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Negative affect increases reanalysis of conflicts between discourse context and world knowledge

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Introduction: Mood is a constant in our daily life and can permeate all levels of cognition. We examined whether and how mood influences the processing of discourse content that is relatively neutral and not loaded with emotion. During discourse processing, readers have to constantly strike a balance between what they know in long term memory and what the current discourse is about. Our general hypothesis is that mood states would affect this balance. We hypothesized that readers in a positive mood would rely more on default world knowledge, whereas readers in a negative mood would be more inclined to analyze the details in the current discourse.

Methods: Participants were put in a positive and a negative mood via film clips, one week apart. In each session, after mood manipulation, they were presented with sentences in discourse materials. We created sentences such as "*With the lights on you can see...*" that end with critical words (CWs) "*more*" or "*less*", where general knowledge supports "*more*", not "*less*". We then embedded each of these sentences in a wider discourse that does/does not support the CWs (a story about driving in the night vs. stargazing). EEG was recorded throughout.

Results: The results showed that first, mood manipulation was successful in that there was a significant mood difference between sessions. Second, mood did not modulate the N400 effects. Participants in both moods detected outright semantic violations and allowed world knowledge to be overridden by discourse context. Third, mood modulated the LPC (Late Positive Component) effects, distributed in the frontal region. In negative moods, the LPC was sensitive to one-level violation. That is, CWs that were supported by only world knowledge, only discourse, and neither, elicited larger frontal LPCs, in comparison to the condition where CWs were supported by both world knowledge and discourse.

Discussion: These results suggest that mood does not influence all processes involved in discourse processing. Specifically, mood does not influence lexical-semantic retrieval (N400), but it does influence elaborative processes for sensemaking (P600) during discourse processing. These results advance our understanding of the impact and time course of mood on discourse.

KEYWORDS

mood, discourse, semantics, world knowledge, ERP, N400, LPC (late positive component)

Introduction

Mood state, different from emotion, is a low-intensity, diffuse, and relatively enduring affective state (Forgas, 1995). People are in a mood as soon as they wake up and could be, for instance, cheerful, irritated, hopeful, gloomy... etc., with non-specific causes. Given the relatively enduring and long-lasting nature, people carry out daily tasks while in a certain mood. It is important to understand the effects of mood, because research has shown that mood states permeate many levels of information processing. This is the case both in obvious ways, such as prioritizing access for mood-congruent content (Egidi and Nusbaum, 2012), and also in non-obvious ways, such as loosening cognitive control to include distantly related semantic associates (Rowe et al., 2007).

Because of the high speed, incrementality, and complex interweaving of the various processes involved, much of the relevant work on mood effects in language processing has used scalp EEG (Electroencephalography)—electrical activity recorded *via* sensors on the scalp—to obtain the millisecond-by-millisecond temporal resolution needed. Similar to studies of mood on general cognition, EEG studies of mood on language have shown that mood not only affects the processing of language content but also the styles/modes of processing of readers or listeners. The present study built on this literature and used Event Related Potential (ERP) to further investigate whether and how mood influences readers' processing of discourse with language content that is relatively neutral.

Past ERP studies on mood effects on discourse focused on discourse content that is emotionally valenced, and the consensus is that mood provides affective constraint to facilitate mood-congruent content (Chung et al., 1996; Egidi and Gerrig, 2009; Egidi and Nusbaum, 2012). In Chung et al. (1996), participants were put in an optimistic or a pessimistic mood by means of personal emotional memory recall. Then, participants read stories about daily life events (e.g., a story about receiving exam grades) that ended with good and bad outcome words (*passed/failed*). They reported two ERP effects: An increased N400 (350–450 ms) for semantic- and mood- incongruent endings, and a larger LPC or Late Positive Component (300–700 ms) for mood incongruent endings. Their results indicate that participants in a pessimistic mood expected bad outcomes, and participants in an optimistic mood, good outcomes. These findings were not only replicated but also expanded in Egidi and Gerrig (2009), Egidi and Nusbaum (2012).

In terms of processing styles, past studies reported mood-specific processing styles during sentence processing (Federmeier et al., 2001; Chwilla et al., 2011; Pinheiro et al., 2013; Van Berkum et al., 2013; Wang et al., 2016). Federmeier et al. (2001), Pinheiro et al. (2013) examined mood effects on semantic categories in words in sentences. In Federmeier et al. (2001), participants were put in a positive or neutral mood. In Pinheiro et al. (2013), male participants were put in a positive, neutral, or negative mood. In both studies, participants read stories (e.g., *they wanted to make the hotel look more like a tropical resort. So, along the driveway they planted rows of...*) that ended with target words (*palms/pines/tulips*). The three target words represented three conditions: expected, within-category violation, and between-category violation. In neutral mood, they found graded N400s, largest for the between-category violation (*tulips*), intermediate for the within-category violation (*pines*), and smallest for the expected (*palms*). In positive mood, the within-category violation (*pines*) patterned with the expected (*palms*). The authors provided three possible interpretations: positive mood includes a richer set of semantic associates, positive mood flexibly accommodates unexpected/distantly related words, and positive mood entertains a plausibility-driven strategy (as opposed to a prediction-based strategy). In negative mood (Pinheiro et al., 2013), the within-category violation (*pines*) patterned with the between-category violation (*tulips*), suggesting that readers in negative mood zoom in to a narrower set of relevant semantic associates or become more critical to distantly related words.

Chwilla et al. (2011), Van Berkum et al. (2013) examined mood effects on prediction and anticipation in language. In Chwilla et al. (2011), female participants were put in a positive or negative mood, before they were presented with highly predictive sentences (e.g., *The pillows are stuffed with* ...) that continued with predicted or non-predicted critical words (*feathers/books*). In both mood states, the unpredicted (*books*) elicited a larger N400 than the predicted (*feathers*). But such N400 effect was reduced in the positive mood, compared to the negative mood. The authors suggested that positive mood allows for more prediction than negative mood does. In addition, within negative mood, there was a Late Positivity (LP) effect, larger for the unpredicted than the predicted words. The authors suggested that participants in a negative mood noticed the details and reanalyzed the unpredicted items more in this later, LP window, whereas participants in a positive mood did not. In Van Berkum et al. (2013), female participants were put in a positive or negative mood, before they read texts that contained verbs with "implicit causality biases"—that is, readers' typical expectation about who does what to whom. For example, in "*Linda apologized to David because she/he...*", readers tend to anticipate more information about Linda, which renders the pronoun "*she*" expected. However, in "*Linda praised David because he/she...*" readers tend to anticipate more information about David, which then renders the pronoun "*she*" unexpected. Such contextually unexpected pronouns have been shown to elicit larger LPs than the expected ones, and as such reveal verb-based heuristic anticipation of who will be talked about next (Van Berkum et al., 2007). Van Berkum et al. (2013) found that positive mood maintained such heuristic anticipation, whereas negative mood attenuated it. The authors speculated that a negative mood might lead the system to cut back on anticipatory referential processing of the type studied here, because the low-energy state that is typically signaled by such a mood makes such referential anticipation too resource-intensive to engage in.

The abovementioned literature supports a mood-dependent information processing style (Fredrickson, 1998) during language processing (see also Wang et al., 2016; Mills et al., 2019). Positive mood allows readers to widen semantic associates and see the bigger picture of meaning, whereas negative mood orients readers toward scrutinizing details. However, what is considered big in "big picture" may vary in language: It can stand for highly familiar, default world knowledge (e.g., knowing that more light tends to help seeing), but it can also stand for the specific discourse context that is currently configured (e.g., the astronomy context that more light tends to hinder star gazing). Relative to local processing of a word in an unfolding sentence context, *both* can in a way be considered to provide "the bigger picture" in which that processing occurs. Past non-mood studies have examined how readers juggle these two sources of knowledge, when their mood is not manipulated. Nieuwland and Van Berkum (2006) showed that all information from all sources is considered in parallel. In their study, a "local" semantic feature (animacy) in a sentence (e.g., *the peanut was salted/in love* ...) was supported or unsupported by a preceding "global" discourse context (e.g., a story about a peanut that sings and dances). They found that local semantic feature and global discourse context are processed within the same, N400 time window, suggesting that current discourse knowledge fully overrules global/default world knowledge. In contrast, Hald et al. (2007) reported that "local" discourse knowledge cannot fully override "global" world knowledge. In their study, participants read sentences that contained a critical word that was correct or incorrected based on general/global world knowledge (e.g., *The city Venice has very many canals/roundabouts* ...). These sentences were embedded in "local" discourse contexts that validate or invalidate such world knowledge (a story about this historical water city vs. a story about recent traffic control). They found a local by global interaction at the N400 time window, which indicates that while both global world knowledge and local discourse context have an effect on sentence interpretation, neither overrides the other. It appears that Nieuwland and Van Berkum (2006) viewed discourse context as being global, whereas Hald et al. (2007) viewed world knowledge as being global. An interesting question here is: which "global" or which source of knowledge would be facilitated by the "details vs. big picture" shift induced by a positive or a negative mood?

The present study examined how mood affects readers' balance between relying on world knowledge and relying on discourse knowledge. Following the abovementioned literature, we tested female participants only and manipulated their mood *via* happy and sad film clips. After mood manipulation, participants were presented with language materials. Each item contained two major pieces of world knowledge, one was cued by the discourse context and the other was cued by the critical sentence. For instance, a critical word (e.g., *more/less*) in a critical sentence (*with the lights on, you can see more/less* ...) was either supported or violated by default world knowledge cued by the critical sentential context. This critical sentence was then embedded in a discourse context that either supported the familiar world knowledge (a story about driving in the night) or supported an alternative, less familiar, but possible real world scenario (an astronomy story about stargazing). As such, our design was 2 mood (positive, negative) x 2 discourse context (supported, unsupported) x 2 critical sentence (supported, unsupported) (Table 1).

Our general predictions are that participants in a positive mood would be shifted to relying on the default world knowledge, whereas participants in a negative mood would be shifted to relying on the knowledge conveyed by discourse. As for the specific ERP components, based on the abovementioned literature, mood would impact language processing in the N400 and LPC time windows. We have mentioned these ERP components in the review above, but here we clarified the component properties and our assumptions about what they reflect. The N400 is a negative-going waveform, peaking between 200 and 600 ms, that indexes the context-dependent ease of lexical retrieval from the semantic memory (Kutas and Federmeier, 2000, 2011; Lau et al., 2008; Van Berkum, 2009; Brouwer et al., 2017). The LPC is a positive-going waveform typically occurring between 500 and 1,000 ms. The functional significance of LPC has not been settled. Some suggest that it reflects a reanalysis process of combining and recombining words for outputting sensible sentence meaning (Kuperberg, 2007). Others suggest that it reflects the demand of inference making during discourse processing (Burkhardt, 2007). Yet others associate it with an integration process that integrates all sources of information (Brouwer et al., 2012). Recently, the LPC has been linked to elaborative processes and inferences (Canal et al., 2019). Based on the synthesis of these interpretations, here we assume that LPC reflects some form of elaborative processing, e.g., more integration, or conflict resolution. Given our assumptions of these two ERP components, we expect that in the positive mood condition, words that violated default world knowledge (*with the lights on, you can see less* ...) would elicit the largest N400s, even if such reading was justified and supported by the discourse context (stargazing), following Hald et al. (2007), who used comparable materials. This expectation should also hold based on Van Berkum et al. (2013), who showed that positive mood maintains heuristics. In the negative mood condition, such discourse and sentence combination would show a reduced N400, because negative mood is more likely to pick up linguistic details in the discourse context (stargazing) to make sense of the world knowledge violation. Regarding the LPC, since both (Chwilla et al., 2011; Van Berkum et al., 2013) found that sad mood modulates LPCs (albeit the directionalities of the effects differ), we expect that readers in a negative mood would be more likely to be engaged in elaborative processing,

TABLE 1 Example stimuli.

Stimuli	CWs supported by discourse context [d+]	CWs unsupported by discourse context [d-]
CWs supported by sentence context [s+]	(1) CWs supported [d+s+] [d+]: More and more lamp posts are placed in the Netherlands. This way it is easier to see the road. This is nice for drivers. [s±] With the lights on you can see more at night.	(2) CWs partial-support [d-s+] [d-]: More and more lamp posts are placed in the Netherlands. This way it is harder to see the night sky. This is sad for astronomers. [s±]: With the lights on you can see more at night.
CWs unsupported by sentence context[s-]	(3) CWs partial-support [d+s-] [d+]: More and more lamp posts are placed in the Netherlands. This way it is harder to see the night sky. This is sad for astronomers. [s-]: With the lights on you can see less at night.	(4) CWs unsupported [d-s-] [d-]: More and more lamp posts are placed in the Netherlands. This way it is easier to see the road. This is nice for drivers. [s-] With the lights on you can see less at night.

CWs refers to critical words.

and this will be reflected in the LPCs, larger (Chwilla et al., 2011) or smaller (Van Berkum et al., 2013) LPCs.

Materials and methods

Participants

Thirty-four female, native speakers of Dutch from the Raboud University Nijmegen gave informed consent and participated in the EEG experiment for payment. Only female participants were recruited, because mood manipulation has found to be more successful in women than in men (Gross and Levenson, 1995; Federmeier et al., 2001, though see limitations in Section Limitations). Participants were assessed with the Edinburgh Inventory of Handedness (Oldfield, 1971) and the personality trait questionnaire of Positive Affect Negative Affect System (Watson and Clark, 1997). The data of several participants were excluded from the analysis, due to left-handedness ($N = 1$), PANAS personality outlier ($N = 1$), physical discomfort of illness, broken finger, and back pain ($N = 3$), technical failure ($N = 4$), and loss of trials >40% due to artifacts ($N = 1$). The remaining 24 participants (mean age = 20.4 years, range: 18–27) were right handed with normal or corrected-to-normal vision.

Design and materials

We employed a within-subject design of 2 mood (happy, sad) x 2 discourse context (support, unsupported) x 2 critical sentence (support, unsupported).

We constructed 240 quadruplets in Dutch, in the following ways (Table 1 and Supplementary material): First, we created a sentence that describes familiar world knowledge, e.g., "*with the lights on you can see more at night*". The critical word "*more*" was supported (+s) by the world knowledge. We created the condition that violates the elicited world knowledge by changing the critical word to "*less*", which was not supported (–s) by the sentence context. Next, we created a preceding discourse context whose content either reinforces the familiar knowledge ("driving in the night", d+), or goes against it ("star gazing night", d–). Thus, in condition d+s+, the critical word *more* is supported both by the familiar knowledge in the sentence (standard ideas about how light affects vision) and the discourse context (driving at night). In condition d–s–, the critical word *less* is not supported by either, as the word goes against the world knowledge (with lights on one is supposed to see better), and is also not what one would expect according to the discourse context (properly lit roads are supposed to help night driving). In condition d-s+, the critical word *more* is supported by the world knowledge, but is not what one would expect given the stargazing discourse context. It does, however, receive partial support from the sentence. Finally, in condition d+s–, although the critical word *less* is not supported by the critical sentence, it is supported by the stargazing discourse context.

We were able to recycle about a quarter of the materials from Menenti et al. (2009), Hald et al. (2007). We excluded their materials that contain scenarios that do not happen in the real world, e.g., Donald Duck, Winnie the Pooh … etc. Of the recycled ones, we edited them such that they fit our criteria described above. We also made sure to use linguistic constructions that sound natural and neutral. For example, instead of "*Amsterdam is a city that is big...*", we used "*Amsterdam is a big city...*". While both are grammatical, the former is pragmatically marked with a cleft construction (It is X that is Y), placing unnatural emphasis on the CWs.

The materials between conditions were tightly matched. In each of the 4-sentence discourse context, the first sentence introduces the topic, and is identical across all four conditions. The second and the third sentences differed between discourse types (d+) and (d–), by providing content that either supports or does not support the upcoming world knowledge cued by the critical sentence. We matched the sentence length and syntactic structure between (d+) and (d–), with minimum word differences. The critical sentential context is identical across all four conditions until the critical words (CWs hence forth), cuing world knowledge. Then, the world knowledge was either supported or not supported by the CWs, (s+) or (s–). Between (s+) and (s–), the word lengths were matched (both 7.33 letters) and the averaged log word frequencies were matched (0.85 vs. 0.84 based on CELEX (Baayen et al., 1995) and 0.80 vs. 0.80 based on SubtLex (Keuleers et al., 2010), all *p*-values n.s.). The CWs are never in a sentence-final position, nor are they also used in the discourse context.

Two pretests were conducted to verify how plausible the CWs are in the critical sentence with and without the preceding discourse contexts. Pretest 1 examined CWs in sentences without discourse contexts. The 240 sentence fragments that supported CWs and 240 sentence fragments that did not support CWs ("*With the lights on you can see more/less...* ") were divided into 2 lists *via* Latin Square rotation, such that each fragment appeared in each list only once. Within each list, the 240 items were randomized. Twenty-eight participants who did not participate in the EEG experiment or Pretest 2 (mean age 20.8, range 18–26) were randomly assigned to one of the lists, and were instructed to rate how plausible the critical word was given the preceding sentential context on a scale from 1 to 5 (1 = implausible; 5 = plausible). The mean plausibility ratings were 4.14 for (s+) and 2.38 for (s–) (Table 2). Repeated Measures ANOVA of 2 sentence x 2 list showed that list did not interact with sentence ($F < 1$), as expected. Combining lists, (s+) were more plausible than (s-) ($F(1, 239) = 77.6$, $p < 0.001$), verifying our manipulation.

Pretest 2 examined CWs in sentences with discourse contexts. The 240 [d+s+], 240 [d+s–], 240 [d–s+], and 240 [d–s–] were divided into 4 lists *via* Latin Square rotation, such that each pairing of the discourse context and the critical sentence appeared only once in each list. Forty-four participants (mean age 20.1, range 18–26) who did not take part in Pretest 1 or the main EEG experiment were randomly assigned to one of the lists each. The instructions for Pretest 2 were the same as Pretest 1. The mean plausibility ratings were 4.0 for [d+s+], 3.4 for [d–s+], 3.3 for [d+s–], and 2.2 for [d–s–] (Table 2). RM ANOVA of 2 discourse context x 2 sentence context x 4 lists showed that list did not interact with context or sentence ($F < 1$), as expected. Combining lists, There was a significant discourse context x sentence context interaction ($F(1,239) = 191.14$, $p < 0.0001$). All pairwise comparisons were significant, listed as follows. [d+s+] vs. [d+s–]: $F(1,239) = 288.91$, $p < 0.001$; [d+s–] vs. [d–s+]: $F(1,239) = 83.62$, $p < 0.001$; [d+s+] vs. [d-s-]: $F(1,239) = 118.94$, $p < 0.001$; [d+s-] vs. [d–s+]: $F(1,239) = 118.95$, $p < 0.001$; [d-s+] vs. [d-s-]: $F(1,239) = 158.73$, $p < 0.001$; [d-s+] vs. [d-s+]: $F(1,239) = 17.26$, $p < 0.001$.

Next, we divided each of the 4 lists in Pretest 2 in half into 2 sub-lists for each of the 2 mood sessions (positive, negative). That is, 120 quadruplets of sentences in each mood state. We made sure that the two sublists were comparable. The word length and frequency of the CWs between the 2 sub-lists of each list were again matched. The order of the 2 sub-lists and 2 mood sessions were counterbalanced, such that a sub-list was not always presented in one kind of mood. Then, each sub-list was divided into 5 blocks to be presented after each of the 5 mood induction video clips (more in Mood Manipulation Procedure). Within each block, the items were randomized for each participant.

To reduce session time and to avoid fatigue, we used auditory presentation of the discourse contexts that preceded the critical sentences (cf. Hald et al., 2007). One trained female Dutch speaker recorded all discourse contexts, speaking with neutral/natural intonation at a normal speaking rate. The average length of the auditory discourses is 10.5 sec (SD: 1.8 sec). The target sentences were presented visually (see Procedure for details).

We used film clips to elicit the targeted mood states, positive and negative. Meta-analyses of mood induction methods showed that films are effective in inducing the targeted emotion and that the induced emotion/mood is relatively long-lasting (Gross and Levenson, 1995; Westermann et al., 1996; Rottenberg and Gross, 2007). Based on Van Berkum et al. (2013), we used 5 film clips from a sad movie "Sophie's Choice" to induce a negative mood, and 5 film clips from a situation comedy "Friends" to induce a positive mood. Each clip lasted 3–5 min (mean 4.01 min). We verified the cheerfulness or gloominess of the film clips with a post-EEG-survey, by having EEG participants rate each film clip after the second EEG session. They were instructed to rate the films on a 1–5 scale (1 = *erg somber* "very downcast"; 5 = *erg vrolijk* "very cheerful"). The averaged film ratings were 4.5 for the "Friends" clips and were 1.6 for the "Sophie's Choice" clips (independent *t*-test: $t(30) = 16.4$, $p < 0.0001$).

Participants' mood was assessed *via* a computerized questionnaire, designed with reference to prior studies (De Vries et al., 2010; Van Berkum et al., 2013). The questionnaire contains 26 common Dutch adjectives, including 5 positive adjectives (*goed "good", tevreden "content", opgewekt "good-humored", positief "positive", vrolijk "cheerful"*), 5 negative adjectives (*down "down", slecht "bad", negatief "negative", somber "gloomy", verdrietig "sad"*), and 16 filler adjectives (*afgeleid "focused", boos "angry", geirriteerd "irritated", ongemakkelijk "uncomfortable", vermoeid "tired", zenuwachtig "nervous", slaperig "sleepy", gespannen "tense", verveeld "bored", actief "active", geconcentreerd "focused", geinteresseerd "interested", gemotiveerd "motivated", nieuwsgierig "curious", kalm "calm", ontspannen "relaxed"*). Participants were instructed to rate their mood tailored to each adjective on a 1–7 scale (1 = *Ik voelde me*

TABLE 2 Pretest results: Plausibility ratings of critical words (CWs) supported and unsupported by the critical sentence with and without discourse context.

Stimuli	No discourse	CWs supported by discourse context [d+]	CWs unsupported by discourse context [d-]
CWs supported by sentence context [s+]	4.1	4.0	3.4
CWs unsupported by sentence context [s-]	2.4	3.3	2.2

*helemaal niet "I did not at all feel"*_________; 7 = *If voelde me heel erg "I strongly feel"* _________).

Procedure

Each participant was scheduled for 2 sessions, with one week in between, at the same time-of-day and the same day-of-week. The order of mood sessions (sad first or happy first) was counterbalanced with participant number. Each session started with a 30-min EEG setup. During the setup, participants filled out the Edinburgh Inventory of Handedness and the PANAS [Positive Affect Negative Affect System, Watson et al. (1988)] personality trait questionnaire. After the setup, participants entered a soundproof, electrically shielded, and dimly lit room. They sat in a comfortable chair at a desk looking at a computer screen 70–80 cm away from their eyes. Participants were told the cover story that we were studying how concentration affects reading. They were not told that the study was about their mood states, because it is known that if participants were aware of the cause of mood change, there would be mood effects (Schwarz and Clore, 1983).

Participants first did the computerized mood rating questionnaire (baseline mood), before watching any film clip. They were asked to do the rating based on how they felt in the moment, not what they were like in general. Then, the experiment was sectioned into 5 consecutive blocks. In each block, participants watched 1 film clip, did 24 language trials, and rated their mood (in this order). Participants were instructed to watch the film clips for understanding and to listen/read the language materials attentively. Placing the mood rating at the end of each block ensured that the film-induced mood state lasted through the end of the block. The 26 adjectives on the mood questionnaire were randomized for each rating in each block, to prevent participants from memorizing their own ratings in the previous block.

In the language trials, each trial began with a discourse context presented over speakers, during which participants were told to look at the fixation sign "+" at the center of the screen. At the offset of the auditory discourse, the fixation sign remained for 1 sec, before the first word of the visual critical sentence came on the screen. The sentence was presented word-by-word, with each word presented for a length dependent duration: If a word has fewer than 8 letters, the formula was 27 ms x number of letters + 187 ms (cf. Coulson and Van Petten, 2002). If a word has more than 8 letters, the duration for 8-letter words was used. This resulted in a mean presentation duration of 370 ms for the CWs. The Inter-word Interval was a black/blank screen of 150 ms. The words were white on a black background, in Arial font, 20-point font size, and in sentence-case. The last word was presented with a period. At this point, the participant could take a tiny break or press a button to continue on to the next trial. Participants were instructed to refrain from blinking and moving during the visual presentation, but were encouraged to blink or rest their eyes between trials. There were 8 practice trials. Each EEG session lasted approximately 2 h. At the end of the 2nd session, they rated each of the film clips using a paper-and-pencil survey (cf. materials).

EEG acquisition and processing

Continuous EEG was recorded from 60 surface active electrodes placed in an elastic cap (Acticap, Brain Products, Germany) arranged in an equidistant montage (Figure 1). During recording, the left mastoid electrode served as the reference, and a forehead electrode served as the ground. A supra- to suborbital bipolar montage was used to monitor vertical eye movements (electrode 53 and VEOG), while a right to left canthal bipolar montage was used to monitor horizontal eye movements (electrodes 57 and 25). All electrode impedances were kept below 5 KΩ during recording. EEG data were amplified (0.30–100 Hz band-pass), digitized at a rate of 500 Hz with a 100 Hz high cut-off filter and a 10 second time constant.

Brain Vision Analyzer 2.0 was used to pre-process the EEG data. The EEG data were re-referenced off-line to the average of both mastoids, and low-pass filtered at 30 Hz (48 dB/oct slope). Then, the data were segmented from 200 ms before the critical word onset to 1,000 ms after, with the baseline correction from −200 to 0 ms preceding the word onset. Blinks were corrected using ICA Infomax algorithm. After that, a semi-automatic artifact rejection procedure was applied. Segments were rejected when they contained signals exceeding ±75 μV, and featured a linear drift of more than ±50 μV, beginning before the onset

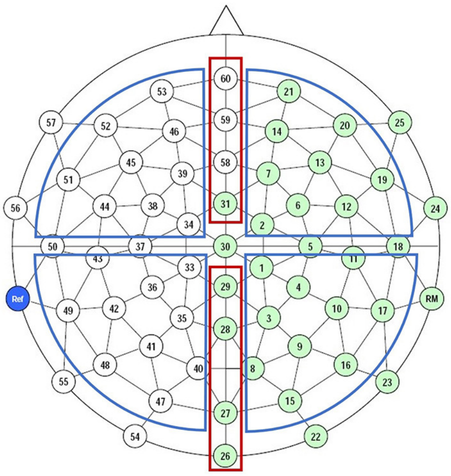

FIGURE 1
Layout of electrodes. The two red boxes indicate electrodes included in the midline analysis. The four blue boxes indicate electrodes included in the quadrant analysis.

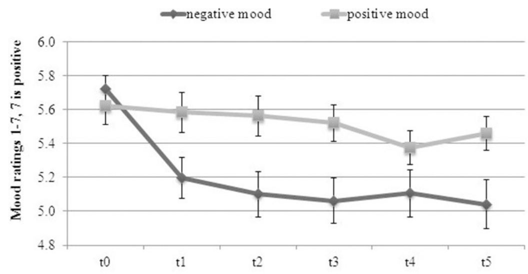

FIGURE 2
Averaged mood ratings at the baseline (t0) and the end of each block (t1, t2, t3, t4, t5), on a 1-7 scale (1 = negative mood state; 7 = positive mood state). The error bars are standard errors.

of the critical word. On average, 10% of the trials were lost. The accepted trials were averaged for each condition for each participant, and used for further statistical analysis.

Results

Mood manipulation

Mood ratings for each block were calculated by averaging the ratings from the 5 positive adjectives with transformed ratings from the 5 negative adjective. Because the scale was 1–7, we transformed the ratings by subtracting each rating from 8. In the analysis, order of mood sessions did not interact with any variable.

Figure 2 summarizes participants' mood states over time. At the baseline, there was no mood difference between the two sessions ($t(23) = 0.81$, $p = 0.426$), as expected. After watching film clips, there was significant mood difference between sessions (positive mood state vs. negative mood state in block 1: $t(23) = 2.43$, $p = 0.024$; block 2: $t(23) = 3.32$, $p = 0.003$; block 3: $t(23) = 4.75$, $p = 0.0001$; block 4: $t(23) = 2.20$, $p = 0.039$), and block 5 ($t(23) = 2.75$, $p = 0.012$). This indicates that participants were indeed in different mood states between two sessions.

Within a session, after watching the sad film clips, participants' mood dropped negative significantly relative to baseline (block 0 vs. block 1: $t(23) = 5.52$, $p < 0.0001$; block 0 vs. block 2: $t(23) = 4.93$, $p < 0.0001$; block 0 vs. block 3: $t(23) = 5.36$, $p < 0.0001$; block 0 vs. block 4: $t(23) = 4.24$, $p < 0.0001$; block 0 vs. block 5: $t(23) = 5.08$, $p < 0.0001$). However, after watching the cheerful film clips, participants' mood states were not elevated relative to baseline, but were also not down.

ERP results

The grand averages are displayed in Figure 3. Visual inspection suggested that perceptual ERP components of N1 and P2 are present, indicating normal visual processing, in both mood sessions. Following the perceptual components, there are negative-going waveforms peaking at 400 ms, identified as the N400s. The CWs unsupported by both the discourse context and the sentence context [d-s-] elicited N400s more negative than the CWs supported by both [d+s+], at the posterior sites, in both mood states. The LPCs became obvious at 600 ms and were sustained through the end of the segments at 1,000 ms. The CWs unsupported by the sentence context, the discourse context, or both ([d+s−], [d-s+], [d−s−]) elicited LPCs more positive than the CWs supported by both [d+s+], when participants were in a negative mood state (Figure 3B), but not when they were in a positive mood state (Figure 3A). These observations are supported by statistics, reported in sections 3.3 and 3.4. Topographic distributions of the N400 effects (300–500 ms) and LPC effects (600–1,000 ms) effects are displayed in Figure 4.

The mean amplitudes for the CWs from each condition in the 300–500 ms and 600–1,000 ms time windows were exported and entered into two statistical analysis: midline analysis and quadrant analysis. Midline electrodes were selected based on convention in language ERP studies. Electrodes in the quadrant regions were selected to increase coverage of the whole head. All reported numbers and p-values were Greenhouse-Geisser corrected and corrected for multiple comparisons.

N400: 300–500 ms

There is no mood modulation of N400 effects, based on the following analyses. In the midline analysis, Repeated-Measures

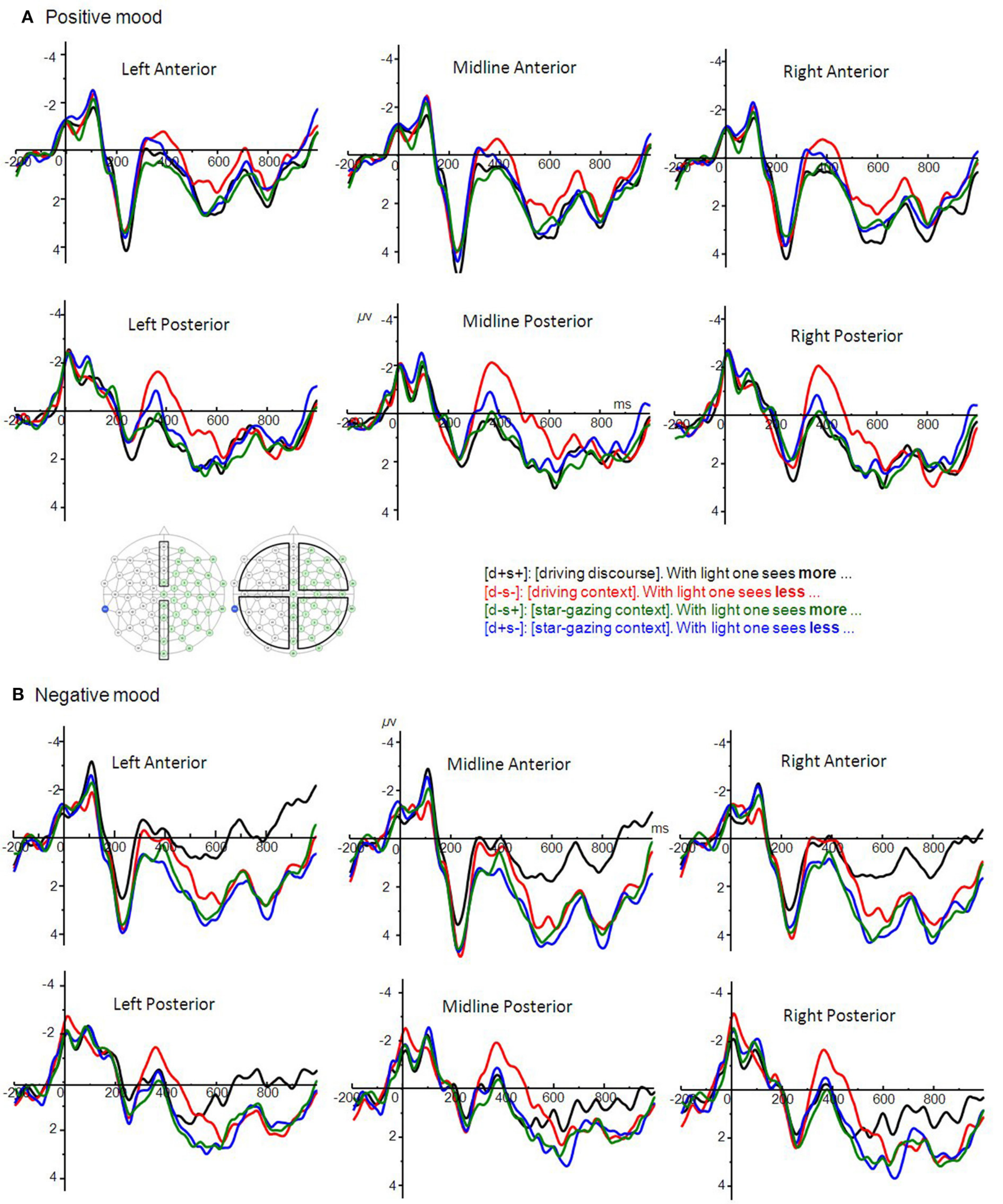

FIGURE 3
Grand ERP averages for the critical words supported by the discourse context and the sentence context ([d+s+], black line), unsupported by the discourse context and unsupported by the sentence context ([d-s-], red line), supported by the sentence context but not by the discourse context ([d-s+], green line), and supported by the discourse context but not by sentence context ([d+s-], blue line) in grouped channels in the 2 (anterior, posterior) x 3 (left, middle, right) regions, in the positive mood state **(A)** and the negative mood state **(B)**. Negative voltage is up.

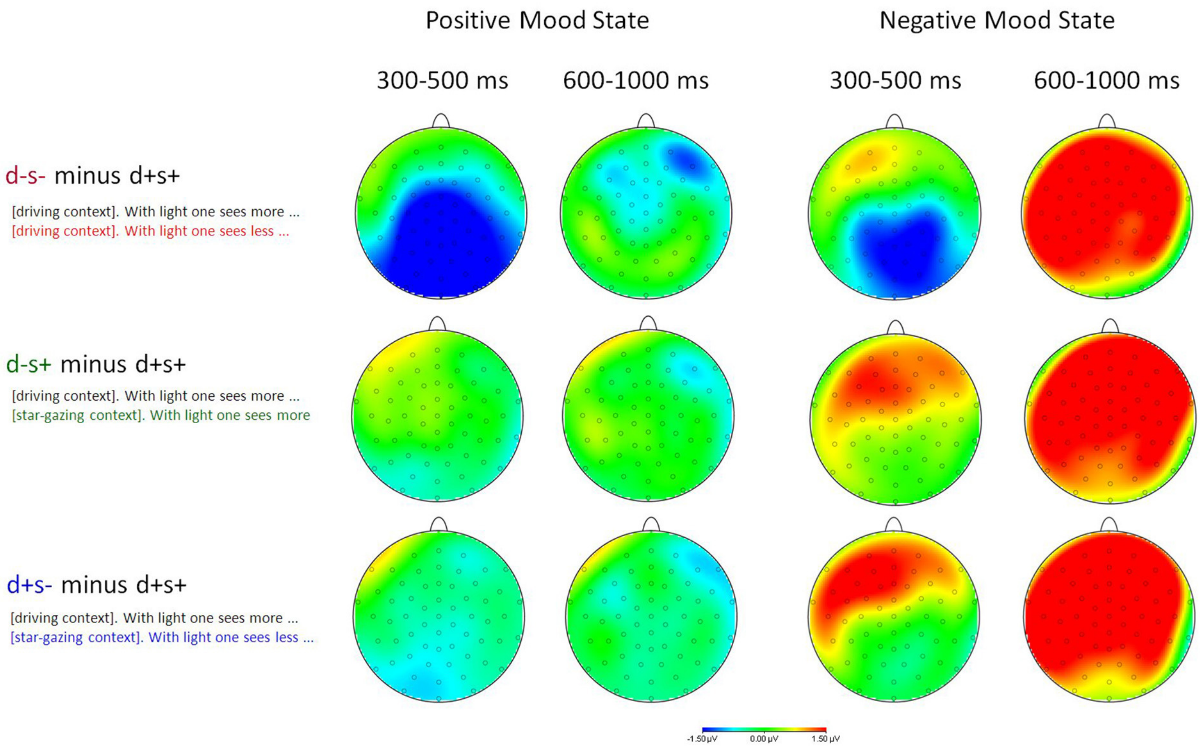

FIGURE 4
Scalp distribution of the effects obtained by subtracting the supported critical word (d+s+) from each of the other conditions (d-s-, d-s+, d+s-) in the N400 time window (300–500 ms) and the LPC (late positivity component) time window (600–1,000 ms).

(RM) ANOVAs of 2 mood (positive, negative) x 2 discourse context (supported, unsupported) x 2 sentence context (supported, unsupported) x 2 regions (frontal, posterior) x 2 order of mood revealed no 5-way interaction ($F < 1$). Combining mood, there was a significant discourse context x sentence context x region interaction ($F(1,23) = 8.74$, $p = 0.007$). Separate RM ANOVAs of 2 discourse context x 2 sentence context within each region were conducted. The N400 effects were significant in the posterior region ($F(1,23) = 6.07$, $p = 0.022$), but not in the frontal region ($F(1,23) = 0.01$, $p = 0.935$). Pairwise comparisons within the posterior region showed that the CWs unsupported by the discourse context and the sentence context [d–s–] elicited significantly larger N400s than control [d+s+] ($F(1,23) = 26.89$, $p = 0.0001$). The CWs supported by either the discourse context or the sentence context ([d+s–], [d-s+]) elicited comparable N400s to control [d+s+].

Similarly, in the quadrant analysis, RM ANOVAs of 2 mood (positive, negative) x 2 discourse context (supported, unsupported) x 2 sentence context (supported, unsupported) x 2 region_LR (left, right) x 2 region_AP (frontal, posterior) revealed no interaction at the highest level ($F(1,23) = 1.75$, $p = 0.199$). Combining mood, significant discourse context x sentence-context x region_AP interaction was observed ($F(1,23) = 10.92$, $p = 0.003$). Combining left and right, the significant discourse context x sentence context interaction came from the posterior region ($F(1,23) = 5.04$, $p = 0.035$), not from the frontal region ($F(1,23) = 0.003$, $p = 0.953$). The CWs unsupported by discourse context and sentence context [d-s-] elicited significantly more negative N400s than control [d+s+] ($F(1,23) = 18.34$, $p = 0.0001$). None of the other comparisons was significant.

Late positivity component (LPC): 600–1,000 ms

There was mood modulation of LPC effects, supported by the following statistics. In the midline analysis, RM ANOVAs of 2 mood (positive, negative) x 2 discourse context (supported, unsupported) x 2 sentence context (supported, unsupported) x 2 regions (frontal, posterior) x 2 order of mood revealed a significant 4-way interaction ($F(1,23) = 4.60$, $p = 0.043$). Breaking down the interaction, we conducted separate RM ANOVAs of 2 discourse context x 2 sentence context within each region for each mood. In the negative mood state, in the frontal region, there was a significant discourse context x sentence context interaction ($F(1,23) = 5.01$, $p = 0.035$). Pairwise comparisons showed that in the frontal region, the CWs unsupported by the discourse context [d-s+], the sentence context [d+s-], and both [d-s-] all elicited significantly more positive LPCs than control [d+s+] ([d–s+] vs. [d+s+]: $F(1,23) = 20.43$, $p = 0.0001$); ([d+s–] vs. [d+s+]: $F(1,23) = 22.56$, ($p = 0.0001$); ([d–s–] vs. [d+s+]: $F(1,23) = 17.71$, $p = 0.0001$). These effects were only marginally significant in the posterior region under the negative mood state, and were not significant in any region under the positive mood state.

Similarly, in the quadrant analysis, repeated ANOVAs of 2 mood (positive, negative) x 2 discourse context (supported, unsupported) x 2 sentence context (supported, unsupported) x 2 region_LR (left, right) x 2 region_AP (frontal, posterior) revealed a mood x discourse context x sentence context x region_AP interaction ($F(1,23) = 9.42$, $p = 0.005$). In the negative mood state, in the frontal regions, there were significant discourse context x sentence context interactions both in the left frontal region ($F(1,23) = 6.95$, $p = 0.015$) and the right frontal region ($F(1,23) = 5.55$, $p = 0.027$). Pairwise comparisons showed that the CWs unsupported by the discourse context [d-s+], the sentence context [d+s-], and both [d-s-] all elicited larger LPCs than control [d+s+] (all $p < 0.0001$). Also in the negative mood, in the posterior region, the discourse context x sentence context interaction was significant in the left posterior region ($F(1,23) = 5.40$, $p = 0.029$) and marginally significant in the right ($F(1,23) = 3.99$, $p = 0.06$). In the positive mood state, there was no LPC difference between conditions in any region.

Discussion

We conducted an ERP experiment to examine whether mood states would influence readers when they read discourse content that is not emotionally loaded. Our general hypothesis is that readers in a positive mood would rely more on default world knowledge, whereas readers in a negative mood would analyze the details in the current discourse. Female participants were put in a positive and a negative mood *via* film clips, one week apart. In each session, after mood manipulation, they were presented with vignettes that contained a critical sentence and a wider discourse context. The critical sentence contained a critical word (e.g., *more/less*) that was either supported or unsupported by the familiar world knowledge in sentential context (*with the lights on, you can see* …). Each reading was also either supported or unsupported by the wider discourse context (a story about driving in the night/a story about stargazing).

We found that mood did not modulate the N400 effects. In both moods, CWs that were not supported by world knowledge and not supported by discourse elicited the largest N400, in comparison to the other three conditions, whose N400s were comparable to one another. Mood did modulate the LPC effects that we observed at frontal sites. In negative moods, CWs that were supported by only world knowledge, only discourse, and neither, elicited larger frontal LPCs, in comparison to the condition where CWs were supported by both world knowledge and discourse. These results partially supported our general hypothesis.

LPC (600–1,000 ms): Mood sensitive

The patterns of results in the LPC time window differed significantly between the participants' two mood sessions. Under negative mood, large and sustained LPC effects were elicited by all three experimental conditions ([d-s+], [d+s-], [d-s-]), compared to control [d+s+]. Under positive mood, there was no LPC differences between conditions. These results suggest that negative mood shifts the readers to relying more on current discourse, as opposed to relying more on default knowledge, within the LPC time window, which indexes the meaning elaboration stage (cf. Introduction). That is, readers in a negative mood are more likely to continue processing conflicted meanings from different information sources (world knowledge vs. current discourse). By processing we mean that our negatively minded readers continued to analyze and reanalyze these conflicts in an attempt to come up with a coherent output interpretation (Kuperberg, 2007), during which heavier inference drawing (Burkhardt, 2007) for elaborative processing (Canal et al., 2019) could be at work. All of these elaborative sub-processes would lead to the enhanced LPC amplitudes.

A second interesting possibility could be that the signal of conflicts in meaning triggered a "negativity bias"—i.e., the tendency to attend to negative content (Ito et al., 1998) in younger adults. Note that content-wise, our materials are actually not negatively valenced. Thus we are not suggesting negativity bias in its traditional definition. We suggest that it is the conflict between the two available information sources that might have attracted attention and invited the continued information processing in negative mood, which then led to the enhanced LPC amplitudes. If it is indeed "negativity bias" at work, then our results implicate that the definition of "negativity bias" needs to be broadened to include either (1) more attention toward (non-valenced) information as long as it is conflicting and problematic, or (2) more motivation/willingness to analyze conflicting information. The latter of the two could also become a form of rumination (Bar, 2009), fixating on the irresolvable conflicting information. Future studies will be needed to tease apart these possibilities.

Our LPC results are consistent with some but not all past ERP studies on mood on language. Our results are consistent with Chwilla et al. (2011). They found a larger LPC effect (600–800 ms) for the unpredicted CWs than the predicted CWs, in negative mood, but not in positive mood, which they suggested was due to a mood-induced reanalysis effort for the unpredicted CWs. Similar to their suggestion, we also suggest here that the negative mood nudged our participants toward a more analytical mindset. In terms of the scalp distributions of the LPC effects, ours was significant in the the frontal electrodes, whereas the LPC effect was significant in both the frontal and posterior electrodes in Chwilla et al. (2011). Such difference was likely caused by the content of the stimuli. In non-mood studies (e.g., DeLong et al., 2014), the LPC effects elicited by sentence stimuli with unpredictable but plausible CWs is more frontally distributed, whereas the LPC effects elicited by stimuli with unpredictable and anomalous CWs is distributed at posterior electrode sites. In mood studies such as ours here, we used discourse materials that described scenarios that could happen in the real world. Thus, the frontal distribution of our LPC effect makes sense. In Chwilla et al. (2011), their low predictive stimuli still had plausible endings and their LPC effect was significant at both the frontal and posterior electrodes. Synthesizing both studies, it is consistent that negative mood modulates the frontal LPCs elicited by plausible stimuli. But it is less clear what mood does for posterior LPCs elicited by implausible stimuli. This gap in knowledge is a great opportunity for future studies.

Our results might be consistent with Pinheiro et al. (2013). Pinheiro et al. (2013) did not analyze the LPC time window, likely because their study was based on Federmeier et al. (2001), who only tested positive mood and (therefore) only reported positive mood effect in the N400 time window. But Pinheiro et al. (2013) expanded the design of Federmeier et al. (2001) to include negative mood induction. In the ERPs in their negative mood [Figure 7, Pinheiro et al. (2013)], the between-category violations (*tulips*) showed a much larger LPC (600–900 ms) than their within-category violations (*pines*) in context (a tropical resort context), visually. They did not conduct analysis in this late time window. If their LPC effect was statistically significant, then their results would be consistent with ours and Chwilla et al. (2011), suggesting a more analytical processing style in negative mood. Our LPC effect (600–1,000 ms) seems less comparable to the ERP positivity effects (400–500 ms and 500–600 ms) in Van Berkum et al. (2013), which indexed anticipation heuristics and was not examined here. Overall, past and current research point to the consistent finding that readers in a negative mood tend to be more analytical of unpredicted and unexpected words.

N400 (300–500 ms): Mood insensitive

The patterns of results in the N400 time window did not differ between mood sessions. Under both moods, the [d–s–] condition (a story about driving in the night, followed by "*with the light on you see less* ...") where familiar knowledge from long term memory was not supported and without any discourse justification, elicited a larger N400 than the control [d+s+] condition (a story about driving in the night, followed by "*with the light on you see more* ..."). No N400 effect was found in the other conditions ([d+s–] and [d-s+]), both of which started with a less salient scenario (stargazing story). These results suggest that mood did not shift our readers to relying more on default world knowledge or current discourse, not in the N400 time window, which indexes context-sensitive lexical retrieval.

Combining data from both mood sessions, our N400 results only partially replicated Hald et al. (2007), where there was no mood manipulation. The main finding of Hald et al. (2007) was that neither world knowledge in long-term memory nor discourse context could completely override each other, as indexed by graded N400s. Why such discrepancy between studies? We could think of two potential explanations. The first one has to do with the differences in the materials between studies. The materials in Hald et al. (2007) consisted of a mix of fictional and real world characters and events, whereas our materials consisted of scenarios that could happen in the real world. Perhaps the authenticity of such real world knowledge attracted our participants as much as the current discourse meaning did, which then put participants' semantic system in an indeterminate state. This situation may be similar to the "Moses illusion" phenomenon, where people answer "2" to the question "how many animals of each kind did Moses take on the ark?" without noticing that it was actually Noah, not Moses, that brought animals on the ark in the original story. Notably, studies on the Moses illusion also reported a lack of N400 for a plausible semantic violation (Nieuwland and Van Berkum, 2005). A second possible explanation for the discrepancy between studies is that we used a mood manipulation, whereas Hald et al. (2007) did not. Assuming their participants were in a neutral mood, perhaps they balanced world knowledge and discourse better, not allowing one information source to override the other. And perhaps when people are in a positive or negative mood, like the participants in our study, some neural resources are occupied by the affective system, leaving insufficient resources to the cognitive system to maintain balance. These are speculations and should be tested in future studies.

Our N400 results are inconsistent with past ERP studies on mood on language. In Federmeier et al. (2001), readers in a positive mood showed a reduced N400 effect for within-category violations that had a minor difference (seeing *pines* instead of *palms* in a tropical resort context), suggesting a broader semantic activation. In Pinheiro et al. (2013), readers in a negative mood showed an increased N400 effect for the very same within-category violation, suggesting a stricter semantic activation. However, in Chwilla et al. (2011), readers in a negative mood showed reduced an N400 effect for highly unpredicted (similar to between-category violation) words in context (e.g., pillow was filled with *books* instead of *feathers*). Furthermore, a recent study (Wang et al., 2016) found that readers in a positive mood showed an enhanced N400, but only when the critical words were emphasized (focused) by context, not when they were not emphasized (non-focused). Why these discrepancies? Our current thinking post-experiment now is that at the stage of the N400 time window, mood might need to interact or work with lexical-semantic variables to make a difference: In Federmeier et al. (2001) and Pinheiro et al. (2013), the variable is the fine-grained, within-category feature. In Chwilla et al. (2011), the variable is the strong prediction for the features of the critical words. In Wang et al. (2016), the variable is focus. In our design, we did not manipulate lexical-level variables, and hence the lack of mood effects at the N400 stage.

Limitations

There are several limitations and caveats. First, we used female participants only. While this choice follows existing studies which allows us to compare our results with theirs (e.g., Chwilla et al., 2011; Wang et al., 2016), this practice limits generalization of these findings. Future studies should recruit participants from more diverse populations and mark genders in an inclusive way.

Second, while there was a significant difference between the two elicited mood states, within the positive mood session, participants' mood states were not elevated relative to baseline. It is possible that positive mood induction was not successful enough. Future studies should further examine effects of positive mood on the discourse level of language.

Third, to show mood modulation of ERP components, one might consider a correlation analysis, correlating the observed LPC effect amplitudes with mood ratings. We did not do so for two reasons: We do not have enough sample size and statistical power for a reliable correlation. In addition, the selection of electrode(s) is non-trivial. Past studies that conducted such correlation either used a carpet search approach correlating each and every electrode with mood ratings (Chwilla et al., 2011), or used only a number of electrodes that had significant amplitude results to correlate with mood ratings (Wang et al., 2016). These approaches are not ideal and could lead to incidental findings. The time window selection from anywhere from 0 to 1 second post word onset would be another issue, though recent data-driven methods might help reduce cherry picking time windows (Canal et al., 2022).

Fourth, a reviewer pointed us toward a theoretical framework, the "PET (Process, Emotion, Task) framework" (Bohn-Gettler, 2019). We did not set out to test this framework, because it was not available at the conception of this study. However, our data could certainly be related to this framework, at the situation model level under P (Process), where prior knowledge and current discourse information interact. In terms of E (Emotion), we have focused on the positive/negative valence. In terms of T (Task), we have examined constructive processing, as opposed to reproductive processing.

Finally, we used a very coarse and simplistic "valence" approach, manipulating mood and putting one in a positive or a negative mood. This probably did not capture the whole complexity surrounding the effects of mood states on information processing. Gable and Harmon-Jones (2010) encouraged researchers to also examine the motivation dimension, as they showed that positive affect that is low in approach motivational intensity (e.g., contentment) broadens cognition, whereas positive affect that is high in approach motivation (e.g., desire) narrows cognition. It would be interesting to examine the interplay between world knowledge and discourse under the influence of moods with high and low approach motivational intensity.

Conclusion

In conclusion, the current findings inform us about the effects of mood on readers' reliance on world knowledge and discourse information. Our initial predictions were that people in a positive mood would be more likely to rely on default world knowledge, whereas people in a negative mood would tend to focus on details in discourse. Our results showed that this is not entirely the case. People in a positive mood seem to entertain meaning and knowledge from both sources of real world and discourse context and are attracted to both. In contrast, people in a negative mood were shifted to relying on current discourse, reanalyzed details in all conditions that contained conflicts between different sources of information. These results advance our knowledge on the role of mood states in language meaning processing.

Data availability statement

The materials are available in the Supplementary material. Further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by Max Planck Institute for Psycholinguistics. The patients/participants provided their written informed consent to participate in this study.

Author contributions

JvB, PH, and VL co-designed the study. PH funded the study and provided the basic stimulus materials. VL constructed more stimuli and normed them and collected the EEG data and analyzed them. JvB supervised the analysis. VL prepared the manuscript with suggestions from JvB and PH. JvB and PH co-contributed to the publication fee. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fcomm.2022.910482/full#supplementary-material

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