and distractors, all Fs(1,435) < 1.83, ps > .177.

Procedure

The experiment consisted of two sessions. In the learning session, participants associated pseudowords to monetary gain, loss, or neutral

outcome by means of associative learning. In the test session 1-2 days later, all pseudowords acquired in the learning session were again presented in an old/new decision task amongst unknown distractors. The study was approved by the local ethics committee of the Institute of Psychology at the University of Göttingen.

Learning session

Upon arrival, participants received detailed information about experimental procedure and provided informed consent as well as demographic information. A short, custom-made hearing test was conducted in order to ensure sufficient hearing.

The participants' task was to acquire associations between pseudowords and valence categories by pressing one of three buttons – corresponding to gain, loss, or neutral outcome – after presentation of a pseudoword. Since no information about the correct outcome category for each specific pseudoword was provided prior to the experiment, participants had to employ a trial-and-error procedure in order to learn a pseudoword's respective valence category, using the feedback that was provided after their choice. This feedback indicated the amount of money the participant had won or lost in the present trial. From this information, participants could gain two facts: First, it provided information about the valence category of a given stimulus, since gain stimuli always resulted in monetary gain, loss stimuli in monetary loss, and neutral stimuli in zero change. Second, in case of gain and loss symbols, the amount of money won or lost indicated whether participants had made a correct or incorrect classification. In case of correct classifications, participants either won more money (correct choice: +20 Cents, incorrect choice: +10) or lost less (correct: -10 Cents, incorrect: -20 Cents). For an overview of the learning scheme, see Table 2.

Table 2. *Learning scheme. Monetary consequences resulting from correct and incorrect classifications for each outcome category.*

Valence category	Words per category	Classification	Response	Outcome
Positive	8	Positive	Correct	+20
		Neutral/Negative	Incorrect	+10
Neutral	8	Neutral	Correct	0
		Positive/Negative	Incorrect	0
Negative	8	Negative	Correct	-10
		Positive/Neutral	Incorrect	-20

Half of the pseudowords (n=12 each) was learned in the visual domain; the other half was learned in the auditory domain. The order of learning modalities was counterbalanced. In the visual learning modality, a fixation cross was shown for 0.5 s, followed by a pseudoword that was displayed for up to 5 s until the participant had pressed a response button. During auditory presentation, pseudowords were presented via loudspeakers; the fixation cross was shown for 0.5 s prior to the pseudoword presentation and remained on the screen until button press for up to 5 s. After an inter-stimulus interval of 1.5 s, the feedback stimulus was presented for 1s.

The feedback consisted of a light grey disk that showed the amount of money the participant had won or lost by their choice; gain symbols were presented in green, loss symbols in red, and neutral symbols in dark grey font colours, respectively. The assignment of response buttons to outcome categories (left to right: gain – neutral – loss or loss – neutral – gain) was counterbalanced.

Within each learning modality, all 12 pseudowords were presented once within each block in randomized order. Between blocks, the current balance was displayed on the screen while participants were allowed a short break. For both learning modalities, the learning procedure ended after a participant had finished 30 blocks or reached a learning criterion consisting of 48 correct classifications within the last 50 responses.

Test session

The test session took place 1-2 days after the learning session. It consisted of an old/new decision task; participants had to indicate by button press whether a pseudoword had been acquired during the learning session ('old') or presented an unfamiliar pseudoword ('new' distractor). All pseudowords were presented in the visual modality; for half of the participants, all pseudowords were additionally presented in the auditory modality with counterbalanced order of visual and auditory test sessions. The task consisted of 12 blocks of 48 stimuli each (24 learned pseudowords and 24 novel distractors) per modality; stimuli within each block were presented in randomized order. All distractors (n=288) were only presented once per modality in the course of the test session. In the visual modality, a fixation cross was presented for 0.5 s at the start of each trial, followed by 1.5 s of pseudoword presentation and a 2s intertrial interval. In the auditory modality, the fixation cross remained on the screen for the duration of word presentation. The assignment of buttons to response categories was counterbalanced.

Data acquisition and preprocessing

The electroencephalogram was recorded from 64 electrodes positioned in an electrode cap (Biosemi Active Two System). Additionally, 2 external electrodes were applied to the left and right mastoids; 4 electrodes were positioned at the outer canthi and below both eyes in order to record horizontal and vertical electrooculograms. The continuous EEG was referenced online to a CMS-DRL ground (driving the average potential across all electrodes as close as possible to the amplifier zero) and recorded with a sampling rate of 512 Hz. Offline, data were re-referenced to average reference and band-pass filtered with 0.03 Hz (12dB/oct) to 40 Hz (48dB/oct); additionally, a notch filter was applied. Continuous data were segmented into epochs ranging from 100 ms before to 1000 after stimulus onset and referred to a 100 ms pre-stimulus baseline. Segments containing artefacts, i.e. activations exceeding ± 100 µV or voltage steps larger than 100 µV, were rejected in a semiautomatic way; furthermore, trials with erroneous responses were excluded from analyses. Finally, epochs were averaged per subject and experimental condition (learning modality x emotion), separately for visual and auditory test modality.

Data analyses

Learning performance was assessed as percentage of correct classifications per learning modality and valence condition. It was analysed by a repeated-measures (rm)-ANOVA including the factors learning modality (visual, auditory) and valence (positive, neutral, negative). Reaction times and accuracy rates of the test session were analysed by rm-ANOVAs with the factors learning modality (visual, auditory) and valence (positive, negative, neutral). Analyses were per-

formed separately for the visual and the auditory test modality (according to the different numbers of participants).

Time windows of ERP analyses were determined by visual inspection of grand mean waveforms. Due to pronounced differences between visual and auditory processing (i.e., reading and listening) and different numbers of observations, analyses were performed separately for each test modality. In the visual test modality, P1 amplitudes were analysed as main ERP amplitudes in a time window of 85 to 100 ms at occipital electrodes P7, P8, P9, P10, PO7 and PO8, corresponding to the peak latency of the P1. Furthermore, ERPs were further quantified within a group of parietal electrodes between 85 and 100 ms. As can be seen in Figure 3 A, this negative counterpart of occipital P1 positivities was shifted towards posterior electrode sites, in particular in ERP differences. This negativity was quantified at electrodes P1, Pz, and P2. Visual inspection did not reveal modulations of P3 amplitudes by associated valence, but showed a difference between learning modalities at centro-parietal electrodes, starting around 350 ms after stimulus onset, resembling a latency shift for pseudowords acquired in the auditory domain compared to the visual domain (see Figure 3). In order to quantify this effect, we extracted ERP amplitudes of a set of centro-parietal electrodes (CPz, P1, Pz, P2) in the time windows from 350 to 450 ms and from 700 to 1000 ms.

In the auditory test session, amplitudes of the N1 were quantified at a group of centro-parietal electrodes (CP1, CPz, CP2, P1, Pz, P2) in the time range of 110 to 140 ms after stimulus onset. Like for the visual test modality, inspection showed a latency shift at parietal electrodes at later processing stages, although delayed in time. For quantification of this effect, we extracted ERP amplitudes from the same centro-parietal region of interest than in the visual test session (electrodes CPz, P1, Pz, P2), in the time windows ranging from 500 to 700 ms and from 800 to 1000 ms after stimulus onset.

Within each test modality, the influence of learning modality and emotion was analysed with rm-ANOVAs including the factors learning modality (2), valence (3), and electrode (depending on ROI size).

In addition, we also compared ERP effects elicited by learned pseudowords and new pseudowords (i.e., distractors in the old/new task). Analyses were performed in the same early time windows and regions of interest than comparisons of emotion categories, separately for both visual and auditory test session. In addition, we compared P3 amplitudes for learned pseudowords and new pseudowords. Time windows were selected based on visual inspection and lasted from 400 to 600 ms for the visual test session and from 400 to 900 ms in the auditory test session; analyses were performed at the centro-parietal electrodes CPz, P1, Pz, and P2. Analyses were performed with rm-ANOVAs with the factor old/new (2) and electrode (according to ROI size).

Degrees of freedom in rm-ANOVAs were adjusted using Huynh–Feldt corrections. Results are reported with uncorrected degrees of freedom, but corrected *p*- values. Bonferroni-corrections were applied to *p*-values within post-hoc comparisons.

Results

Behavioural data

Learning session

The analyses of accuracy rates in the learning session showed a main effect of valence, $F(2,140) = 36.36$, $p < .001$, $\eta_p^2 = .342$, indicating that participants classified stimuli associated with positive and negative valence with a higher accuracy than neutral stimuli, indexing overall

facilitated acquisition (see Table 3 and Figure 1). Furthermore, positive associations were acquired faster than negative associations, all $Fs(1,35) > 9.52$, $ps < .01$, $\eta_p^2s > .120$. There was no main effect of learning modality and no interaction between learning modality and valence, $Fs < 1$. On average, participants performed 28.6 learning blocks (SD = 11.6).

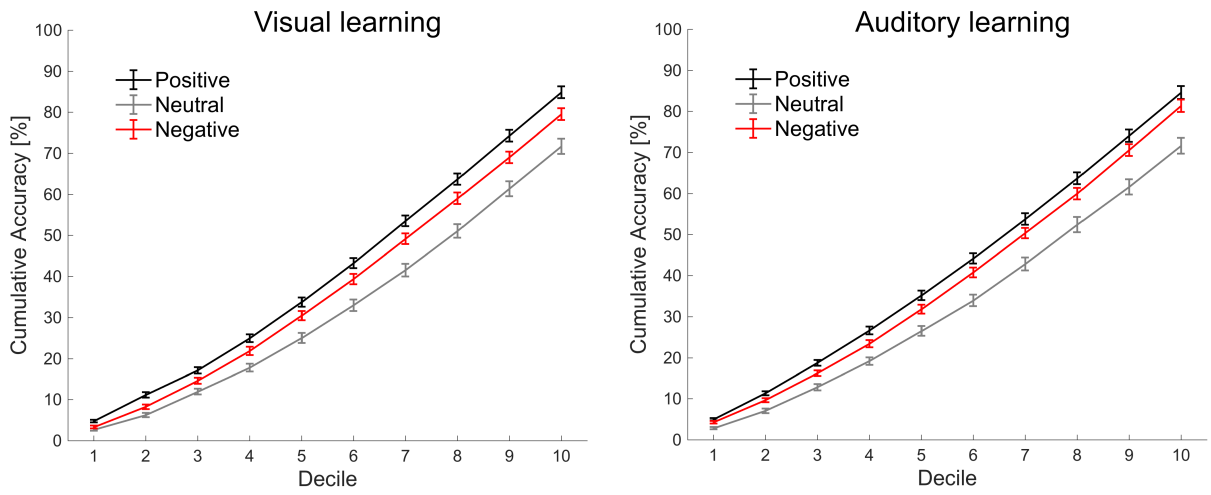

Figure 2. *Cumulative accuracy scores per decile for visual and auditory learning sessions.*

Test session

Behavioural results from both test sessions are depicted in Figure 2. Analyses of RTs in the visual test session revealed an effect of learning modality, $F(1,71) = 10.41$, $p < .01$, $\eta_p^2 = .128$, with faster RTs in response to pseudowords acquired in the same – i.e. visual – modality than in the auditory modality. Furthermore, there was a main effect of valence, $F(2,142) = 22.27$, $p < .001$, $\eta_p^2 = .239$, due to faster reaction times for positive compared to neutral pseudowords, $F(1,71) = 42.16$, $p < .001$, $\eta_p^2 = .373$, and compared to negative pseudowords, $F(1,71) = 12.78$, $p < .01$, $\eta_p^2 = .153$. Finally, RTs for negative pseudowords were faster than in the neutral condition, $F(1,71) = 9.92$, $p < .01$, $\eta_p^2 = .123$. There was no significant interaction between learning modality and valence, $F(2,142) = 2,17$, $p = .117$. Analyses of accuracy rates showed an effect of learning modality, $F(1,71) = 8.55$, $p < .01$, $\eta_p^2 = .107$, based on higher accuracy for pseudowords acquired in the visual domain. A main effect of valence, $F(2,142) = 15.28$, $p < .001$, $\eta_p^2 = .117$, reflected higher accuracy for positive and negative than neutral pseudowords, $Fs(1,71) > 8.65$, $ps < .013$, $\eta_p^2s > .109$, and, as a trend, for positive compared to negative pseudowords, $F(1,71) = 6.01$, $p = .050$, $\eta_p^2 = .078$. There was no interaction between learning modality and valence, $F(2,142) < 1$.

For the auditory test session, analyses also revealed an effect of learning modality, $F(1,35) = 107.08$, $p < .001$, $\eta_p^2 = .754$, due to shorter responses to stimuli acquired in the same, – i.e. auditory – modality. Furthermore, there was a main effect of valence, $F(2,70) = 4.26$, $p < .05$, $\eta_p^2 = .108$, based on faster reaction times in response to positive compared to neutral pseudowords, $F(1,35) = 8.53$, $p < .05$, $\eta_p^2 = .196$,

whereas the other comparisons did not reach significance, $Fs(1,35) < 4.55$, $ps > .120$. Like before, there was no interaction between learning modality and valence, $F(2,20) = 1.55$, $p = .220$.

Accuracy was higher for pseudowords acquired in the auditory modality during learning, $F(1,71) = 56.90$, $p < .001$, $\eta_p^2 = .619$. Furthermore, a main effect of valence, $F(2,142) = 6.61$, $p < .01$, $\eta_p^2 = .159$, was based on higher accuracy for positive compared to neutral pseudowords, $F(1,35) = 15.26$, $p < .001$, $\eta_p^2 = .304$, and, as a trend, for positive compared to negative pseudowords, $F(1,35) = 5.54$, $p = .073$, $\eta_p^2 = .137$.

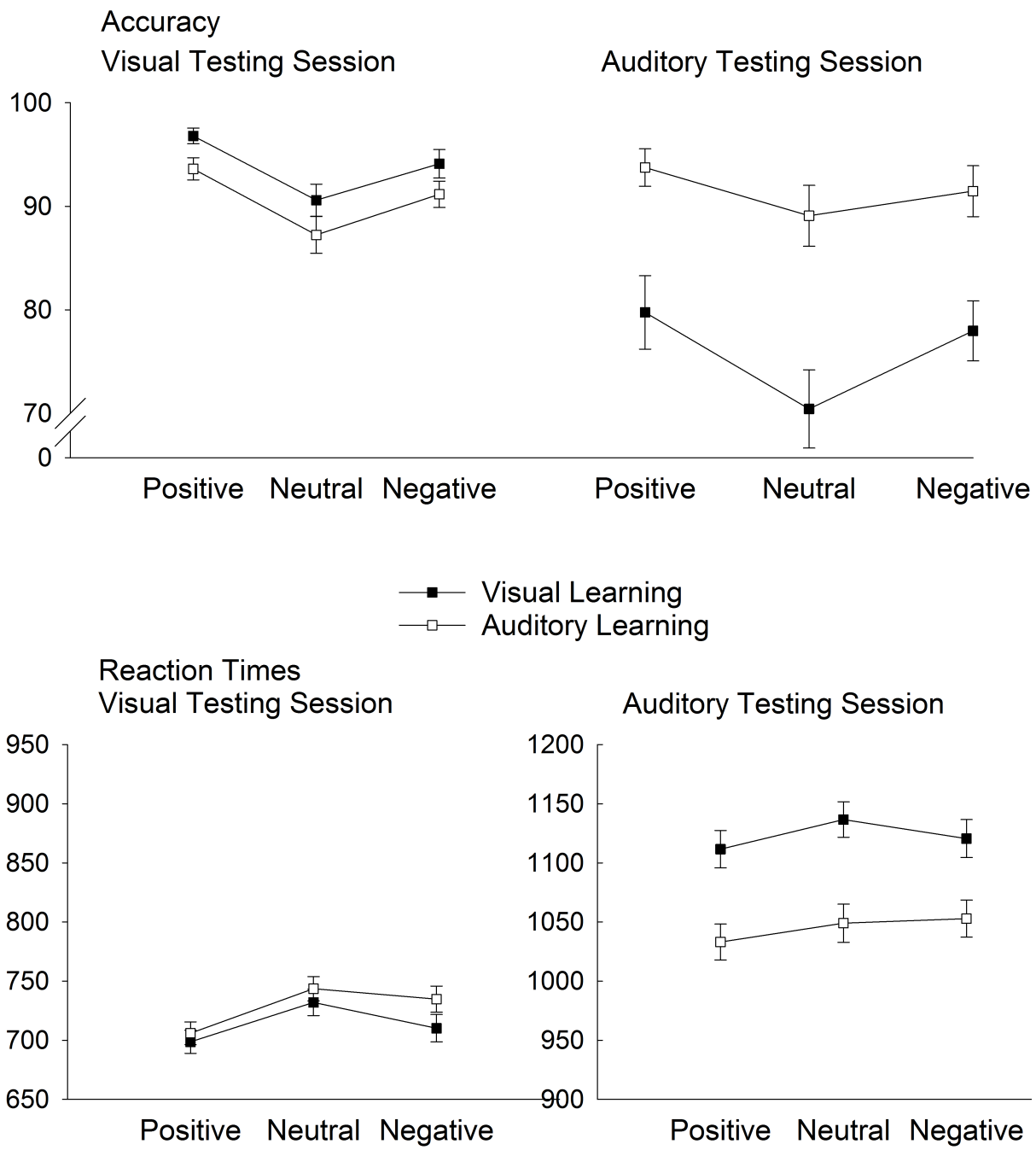

Figure 2. *Accuracy and reaction times. Accuracy rates and reaction times per learning modality and valence category, separately for visual and auditory test session. Error bars indicate standard errors. Note the different scaling for reaction times in the visual and auditory test session.*

ERPs

Visual test session

In the time range from 85 to 100 ms, analyses of P1 amplitudes showed a significant interaction between learning modality and valence, $F(2,142) = 4.23$, $p < .05$, $\eta_p^2 = .056$, but post-tests within each learning modality did not show significant results, Fs(2,142) < 3.19, ps > 0.96. At the centro-parietal ROI, analyses also revealed a significant interaction between learning modality and valence, $F(2,142) = 3.11$, $p < .05$, $\eta_p^2 = .042$. This interaction was based on the fact that valence effects were limited to visually acquired pseudowords, $F(2,142) = 3.94$, $p < .05$, $\eta_p^2 = .053$, but were absent for pseudowords acquired in the auditory domain, $F(2,142) = 1.23$, $p = .592$. Within the visual learning modality, post-tests showed an increased negativity for negative compared to neutral pseudowords, $F(1,71) = 7.61$, $p < .05$, $\eta_p^2 = .097$ (see Figure 3A).

During later processing stages, analyses revealed differences between learning modalities in form of a latency shift (Figure 3B). Between 350 and 450 ms after stimulus onset, amplitudes at parietal electrodes were increased for visually compared to acoustically acquired pseudowords, $F(1, 71) = 4.06$, $p < .05$, $\eta_p^2 = .054$, whereas the opposite effect was evident in the time window from 700 to 1000 ms, $F(1,71) = 12.05$, $p < .01$, $\eta_p^2 = .145$. In the latter interval, there was also a main effect of valence, $F(2,142) = 3.72$, $p < .05$, $\eta_p^2 = .050$, based on larger amplitudes for negative compared to positive pseudowords, $F(1,71) = 8.18$, $p < .05$, $\eta_p^2 = .103$. Furthermore, in the time interval from 700 to 1000 ms, there was an interaction between learning modality and valence, reflecting larger amplitudes for neutral compared to positive pseudowords in the visual learning modality, $F(1,71) = 7.37$, $p < .05$, $\eta_p^2 = .094$, and for negative compared to positive pseudowords in the auditory learning modality, $F(1,71) = 8.78$, $p < .05$, $\eta_p^2 = .110$.

The comparison of associated pseudowords and new pseudowords (old/new effect) revealed no significant differences in the early time window from 85 to 100 ms after stimulus onset, $F(1,71) < 1$. However, associated pseudowords elicited larger P3 amplitudes than new pseudowords from 400 to 600 ms, $F(1,71) = 376.00$, $p < .001$, $\eta_p^2 = .841$, see Figure 3C.

Auditory test session

Analyses of N1 amplitudes revealed an interaction between learning modality and valence, $F(2,68) = 3.164$, $p < .05$, $\eta_p^2 = .085$; however, post-tests of emotion within learning modalities failed to reach significance. No other effects were obtained.

From 500 to 700 ms, amplitudes at centro-parietal electrodes were increased for pseudowords acquired in the auditory modality, $F(1,34) = 24.22$, $p < .001$, $\eta_p^2 = .416$, see Figure 4A. In the time interval ranging from 800 to 1000 ms, analyses revealed the opposite effect with increased amplitudes for visually compared to acoustically acquired pseudowords, $F(1,34) = 7.63$, $p < .01$, $\eta_p^2 = .183$, confirming the impression of a latency shift at higher-order processing stages. No other effects were observed.

The comparison of associated pseudowords and new pseudowords showed no significant differences in the N1 component, $F(1,35) < 1$. In the time range of 400 to 900 ms, associated pseudowords elicited larger P3 amplitudes than new pseudowords, $F(1,35) = 171.24$, $p < .001$, $\eta_p^2 = .830$ (Figure 4B).

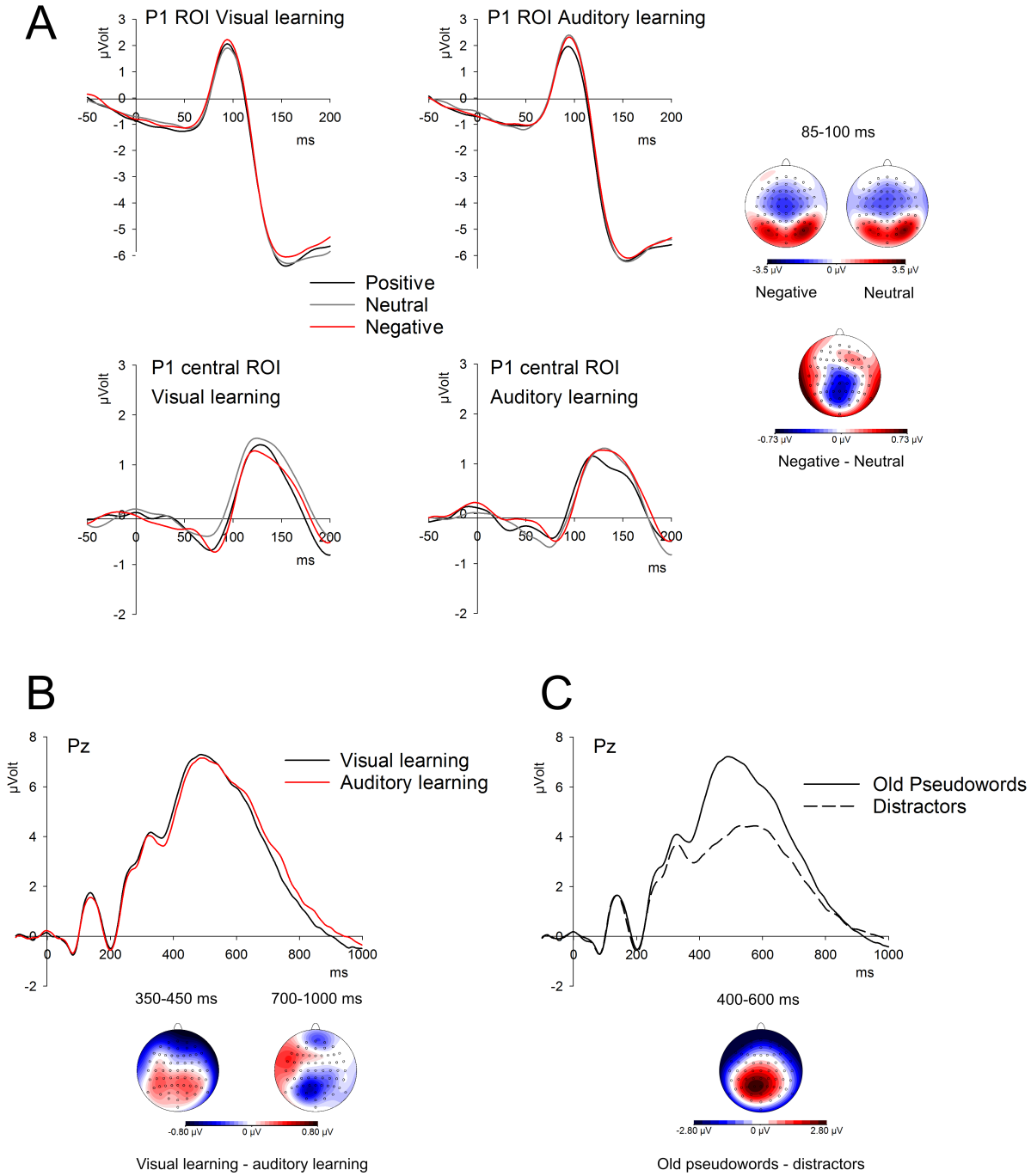

Figure 3. *Visual test session: ERP grand mean waveforms and topographies. A: Visual test session – P1 time window. ERP means per valence category, separately for visually and acoustically acquired pseudowords. Scalp topographies show distributions for neutral and negative words, and the difference topography of the two conditions. B: ERP waveforms at electrode Pz for visually and acoustically acquired pseudowords. Scalp topographies depict difference distributions for visually minus acoustically acquired pseudowords at indicated time intervals. C. Grand mean waveforms for old pseudowords and distractors at electrode Pz, and their difference topography in the P3 interval from 400 to 600 ms*

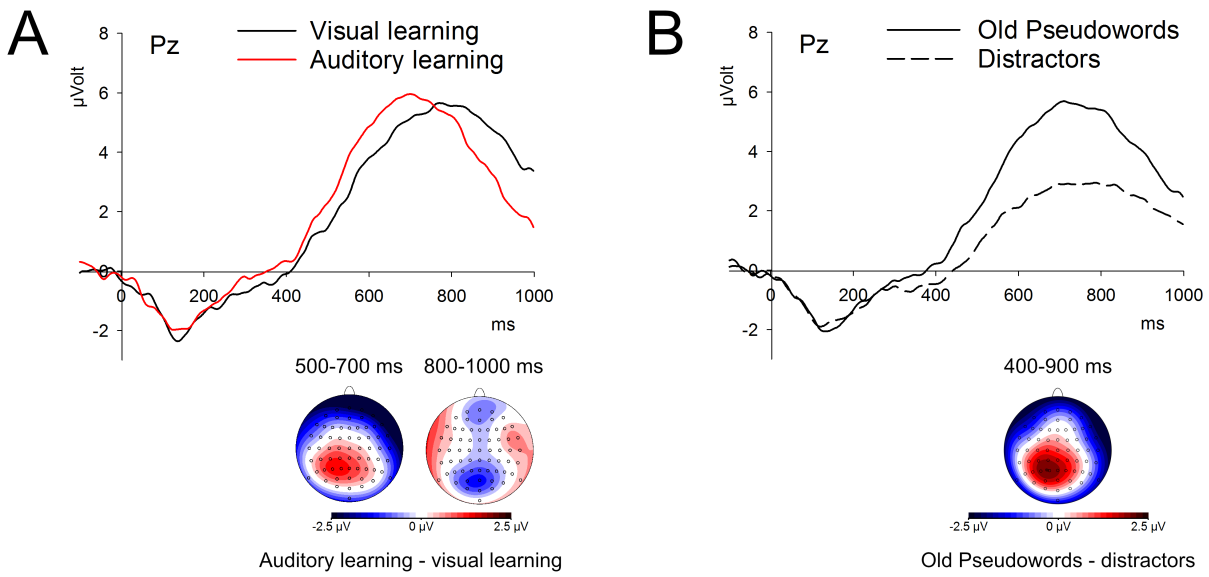

Figure 4. *Auditory test session. A: ERP waveforms for pseudowords acquired in the visual and auditory domain at electrode Pz. Scalp topographies depict the difference between conditions at indicated time intervals. B: ERP waveforms for old pseudowords and distractors at electrode Pz, and their difference topography.*

Discussion

This study investigated whether early emotion-related ERP effects in response to verbal stimuli would be based on associative learning of perceptual features or on fast access to semantic valence information. In order to distinguish between these two options, we applied an associative learning paradigm where half of the pseudowords were acquired in the visual domain, and the other half in the auditory domain with monetary gain, loss, or zero outcome.

In the visual test session, early valence effects were limited to pseudowords acquired in the visual domain, but were absent for pseudowords learned in the acoustic domain. Therefore, our data imply that associative learning of a word's shape might play an important role in the emergence of valence effects in the visual cortex. Associative learning of perceptual features has previously been demonstrated for other symbolic stimuli (Rossi et al., 2017; Schacht et al., 2012), and also for pseudowords using an evaluative conditioning paradigm (Fritsch & Kuchinke, 2013; Kuchinke et al., 2015). However, by using a design where pseudowords were acquired in two modalities, our study is the first to allow for a distinction between the influence of semantic valence information and experience with a stimulus' perceptual features. Furthermore, by careful counter-balancing of learning modalities and valence categories, we were able to avoid any perceptual differences between experimental conditions.

Early emotion effects in response to written words have previously been reported in a small number of studies (Bayer et al., 2012; Hofmann et al., 2009; Kuchinke et al., 2014; Rellecke et al., 2011; Scott et al., 2009), but the boundary conditions of these effects remain unclear, especially since the majority of studies on emotional language processing failed to report these effects. Furthermore, emotion effects within such an early time range seem to contradict established reading models, which assume that lexico-semantic features are accessed only at around 200 ms after stimulus onset, while earlier time windows are indicative of orthographic analyses (for review, see Barber & Kutas, 2007).

Our data suggest that early emotion effects do not necessarily contradict these models. Instead, they might be based on an additional mechanism, which might enable the system to quickly detect stimulus valence associated with a word's perceptual features. Importantly, the notion of two distinguishable mechanisms underlying emotion effects in visual language processing does not imply their independence. As an example, interactions between associated and semantic valence might be at the core of findings like faster lexical access to emotional as compared to neutral words (Kissler & Herbert, 2013).

Reports of early emotion effects within 200 ms after stimulus onset in response to existing and associated/conditioned stimuli across stimulus domains are characterised by a marked heterogeneity concerning the direction of effects. While a number of studies report increased amplitudes for positive valence (Hammerschmidt et al., 2017; Schacht et al., 2012), others report increased amplitudes for negative valence (Kuchinke et al., 2015; Rossi et al., 2017). Our results are in accordance with the latter findings; we observed evidence for increased activation in the P1 time window for negative stimuli, mostly visible as an increased negativity at centro-parietal electrodes. The heterogeneity of early effects even in similar experimental paradigms suggests that this attention allocation is not hard-wired to a certain valence category, but might ultimately depend on specific task requirements and stimulus properties.

Behavioural data showed a clear advantage for positive associated valence. Participants made more correct classifications for positive pseudowords than for negative and neutral pseudowords during the learning session, indicating faster acquisition. In the test session, participants reacted faster and made fewer errors in response to positive pseudowords. These results corroborate behavioural findings of associative learning studies using a similar design (Hammerschmidt et al., 2017; Rossi et al., 2017), showing a strong impact of reward on human perception and behaviour in service of optimizing goal-related behaviour (Anderson, 2013; Bourgeois, Chelazzi, & Vuilleumier, 2016; Navalpakkam, Koch, & Perona, 2009). Interestingly, the behavioural advantage for positive valence does not necessarily seem to translate to early valence effects in ERPs. While the advantage for positive valence corresponded to increased P1 effects for faces associated with positive valence in the study by Hammerschmidt and colleagues (Hammerschmidt et al., 2017), it was in other cases accompanied by increased amplitudes of the C1 in response to loss-associated stimuli (Rossi et al., 2017) and by increased amplitudes to loss-associated stimuli in the present study. Taken together, a number of studies using associative learning paradigms showed an advantage for reward-associated stimuli in behavioural parameters both during acquisition and when reward was no longer delivered, while the mechanisms underlying early modulations of visual stimulus processing remains to be fully understood.

Both in visual and auditory test data, modality switches, i.e. visual processing of acoustically acquired pseudowords and auditory processing of visually acquired pseudowords, were accompanied by latency shifts at later processing stages in the P3b complex. The P3b was associated with task demands and cognitive load (Donchin, 1981; Johnson, 1986), and its latency was shown to vary with cognitive demands (Kok, 2001; Polich, 2007). Thus, the latency shifts reported in the present study likely represent the increased processing demands for 'translating' stimuli from one domain to the other. There was, however, no sign of a latency shift of the P1 component that would indicate differences in perceptual analyses, which might

account for the modulations of early effects and their dependence on learning modality.

Conclusion

This study used an associative learning paradigm to associate pseudowords with monetary gain, loss, or neutral outcome. After acquisition, pseudowords associated with negative valence elicited increased ERP amplitudes around 100 ms after stimulus onset in the visual modality. Importantly, these effects were limited to pseudowords acquired in the visual domain, but were absent for acoustically acquired pseudowords. Thus, the present results indicate that associative learning of a word's perceptual features might play a crucial role in the elicitation of emotion effects within 200 ms after word onset that was reported for existing words of emotional content.

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