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Jankowiak, Katarzyna; Naranowicz, Marcin; Thierry, Guillaume

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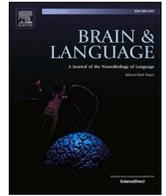
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# Positive and negative moods differently affect creative meaning processing in both the native and non-native language

Katarzyna Jankowiak<sup>a,\*</sup>, Marcin Naranowicz<sup>a</sup>, Guillaume Thierry<sup>a,b</sup>

<sup>a</sup> Faculty of English, Adam Mickiewicz University, Poznan, Grunwaldzka 6, 60–780 Poznan, Poland

<sup>b</sup> Bangor University, Bangor LL57 2DG, UK

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## ABSTRACT

Previous research has shown that positive and negative moods differently modulate lexico-semantic processes. However, little is known about effects of mood on creative meaning comprehension in bilinguals. Here, Polish–English (L1–L2) female bilinguals made meaningfulness judgments on L1 and L2 novel metaphoric, literal, and anomalous sentences during an EEG session featuring positive and negative mood induction. While novel metaphors elicited comparable event-related potential responses to anomalous sentences in the N400 time frame indexing lexico-semantic processing, the former evoked smaller amplitudes than the anomalous condition in the late positive complex (LPC) window, marking meaning re-evaluation. Also, the LPC responses to the three sentence types all converged when participants were in a negative mood, indicating that a negative mood, unlike a positive one, inhibits reliance on general knowledge structures and leads to more detail-oriented processing of semantically complex meanings in both L1 and L2.

## 1. Introduction

Mood, conceptualized as a slowly changing affective background state of low intensity that oscillates from feeling good (i.e., a positive mood) to feeling bad (i.e., a negative mood), unobtrusively tunes the dynamics of human behavior (see Forgas, 2017 for a review). Accumulating electrophysiological evidence has demonstrated that positive and negative moods may also differently regulate various cognitive mechanisms, including those engaged in language comprehension, activating broad and heuristics-based processing of semantic information in a positive mood and a narrow and detail-oriented one in a negative mood (e.g., Pinheiro et al., 2013; Vissers et al., 2013; Wang et al., 2016). Recently, interactions between mood and language processing have also been investigated in the bilingual context (Kissler & Bromberek-Dyzman, 2021; Naranowicz et al., 2022a,b). Yet, electrophysiological research has not yet explored how positive and negative moods affect creative meaning processing, and whether these mechanisms may be modulated by language of operation. Such research could provide valuable insights into mood-driven modulations of complex semantic processes engaged in metaphor comprehension, which entails extensive conceptual mapping mechanisms required to construct a new meaning in both the native (L1) and non-native (L2) language. The

present study is the first to test whether and how bilinguals' current affective states impacts mechanisms engaged in creative meaning processing.

Previous event-related potential (ERP) research on the interplay between mood and semantic processing has reported modulations within the N400 range (e.g., Federmeier et al., 2001; Chwilla et al., 2011; Pinheiro et al., 2013). The N400 is a negative-going wave that peaks in amplitude at around 400 ms after stimulus onset. It is usually maximal over centroparietal electrode positions and indexes the amount of information retrieved from long-term memory (Kutas & Federmeier, 2000, 2011). Consequently, N400 modulations by mood provide insights into how positive and negative moods influence lexico-semantic processing. For instance, Pinheiro et al. (2013) observed that, in a baseline condition, closely related yet unexpected items (e.g., *The books were set aside for her by a teacher.*) elicited an increased N400 response relative to expected words (e.g., *...librarian.*) and decreased relative to unrelated words (e.g., *...dentist.*). Crucially, the processing of such closely related yet unexpected items was modulated by mood: the N400 response to these items resembled the response elicited by distantly related items in a negative mood and by expected items in a positive mood. Such results suggest that a positive mood enhances and a negative mood hinders lexico-semantic processing of words of varying semantic

\* Corresponding author at: Faculty of English, Adam Mickiewicz University, Poznan, Grunwaldzka 6, 60–780 Poznan, Poland.

E-mail addresses: [katarzyna.jankowiak@amu.edu.pl](mailto:katarzyna.jankowiak@amu.edu.pl) (K. Jankowiak), [marcin.naranowicz@amu.edu.pl](mailto:marcin.naranowicz@amu.edu.pl) (M. Naranowicz), [g.thierry@bangor.ac.uk](mailto:g.thierry@bangor.ac.uk) (G. Thierry).

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relatedness, respectively, strengthening and weakening the connections between them in semantic memory. Interestingly, Pinheiro et al. (2013) also found highly expected linguistic stimuli to elicit attenuated N400 amplitudes in a negative relative to a positive mood. According to Pinheiro et al. (2013), this suggests an increased word expectancy effect in a negative mood, potentially due to a closer attention to detail. Others, however, have failed to observe mood-driven differences in the N400 time frame, which may be linked to the lexico-semantic mechanisms of interest (i.e., semantic plausibility vs expectancy; Vissers et al., 2013) and the level of language processing (i.e., single-word vs sentence levels; Ogawa & Nittono, 2019).

Another semantics-related component sensitive to mood changes is the late positive complex (LPC; Chwilla et al., 2011; Vissers et al., 2013): a positive-going brainwave peaking in amplitude at around 600–800 ms after the stimulus onset (Luck, 2014), reflecting meaning re-analysis or additional working memory load (e.g., Brouwer et al., 2012; Regel et al., 2011; Spotorno et al., 2013). For instance, Vissers et al. (2013) found a robust LPC plausibility effect (i.e., higher LPC amplitudes evoked by semantically implausible relative to plausible sentences) in a positive but not negative mood, suggesting that semantic re-analysis processes might be mood-dependent (Schwarz & Clore, 1983).

Altogether, previous ERP studies on the role of mood in semantic processing are consistent with cognitive psychology research suggesting that a positive mood enables effortless integration of incoming information and leads to associative thinking (see Forgas, 2017 for a review). A negative mood, on the other hand, inhibits reliance on heuristics and leads to accommodative thinking (e.g., Bolte et al., 2003; Forgas, 2018). Consequently, while language processing might be more automatic in a positive mood, it may be more analytical and detail-oriented in a negative mood.

Accumulating evidence on the interplay between mood and semantic processing may also provide insights into research on affect and bilingualism (e.g., Morawetz et al., 2017; Thoma, 2021; Naranowicz et al., 2022a,b). Previous empirical studies have repeatedly shown decreased sensitivity to the affective value of the presented stimulus in L2 relative to L1 (e.g., Chen et al., 2015; Hsu et al., 2015; Jankowiak & Korpala, 2018; see Jankowiak, 2021 for a review), especially in the case of negatively-valenced content (Jończyk et al., 2016). Such findings concur with the assumption that bilinguals may implicitly down-regulate their emotional response in a different manner depending on whether they are in an L1 or L2 context (Morawetz et al., 2017). Recently, research on the affect–bilingualism interactions has been extended to the role of mood in bilingual language processing (Kissler & Bromberek-Dyzman, 2021; Naranowicz et al., 2022a,b). For instance, Naranowicz et al. (2022b) observed a reduced N400 response to meaningless sentences in L1 relative to L2 in a positive mood only, followed by larger LPC amplitudes for meaningful sentences in L2 relative to L1 in a negative but not a positive mood. These between-language differences in the N400 and LPC time windows extend previous research, potentially pointing to the activation of implicit emotion-regulation mechanisms, not only during L2 production (e.g., Morawetz et al., 2017), but also in L2 comprehension. At the same time, this pattern is suggestive of reduced emotional sensitivity for negative L2 content processing (e.g., Wu & Thierry, 2012), also evinced when unbalanced bilinguals operate in a negative mood. More research on emotion regulation strategies and decreased emotional reactivity in an L2 context is still needed in order to understand the underlying mechanisms behind such differential mood effects in bilinguals.

Previous neurophysiological studies on the role of mood in semantic processing have, however, mostly focused on the processing of semantically meaningful and meaningless stimuli (e.g., Chwilla et al., 2011; Vissers et al., 2013; Naranowicz et al., 2022b). They have not yet been extended to semantically complex language that features creative meaning, such as that conveyed by novel metaphors, though. Novel metaphors are defined as unfamiliar and creative meanings, whose comprehension requires extended cross-domain mapping mechanisms

that include recognizing features common to two distinct concepts and enable new meaning creation (Gibbs & Colston, 2006, 2012). The complexity of these mechanisms is reflected in ERP patterns, whereby a graded effect is often observed, with the largest modulations recorded within the N400 and LPC time windows elicited by anomalous sentences, followed by novel metaphors, and finally literal meaning (e.g., Tang et al., 2017a,b; Jankowiak et al., 2021). Such a graded effects suggests a progressive decrease in cognitive load. Importantly, processing creative meaning also entails the employment of more complex response strategies, as participants are more likely to search for a possible meaning of presented stimuli in the presence of novel metaphors compared to the experiments employing only two levels of a sentence type (meaningful vs meaningless sentences). Crucially, experiments conducted thus far have not accounted for the role of mood in either monolingual or bilingual creative meaning processing, and it therefore remains under-investigated whether participants' mood can modulate brain responses to creative meaning conveyed by novel metaphoric sentences.

The present ERP study aims to determine whether and how mood modulates creative meaning processing (i.e., novel metaphor processing) in unbalanced bilingual speakers. To address this research question, we elicited positive and negative moods with animated films in Polish–English bilinguals and asked them to make semantic judgements on L1 and L2 novel metaphoric, literal, and anomalous sentences. Building upon previous research, we predicted that the relationship between the processing of creative meanings (i.e., novel metaphors) and language of operation would be modulated by mood, as indexed by N400 amplitude modulations (Pinheiro et al., 2013). Also, we exploratorily aimed to analyze potential mood-driven effects within the LPC window, given prior research exploring LPC modulations in response to positive and negative moods (Chwilla et al., 2011; Vissers et al., 2013; Naranowicz et al., 2022b). Namely, in the positive mood condition in L1, we expected L1 novel metaphors to evoke N400 and LPC responses of similar magnitudes as compared to L1 literal sentences, both eliciting attenuated ERP responses compared to anomalous sentences (Hypothesis 1). Such results would be consistent with facilitatory effects of mood on semantic processes observed in monolingual contexts (e.g., Federmeier et al., 2001; Pinheiro et al., 2013; Wang et al., 2016). In the negative mood condition, however, N400 and LPC responses elicited by L1 creative meanings should converge with those elicited by L1 anomalous sentences, both evoking more robust ERP responses compared to literal sentences (Hypothesis 2). Such a pattern would thus reflect increased processing difficulty, triggered by decreased attentional resources (e.g., Bolte et al., 2003; Forgas, 2018). In L2, in line with recent ERP research on novel meaning processing in bilinguals (Jankowiak et al., 2017; Jankowiak et al., 2021; Wang & Jankowiak, 2021), we expected the N400 and LPC amplitudes evoked by L2 novel metaphors to converge with those evoked by L2 anomalous sentences regardless of mood, reflecting reduced mood effects in L2 (Hypothesis 3; Naranowicz et al., 2022b). Such a prediction would simultaneously point to reduced emotional sensitivity in L2 (Wu & Thierry, 2012) and/or differential implicit emotional regulation mechanisms in L1 and L2 (Morawetz et al., 2017).

## 2. Methods

### 2.1. Participants

Fifty-one Polish–English bilinguals participated in the study, four of whom were excluded from the analyses due to low quality of the recorded EEG data (i.e., heavy Alpha contamination). The final sample therefore consisted of 47 participants aged 21–30 ( $M_{Age} = 23.32$ , 95 % CI [22.72, 23.92]), who were students or graduates of English Studies at the Faculty of English, Adam Mickiewicz University, Poznań. Participants were randomly assigned to either a native ( $n = 24$ ) or a non-native ( $n = 23$ ) language block (i.e., a between-subject design). Due to gender-driven mood effects on language processing observed in previous

research (e.g., Naranowicz et al., 2022a), only females participated in the present study. Consistent with de Groot (2011), participants were classified as highly proficient unbalanced late Polish–English bilinguals who had not lived in the L2 (English) environment and had acquired their L2 in an instructional yet immersive learning context (see Table 1). All participants were in a generally good affective state, reporting low degrees of depression, anxiety, or stress around the time of data collection, as corroborated by DASS-21 (Lovibond & Lovibond, 1995; see Supplementary materials for the results of the DASS-21 questionnaire). They had normal/corrected-to-normal vision and hearing and no neurological, mood, psychiatric, and language disorders. Additionally, the Big Five Inventory (Goldberg, 1992), Empathy Quotient (Baron-Cohen & Wheelwright, 2004), and Interpersonal Reactivity Index (Davis, 1980) were used to assess participants' personality and empathy-related traits, which could potentially interact with their susceptibility to mood manipulation (see Supplementary materials for the results of the questionnaires). For their participation, participants received a gift card of 200 PLN and extra credit points.

## 2.2. Linguistic and mood-inducing stimuli

**Linguistic stimuli.** The linguistic stimuli included 180 Polish and 180 English sentences divided into three categories: 60 novel metaphors (e.g., *My heart is a drawer for secret feelings.*; *Bacteria are fighters attacking the immune system.*; *Motivation is an engine keeping our actions going.*), 60 literal sentences (e.g., *This piece of furniture is a drawer filled with socks.*; *These boxers are fighters from a local club.*; *This machine is an engine running on petrol.*), and 60 anomalous sentences (e.g., *A bug is a drawer shut with a bang.*; *Gifts are fighters warming up all together.*; *A frog is an engine repaired yesterday.*) in each language (see Supplementary materials for the whole list of stimuli). The linguistic stimuli were adopted from a database by Jankowiak (2020) that provides a set of pre-tested novel metaphors, literal, and anomalous sentences. The stimuli were highly controlled for their level of meaningfulness, familiarity, and metaphoricity by means of conducting norming tests on Polish and English native speakers. Furthermore, critical words were all concrete nouns, and were controlled for their frequency (SUBTLEX-PL, Mandera et al., 2015; SUBTLEX-UK, van Heuven et al., 2014;  $M = 3.93$ ,  $SD = 0.56$ ), number of letters ( $M = 6.57$ ,  $SD = 1.45$ ) and syllables ( $M = 2.34$ ,  $SD = 0.48$ ), as well as a cognate status (Jankowiak, 2020). Since the original database (Jankowiak, 2020) provides sentences where critical words are placed in a sentence-final position, we lengthened the original sentences so that the critical (ERP time-locking) words could be placed in a mid-sentence position, thus minimizing the likelihood of sentence wrap-up mechanisms that could affect critical word processing. Additionally, so as to avoid potential response strategies to literal as compared to non-literal sentences, we counterbalanced the novel metaphoric sentence meaningfulness such that, out of 60 novel

**Table 1**

Participants' sociolinguistic data (means with 95 % CI).

	Polish (L1)	English (L2)
Proficiency <sup>1</sup>	n/a	86.41 [84.60, 88.23]
Proficiency <sup>2</sup>	97.72 [96.48, 98.96]	87.55 [85.83, 89.28]
Listening skills	6.98 [6.94, 7.00]	6.28 [6.12, 6.43]
Speaking skills	6.77 [6.63, 6.90]	5.91 [5.74, 6.09]
Reading skills	6.94 [6.87, 7.00]	6.38 [6.24, 6.52]
Writing skills	6.70 [6.51, 6.90]	5.91 [5.72, 6.11]
Dominance <sup>2</sup>	61.34 [59.14, 63.54]	53.62 [51.55, 55.68]
Immersion <sup>2</sup>	78.32 [75.16, 81.48]	69.29 [67.07, 71.52]
Age of acquisition <sup>2</sup>	n/a	6.51 [6.98, 7.04]

<sup>1</sup> LexTALE (Lemhöfer & Broersma, 2012; percentages);

<sup>2</sup> Language History Questionnaire 3.0 (Li et al., 2020, as translated into Polish by Naranowicz & Witczak): the proficiency, dominance, and immersion scores (percentages); listening, speaking, reading, and writing skills (1 – very low proficiency, 7 – very high proficiency); age of acquisition (years).

metaphors in each language, half had a meaningful ending (e.g., *Ambition is a mountain conquered by students.*), and half – a meaningless ending (e.g., *Knowledge is luggage carried by book monkeys.*). Furthermore, we used Polish/English translation equivalents for each sentence, making the set fully counterbalanced. Crucially, at the point of critical word presentation, all novel metaphors and literal sentences were semantically meaningful, while all anomalous sentences were meaningless (Jankowiak, 2020).

All sentences were declarative and emotionally-neutral. All Polish sentences featured 5–10 words ( $M_{\text{NovelMetaphors}} = 6.03$ ,  $SD = 0.83$ ;  $M_{\text{LiteralSentences}} = 6.92$ ,  $SD = 0.90$ ;  $M_{\text{AnomalousSentences}} = 5.99$ ,  $SD = 0.94$ ). The critical words were presented in the 3rd/4th position in a sentence. Similarly, all English sentences were 5–12 words long ( $M_{\text{NovelMetaphors}} = 7.82$ ,  $SD = 1.36$ ;  $M_{\text{LiteralSentences}} = 8.36$ ,  $SD = 1.31$ ;  $M_{\text{AnomalousSentences}} = 8.01$ ,  $SD = 1.50$ ). The critical words were presented as the 3rd/4th/5th words. The larger number of words per sentence in English compared to Polish was due to articles in English, which do not exist in Polish.

**Mood-inducing stimuli.** We adapted 28 affectively evocative animated films of 90 s each from Naranowicz et al. (2022a) to elicit positive ( $n = 14$ ) and negative moods ( $n = 14$ ; see Supplementary materials). The films were highly controlled for mood valence and arousal in a series of norming tests (Naranowicz et al., 2022a), which showed that the films selected to induce a positive mood were rated as significantly more positive than those selected to induce a negative mood ( $p < .001$ ), and there was no difference between the two film types in terms of their arousal ( $p = .071$ ; see Naranowicz et al., 2022a for details). To sustain the evoked targeted mood, each selected film clip was additionally divided into two 45-second clips, which resulted in the presentation of 56 film fragments (i.e., 42 min in total) in both mood conditions.

## 2.3. Procedure

The procedure applied in the experiment was approved by the Ethics Committee for Research Involving Human Participants at Adam Mickiewicz University, Poznań. The experiment was carried out in the Neuroscience of Language Laboratory (Faculty of English, Adam Mickiewicz University, Poznań), located in the Center for Advanced Technology at Adam Mickiewicz University, Poznań. Participants were randomly assigned to one of the two language blocks: Polish (L1) or English (L2; a counterbalanced order), and the experiment was entirely conducted in either L1 or L2 (a between-subject design). Participants were seated in a dimly lit and quiet booth, 75 cm away from a LED monitor with a screen resolution of 1280 × 1024 pixels. E-prime 3.0 was used to present the stimuli and collect the behavioral data, and Brain-Vision Recorder 1.23 was used to collect the EEG data.

Participants were asked to rate their mood prior to and after mood manipulation and complete the Polish version of the PANAS (Watson et al. (1988) as translated into Polish by Fajkowska & Marszał-Wiśniewska (2009)). They first watched four mood-inducing film fragments and were instructed to put themselves in the targeted mood (Rottenberg et al., 2018), by imagining themselves as one of the protagonists and sympathizing with them (Werner-Seidler & Moulds, 2012). Then, participants were presented with a set of sentences and performed a semantic decision task, wherein they decided if a sentence was meaningless or meaningful by pressing designated keys, whose designation and order was counterbalanced. Each film clip was presented every ten sentences (in a counterbalanced order) to sustain the targeted mood. Participants completed one block with negative films and one block with positive films within each session (in a counterbalanced order), each comprising 60 novel metaphoric, 60 literal, 60 anomalous sentences, and 60 filler (meaningless) sentences ( $n_{\text{Total}} = 480$  sentences). The sentences were randomly presented on a computer screen using black letters and were centered on a gray background. The time sequence of stimuli presentation is provided in Fig. 1.

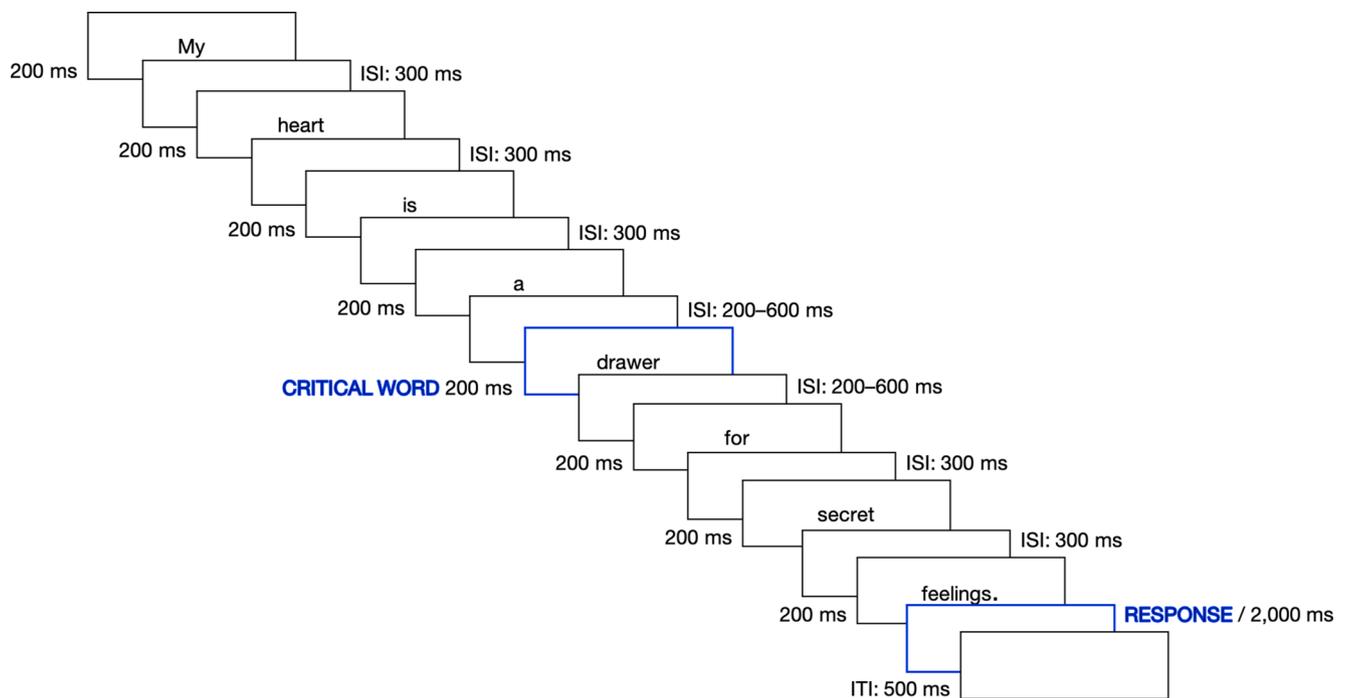


Fig. 1. Time sequence of stimuli presentation.

#### 2.4. EEG data recording

EEG signals were recorded from 64 active actiCAP slim electrodes (Brain Products), placed at the standard extended 10–20 positions. The bipolar electrodes monitoring vertical (vEOG) and horizontal (hEOG) eye movements were placed above and below the left eye and next to the outer rims of both eyes, respectively. The EEG signals were amplified using a BrainVision actiCHamp amplifier (Brain Products), referenced to Fz, and sampled at 500 Hz. ERPs were time-locked to the onset of the critical word of each sentence, which was placed in a mid-sentence position.

#### 2.5. Self-report and behavioral data analysis

All data analyses were performed in R (R Development Core Team, 2020). As part of self-report measures, participants rated their current mood with 7-point mood valence and arousal scales (i.e., bipolar dimensions) as well as PANAS (Watson et al., 1988), employing 10 positive adjectives (i.e., *positive affect*) and 10 negative adjectives (i.e., *negative affect*; i.e., unipolar dimensions). The summed positive and negative affect scores were presented as a ratio to make them comparable to mood valence ratings. Mood ratings were analyzed using repeated measures (RM) ANOVAs on the basis of a 2 (Time of testing: Pre-experiment vs Post-experiment)  $\times$  2 (Film type: Positive vs Negative) within-subject design, with Language (Polish [L1] vs English [L2]) as a between-subject factor. To ensure the effectiveness of our mood manipulation, we compared mood valence, arousal, and PANAS ratings post- relative to pre-experiment separately in each mood condition as planned comparisons, predicting increased/comparable mood ratings in the positive mood condition along with decreased mood ratings in the negative mood condition.

Behavioral data analyses were based on response accuracy (see Supplementary materials for accuracy rates results) data only, so as to measure participants' engagement in the task. Reaction times were, on the other hand, uninformative due to the fact that they were time-locked to the final word of a sentence, while the critical words were placed in a mid-sentence position. Also, participants were likely to have selected their response before the presentation of a final word of a sentence.

However, it must be noted that behavioral data (both reaction times and accuracy rates) and ERP patterns measured in the present study did not primarily relate to one another, because ERPs were time-locked to critical words placed in a mid-sentence position and behavioral responses reflected the processing of the complete sentence in every case.

#### 2.6. Electrophysiological data analysis

We analyzed two ERP components previously reported to be modulated by metaphoricity level (e.g., Jankowiak et al., 2017), language of operation (e.g., Jończyk et al., 2016), and mood (e.g., Naranowicz et al., 2022b): the N400 and LPC. In line with previous studies on bilingualism and semantic processing (Wu & Thierry, 2012; Jończyk et al., 2016; Naranowicz et al., 2022b), both components were analyzed over the FC1, FCz, FC2 (fronto-central), C1, Cz, C2 (central), CP1, CPz, and CP2 (centro-parietal) electrodes. The analyses were performed within pre-defined time windows, in accordance with previous electrophysiological research: 300–500 ms (N400; e.g., Kuperberg et al., 2003; Lau et al., 2016; Delogu et al., 2019) and 600–800 ms (LPC; e.g., Dowens et al., 2010; Jankowiak et al., 2021).

BrainVision Analyzer 2.1 software (Brain Products) was used to analyze the data offline. Continuous EEG data were re-referenced to the common average reference (Nunez & Srinivasan, 2006; Luck, 2014) and filtered offline (Butterworth zero phase filters) with a high-pass filter set at 0.1 Hz (slope 24 dB/octave) and a low-pass filter set at 20 Hz (slope 24 dB/octave). They were then segmented from 200 ms before critical word onset to 1500 ms afterward, baseline-corrected relative to signal between –200–0 ms before stimulus onset, and edited for artifacts (i.e., rejecting trials with flatlining events, voltage differences higher than 100  $\mu$ V, or voltage steps higher than 50  $\mu$ V). Ocular artifacts were corrected using the ocular artefact regression method by Gratton et al. (1983).

Within both the N400 and LPC time frames, mean ERP amplitudes were analyzed employing a 2 (Mood: Positive vs Negative)  $\times$  3 (Sentence type: Literal sentences vs Novel metaphors vs Anomalous sentences) within-subject design, with Language (Polish [L1] vs English [L2]) as a between-subject factor. The Greenhouse-Geisser correction was applied when the sphericity assumption was violated, as indicated

by the Mauchly's tests.

### 3. Results

#### 3.1. Self-report data: Mood ratings

For the mood valence and PANAS ratings, the RM ANOVA showed a Film type  $\times$  Testing time interaction,  $F_{MoodValence}(1, 45) = 27.68, p < .001, \eta_p^2 = 0.381, F_{PANAS}(1, 45) = 16.34, p < .001, \eta_p^2 = 0.266$ , as well as main effects of both Film type,  $F_{MoodValence}(1, 45) = 34.70, p < .001, \eta_p^2 = 0.435, F_{PANAS}(1, 45) = 22.74, p < .001, \eta_p^2 = 0.336$ , and Testing time,  $F_{MoodValence}(1, 45) = 84.87, p < .001, \eta_p^2 = 0.653, F_{PANAS}(1, 45) = 46.17, p < .001, \eta_p^2 = 0.506$  (see Fig. 2). As expected, planned comparisons showed decreased mood ratings in the negative mood condition ( $p < .001$ ), with no change in valence ratings in the positive mood condition post- relative to pre-experiment ( $p = .464$ ), regardless of language of operation. For the arousal ratings, the RM ANOVA showed only a main effect of Testing time,  $F(1, 45) = 6.88, p = .012, \eta_p^2 = 0.133$  (see Fig. 2), whereby participants reported being more aroused after than before the experiment ( $p < .001$ ), regardless of mood and language of operation. All remaining differences in mood ratings were non-significant,  $ps > 0.05$ .

#### 3.2. Electrophysiological data: N400 (300–500 ms)

The RM ANOVA performed within the N400 time window (300–500 ms) yielded a main effect of Sentence type,  $F(2, 90) = 9.39, p < .001, \epsilon = 0.818, \eta_p^2 = 0.173$  (see Fig. 3), whereby literal sentences elicited reduced N400 amplitudes as compared to both novel metaphors ( $p < .001$ ) and anomalous sentences ( $p = .018$ ), with no difference between novel metaphors and anomalous sentences ( $p = 1.00$ ). All remaining differences in N400 amplitudes were non-significant,  $ps > 0.05$ .

#### 3.3. Electrophysiological data: LPC (600–800 ms)

Within the LPC time window (600–800 ms), a main effect of Sentence type was found,  $F(2, 90) = 12.40, p < .001, \epsilon = 0.874, \eta_p^2 = 0.216$ , such that anomalous sentences elicited more pronounced LPC amplitudes relative to both novel metaphors ( $p < .001$ ) and literal sentences ( $p = .016$ ). There was no statistically significant difference between novel metaphors and literal sentences ( $p = .291$ ; see Fig. 3).

Importantly, the analyses also revealed a Mood  $\times$  Sentence type interaction,  $F(2, 90) = 3.28, p = .043, \eta_p^2 = 0.068$  (see Fig. 4). *Post-hoc* analyses were conducted separately for each mood. In the positive mood condition, a main effect of Sentence type was found,  $F(2, 90) = 15.35, p$

$< .001, \eta_p^2 = 0.254$ , whereby anomalous sentences elicited more pronounced LPC amplitudes relative to both novel metaphors ( $p < .001$ ) and literal sentences ( $p < .001$ ). There was no statistically significant difference between novel metaphors and literal sentences ( $p = 1.00$ ). In the negative mood condition, on the other hand, no main effect of Sentence type was observed,  $F(2, 90) = 2.31, p = .113, \epsilon = 0.878, \eta_p^2 = 0.049$ , with literal, novel metaphoric, and anomalous sentences all overlapping. All remaining differences in LPC amplitudes were non-significant,  $ps > 0.05$ .

### 4. Discussion

The present study explored how positive and negative moods regulate creative meaning processing, as exemplified by novel metaphors in L1 and L2. To this end, unbalanced Polish–English female bilinguals performed a semantic decision task to novel metaphoric, literal, and anomalous sentences in Polish (L1) and English (L2), after their mood was manipulated through exposure to animated films. We predicted creative meanings in L1 to be processed in a mood-dependent manner, with N400 and LPC responses to novel metaphors and literal sentences being reduced as compared to anomalous sentences in a positive mood (Hypothesis 1) and only literal sentences showing such reduction as compared to anomalous sentences in a negative mood (Hypothesis 2). In contrast, we expected the processing of creative meanings in L2 to be less mood-dependent, with the N400 and LPC responses to novel metaphor differing significantly from literal sentences but not from anomalous sentences in both positive and negative mood contexts. We found similar ERP patterns in L1 and L2 contexts, whereby in either of the two moods, novel metaphors patterned with anomalous sentences (i.e., differed from literal sentences) in the N400 time frame, and with literal sentences (i.e., differed from anomalous sentences) in the LPC time window. Interestingly, LPC responses were also differentially affected by mood: anomalous sentences evoked increased LPC amplitudes relative to both novel metaphoric and literal sentences in a positive mood, with no differences between the three sentence types in a negative mood.

First of all, within the N400 time window, we observed a main effect of sentence type, whereby novel metaphors converged with anomalous sentences, and both evoked a larger N400 response as compared to literal sentences. The fact that mechanisms engaged in novel metaphoric were more cognitively taxing than literal meaning processing is in line with previous electrophysiological results in the field (e.g., [Arzouan et al., 2007](#); [Lai et al., 2009](#)), showing that highly creative and unfamiliar meaning processing requires extended lexicosemantic processes in conceptual mapping ([Bowdle & Gentner, 2005](#)).

A language-independent effect of sentence type was also found in the

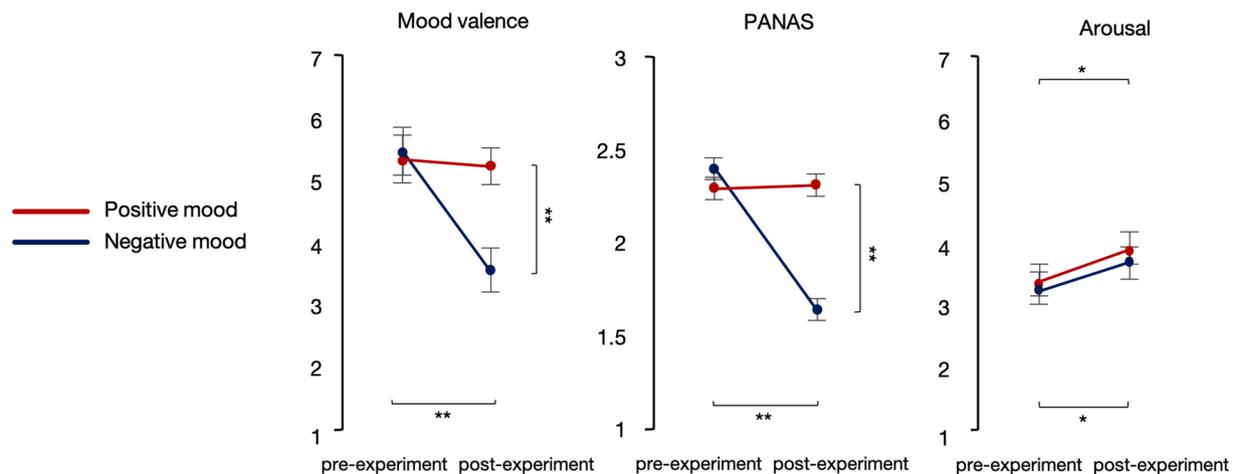
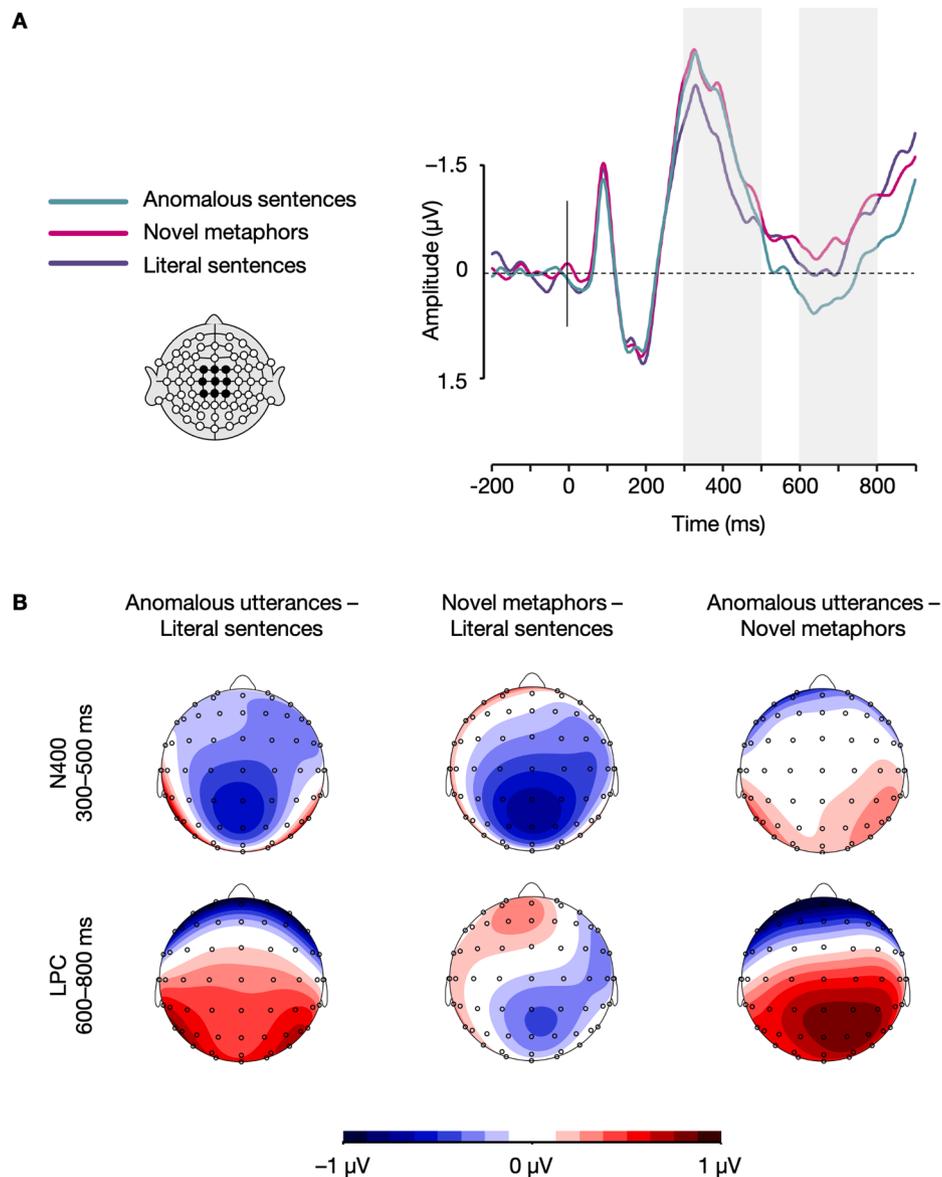


Fig. 2. Mood ratings for the mood valence scale (1 – highly negative, 7 – highly positive), the PANAS, the arousal scale (1 – highly unaroused, 7 – highly aroused) with CI of 95%.

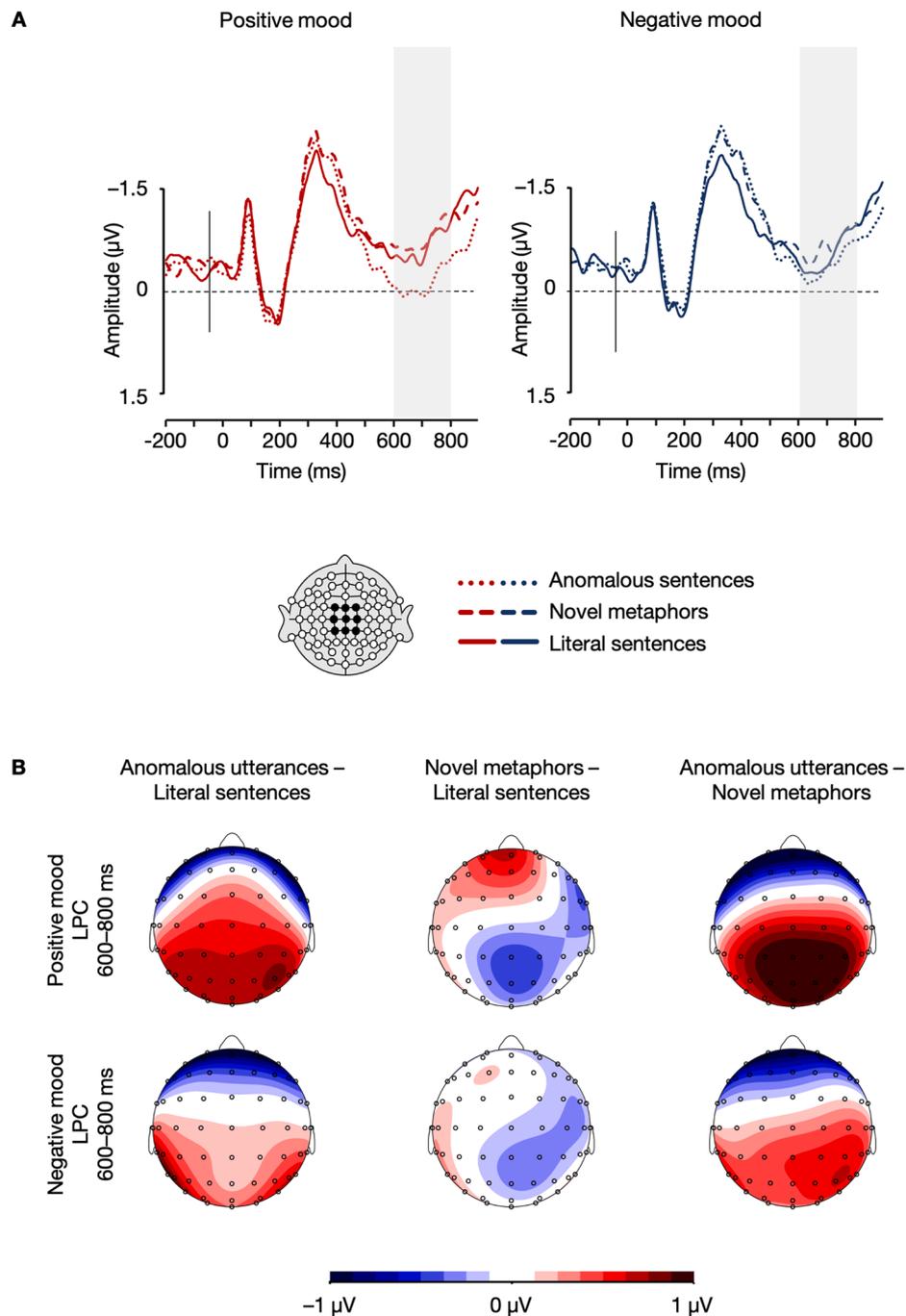


**Fig. 3.** Grand average ERPs for anomalous sentences, novel metaphors, and literal sentences in the 300–500 ms and 600–800 ms time windows (A); topographic distribution of the differences between the mean amplitudes evoked by anomalous, novel metaphoric, and literal sentences in the 300–500 ms and the 600–800 ms time windows (B).

LPC time range, where novel metaphors converged with literal sentences, both of which evoked smaller LPC amplitudes relative to anomalous sentences. A differential LPC response to anomalous relative to novel metaphoric sentences suggests that, though they were not initially processed differently from anomalous sentences, novel metaphors were still better integrated at the stage of meaning reevaluation (De Grauwe et al., 2010). Such findings are interesting in light of previous ERP research that has reported novel metaphors and anomalous utterances eliciting sustained negativity within the LPC window, pointing to a pervasive difficulty of novel metaphoric meaning integration (Goldstein et al., 2012; Tang et al., 2017a; Jankowiak et al., 2021). Such a sustained negativity, unlike the classic LPC effect, was mostly observed in studies in which ERPs were time-locked to the sentence final word (Tang et al., 2017a,b; Jankowiak et al., 2021). Therefore, such an effect might have been in part influenced by wrap-up effects, reflecting increased processing cost connected with final meaning integration (Just & Carpenter, 1980; Rayner et al., 2001; cf. Hirotani et al., 2006). Since a sentence wrap-up effect can be more pronounced when integrating semantically complex meanings (i.e., novel metaphors), in the present study, we

decided to present critical words in a mid-sentence position, which may have made literal and novel metaphoric sentence integration more comparable. Anomalous sentences, however, evoked a robust LPC response possibly because of their systematic requirements for reanalysis (Kolk & Chwilla, 2007; Van de Meerendonk et al., 2009; Van de Meerendonk et al., 2010).

Interestingly, we also found an interaction between mood and sentence type within the LPC range. Namely, in a positive mood, a broadly distributed LPC sentence type effect was found, with significantly greater amplitudes for anomalous relative to both literal and novel metaphoric sentences, echoing the general trend found within the LPC time window described above. This observation is in line with Hypothesis 1, which predicted a facilitatory effect of a positive mood on creative meaning processing in L1. However, we failed to see any interaction with language of operation. Furthermore, partially consistent with Hypothesis 2, between-condition modulations observed in a positive mood vanished in a negative mood, where literal, novel metaphoric, and anomalous sentences all converged. These results accord with those observed by Vissers et al. (2013), who tested how film-



**Fig. 4.** Grand average ERPs for anomalous sentences, novel metaphors, and literal sentences in the positive and negative mood conditions in the 600–800 ms time window (**A**); topographic distribution of the differences between the mean LPC amplitudes evoked by anomalous, novel metaphoric, and literal sentences in the positive and negative mood conditions in 600–800 ms time window (**B**).

induced positive and negative moods affect semantically plausible and implausible sentences processing (i.e., compliant or conflicting with general world knowledge). While the authors did not observe N400 modulations by mood, implausible sentences elicited larger LPC amplitudes relative to plausible sentences in a positive mood but not in a negative mood. This suggests that at the stage of meaning integration, a positive mood activates top-down, heuristics-based, assimilative processing (i.e., relating incoming information to accessible stored information), while a negative mood inhibits the same process, promoting bottom-up, accommodative processing (i.e., focusing on perceptual stimuli from the environment, without associating them with stored knowledge; Schwarz & Clore, 1983; Chwilla et al., 2011; Vissers et al.,

2013). Critically, both the paradigm used by Vissers et al. (2013) and the present study employed comparable linguistic and mood-inducing stimuli. First, similarly to Vissers et al. (2013), semantically anomalous and literal sentences were built here in line with general world knowledge expectations. Second, Vissers et al. (2013) also elicited positive and negative moods employing continuous mood induction with films (and presenting additional films in-between sentence presentation to sustain the target mood). In line with Vissers et al. (2013), the differential effects of positive and negative moods observed in the present study point to the activation of mood-dependent processing style during semantic information reanalysis on the basis of pre-existing general knowledge. Specifically, a negative mood might promote an

enhanced attentive and detail-oriented thinking that may suppress the activation of heuristics (Ruder & Bless, 2003), resulting in a decreased re-evaluation of not only literal and metaphoric sentences but also anomalous sentences.

Yet, the effect of mood on semantic processing was reflected only within the LPC time frame, while some previous ERP studies have also reported mood-dependent modulations in the N400 time window (e.g., Chwilla et al., 2011; Pinheiro et al., 2013; Naranowicz et al., 2022b). Importantly, however, differential effects of positive and negative moods on semantic access, as indexed by the N400 modulations, were previously mostly observed in response to stimuli manipulated in terms of their expectancy (e.g., Chwilla et al., 2011; Pinheiro et al., 2013; Naranowicz et al., 2022b). In the present study, similarly to Vissers et al. (2013), we used sentences that were either plausible or implausible in relation to general world knowledge, as opposed to highly semantically constrained sentences, and we also failed to observe mood-driven N400 modulations. This indicates that whilst mood may modulate N400 effects driven by word expectancy manipulations, it may have less impact when plausibility is manipulated.

Contrary to one of our predictions, we found no evidence for a differential effect of language of operation on the interplay between mood and creative meaning processing, as reflected in the N400 and LPC patterns. This finding is not readily consistent with previous research on emotion–bilingualism interaction, which has suggested variations in implicit emotion regulation mechanisms and/or reduced emotional sensitivity in L2 compared to L1 (Wu & Thierry, 2012; Morawetz et al., 2017; Naranowicz et al., 2022b). Even though our results might be interpreted as partially consistent with those of the ERP study by Kissler and Bromberek-Dyzman (2021), who observed an interaction between mood and language of operation within the early N1 time range but not in the range of later semantics-related markers (i.e., N400 and LPC), their study employed affective words, and therefore, unlike the present experiment, tapped into affect-laden mechanisms engaged in single word processing. A more directly comparable result was obtained by Naranowicz et al. (2022b), who tested the influence of positive and negative moods on meaningful and meaningless sentence processing in unbalanced Polish–English bilinguals. Naranowicz et al. (2022b) observed a broadly distributed LPC sentence type effect (i.e., larger LPC amplitudes for meaningless relative to meaningful sentences) in both L1 and L2 in a positive mood, but increased LPC amplitudes for meaningful sentences in L2 relative to L1 only when participants were in a negative mood. Importantly, as in the present study, Naranowicz et al. (2022b) tested female bilingual speakers whose L2 proficiency was comparable to that of the participants tested here. Thus, differences in the results between the two studies cannot readily be accounted for by differences in L2 proficiency level or participant gender. The contrasting results between the current and previous studies may, therefore, stem from the particular stimuli employed, impacting cognitive mechanisms activated by positive and negative moods. As highlighted by Naranowicz et al. (2022b), the sentences featuring a semantic violation employed in their study were strongly unexpected but not entirely meaningless given that the contexts they were placed into could naturally evoke various semantic associations in participants tested (e.g., *These houses were transformed into country mansions/lobsters...*). Here, in contrast, we employed sentences with a transparent and repetitive syntactic structure (i.e., *A is B*), wherein semantic violations solely violated general world knowledge rather than a particular, elaborate semantic context. Thus, the effect of language of operation on mood–semantics interactions may be dependent upon the type of semantic context implemented. Namely, while a negative mood may activate different implicit emotion-regulation mechanisms and/or be associated with reduced emotionality during the processing of semantically rich information in L2 relative to L1 (Naranowicz et al., 2022b), it may affect L1 and L2 processing more similarly when meaning integration processes are based on general world knowledge. More research is however needed to fully understand how semantic context influences mood–language interactions in

bilinguals.

## 5. Conclusion

The present study revealed ERP modulations by sentence type within two time windows of interest, showing that creative meaning differs from literal meaning integration at a lexico-semantic processing stage (indexed by the N400) and from meaningless sentences during a semantic re-evaluation stage (indexed by the LPC). The results also yielded an interaction between mood and sentence type within the LPC time frame that did not depend on language of operation: in a positive mood, anomalous sentences evoked a more pronounced LPC response relative to both literal and novel metaphoric sentences, whilst no difference was observed in a negative mood. A negative mood might therefore promote more attentive and detail-oriented processing, thus decreasing meaning re-evaluation based on pre-existing general knowledge of not only literal and novel metaphoric meaning but also anomalous content. The lack of an interaction between mood and language (L1 vs L2) in the current study might seem surprising, given that previous research has shown modulation of affective processing by language of operation. Yet, the effects observed here suggest that mood effects do not differentially affect L1 and L2 processing when meaning integration mechanisms depend on pre-existing world knowledge. Future research is needed to shed more light on the interplay between mood, different depths of semantic processing, and languages of operation.

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## CRediT authorship contribution statement

**Katarzyna Jankowiak:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing. **Marcin Naranowicz:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Guillaume Thierry:** Conceptualization, Formal analysis, Writing – review & editing.

## 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.

## Data availability

All the experimental stimuli, R scripts, and supplementary materials are available at: <https://osf.io/uksm3/>.

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