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Setbacks, pleasant surprises and the simply unexpected: brainwave responses in a language comprehension task

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This event-related potential (ERP) study explored the behaviour of N400 and post-N400 frontal positivities (pN400FP) during the processing of emotionally biased and unbiased sentences that randomly led to highly expected or unexpected word outcomes. Unexpected outcomes (as determined by sentence completion written tests) elicited significantly larger N400 and pN400FP responses than did highly expected outcomes. Emotionally neutral outcomes triggered a significant N400 expectancy effect across all scalp locations, including frontal sites, whereas emotionally biased outcomes elicited a significant N400 effect localized to posterior scalp regions. The subsequent pN400FP effect was significant only when emotional expectations were violated and not when emotionally neutral sentences led to unexpected outcomes. This frontal effect, linked to the processing of lexically unexpected but plausible words, showed larger amplitudes for unexpected pleasant surprises than for unexpected setbacks. Our results support the view that the pN400FP response to unexpected verbal outcomes entails more than a generic reaction to a lexical 'misprediction'. Rather, they favour the hypothesis that the affective content of the sentence being processed influences the effort needed to override a lexical prediction, such that more effort is needed to override a pessimistic prediction than an optimistic one.

Keywords: event-related potentials; N400; post-N400 frontal positivity; prediction; emotional sentence processing

INTRODUCTION

Recording electrical brain activity when people read sentences for comprehension shows that unexpected words in a sentence elicit larger negative-going event-related potentials (ERPs) 250–550 ms after word onset than do highly expected words in the same sentence; this is referred to as the N400 context effect. The degree of expectancy of a word in a sentence is measured in what is called a cloze probability (CP) norming study. On a paper-and-pencil questionnaire, people are asked to spontaneously produce a word that would fit best in the incomplete sentence provided. The percentage of people that choose a given word to complete the sentence represents that word's CP value. When the completed sentence is presented to someone whose brain activity is being measured, the amplitude of his/her N400 response to the presented word correlates with the CP value measured offline in the paper-and-pencil questionnaire: the higher the CP value, the smaller the N400. Thus, the N400 component of the ERP serves as an index of how well a word in a sentence matches peoples' offline-measured expectations (see reviews: Debruille, 2007; Kutas and Federmeier, 2011).

When CP is low, i.e. when the word is unexpected in the given context, other factors in addition to CP affect the N400 response. One factor is how the unexpected word semantically relates to the highly expected word in that given context within our long-term memory. Low-CP words more closely related semantically to the highly expected word elicit reduced/smaller N400 responses than do low-CP words that are more distantly related (Federmeier and Kutas, 1999). This means that processing is facilitated for words that are more closely related semantically to the highly expected word, even if those words have similarly low CP. In addition, people's expectations can be manipulated by a wider discourse context: if a *peanut* is introduced as being capable of human behaviour, then the participant may find it easier to process the outcome that the peanut is 'in love' than the outcome that it is 'salted' (Nieuwland and Van Berkum, 2006). This translates into a lower N400 response than that typically expected for out-of-context outcomes.

In fact, N400s can also be influenced by a wider, meta-linguistic context involving factors that go beyond sentence or discourse constraints. For example, experimentally inducing a happy mood prior to a reading task reduces the N400 response to words that are semantically distant from the expected word, but not the response to words semantically close to it (Federmeier *et al.*, 2001). This result suggests that individuals in particular mood states may be more or less open to accepting otherwise 'unacceptable' semantic associations. In addition, N400s are reportedly sensitive to externally measured, stereotyped gender prejudices (Kutas *et al.*, 2000; White *et al.*, 2009); ethical/political beliefs (Van Berkum *et al.*, 2009) and even to personality traits in the subject performing the reading task, including empathizing skills (van den Brink *et al.*, 2012) and impulsivity (De Pascalis *et al.*, 2009). In a preliminary study, we hypothesized that the type of prediction that needed to be made, and particularly whether or not it carried an emotional connotation, might also influence N400 brainwave responses (Moreno and Vázquez, 2011).

Controversy continues over whether the N400 component of the ERP serves as an index of the difficulty someone experiences when integrating upcoming information into a verbal context or the clash one experiences between a given lexical input and a conscious or unconscious lexical prediction (see Van Berkum *et al.*, 2005; Federmeier and Laszlo, 2009; Kutas and Federmeier, 2011). It has been claimed that 'under some circumstances, at a certain age, or even at different parts of our brain we may use predictive or integrative strategies' (Federmeier, 2007). In our view, even if prediction is not pervasive during language comprehension tasks, the reader is likely to venture predictions when faced with sentences that prompt a highly expected (high-CP) word target. In the following discussion, we will not take a position on whether the N400 ERP effect reflects integration or prediction processes. Instead we will take an operational approach and define verbal outcomes as highly expected or unexpected purely on the basis of whether the word eliciting the N400 response was or was not highly expected according to its CP value on a paper-and-pencil questionnaire.

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Researchers have recently focused on brainwave responses to lexical outcomes that run counter to expectations despite remaining plausible in context. These ERP studies have identified a post-N400 frontal positivity (pN400FP) as an index of what may be considered a 'misprediction' cost (Kutas *et al.*, 2011). Several specific situations elicit pN400FP effects: low-CP words in contexts that strongly bias the reader towards a specific lexical item (Federmeier *et al.*, 2007), plausible but less probable noun continuations (Delong *et al.*, 2011), critical words indicating a character's inappropriate emotional response to a prototypical social scenario (Leuthold *et al.*, 2012), and low-CP words that are emotionally opposite to a highly expected emotional word outcome (Moreno and Vázquez, 2011). Functional interpretation of the pN400FP effect remains unclear. It may reflect the appreciation of a mismatch between prediction and outcome, the allocation of more cognitive resources to revise a strongly held prediction (Federmeier, 2007), the effort to inhibit a predicted but not presented lexical item (Van Petten and Luka, 2012) or even the action of some learning mechanism for updating current knowledge (DeLong *et al.*, 2011).

An experimental finding critical for understanding the functional significance of the pN400FP is that the effect is absent in lexical tasks involving wholly incongruous targets (Federmeier *et al.*, 2010). It is similarly absent from brain responses to nonsense endings during the processing of sentences that strongly bias the reader to expect a negative or positive outcome (Moreno and Vázquez, 2011). In a review of the literature by Van Petten and Luka (2012), fully incongruent outcomes were found to occasionally elicit parietally distributed late positivities, whereas low-CP but plausible endings often tended to elicit frontally distributed late positivities.

Consistent with these studies, recent work by Moreno and Vázquez (2011) found that utterly impossible endings to emotionally biased sentences did not elicit pN400FP effects. Only when an outcome was plausible was a pN400FP response observed, both when the unexpected low-CP word represented a setback (a worse-than-expected outcome) or a pleasant surprise (a better-than-expected outcome). The amplitude of the effect was not significantly different between the two cases, although it appeared larger for unexpected pleasant surprises. Analysis of the N400 responses in the same study showed that they were similar for setbacks and pleasant surprises. However, highly expected outcomes of similarly high CP, which elicited the smallest N400 responses overall, elicited a larger N400 response when they were positive than when they were negative. This difference was observed in a midline-posterior scalp region. Based on these findings, the authors tentatively suggested that rather than differentially reacting to *unexpected* emotional events leading to better-than-expected or worse-than-expected outcomes, participants might have been strategically adjusting the strength of their positive and negative predictions as they were being exposed to scenarios in which emotional expectations might be—and in fact were—violated at random, including outright semantic violations.

To follow up on these results, we introduced an emotionally *neutral* sentence condition in this study, and we eliminated the overt semantic violation condition from our previous work (Moreno and Vázquez, 2011). The aim was to further explore the behaviour of both N400 and pN400FP effects during the processing of emotionally biased and now also emotionally *unbiased* linguistic scenarios randomly leading to highly expected or unexpected word outcomes. The rationale to include these emotionally unbiased scenarios was to try to determine to what extent the emotionality of the sentences was making a contribution in terms of N400 and/or pN400FP effects. We expected to replicate previously found results (i.e. unexpected endings in emotionally biased sentences eliciting both an N400 and a pN400FP effect) while we were uncertain as to whether unexpected *emotionally unbiased* endings will just elicit an N400 effect or will also be followed by a postN400FP.

Electrophysiological studies using linguistic emotional contents have recently reported ERP modulations with earlier onsets than N400 and pN400FP. These earlier responses have been observed both in single-word processing paradigms (Scott *et al.*, 2009) and in words embedded in short sentences preceded by emotionally consistent or inconsistent discourse (Leon *et al.*, 2010). Thus, we also examined N1 and P2 ERP modulations occurring during our language comprehension task.

METHODS

Participants

Thirty-two native Spanish speakers volunteered to participate in the study for course credit. All participants gave written informed consent. We herein report results from 26 participants (22 women and 4 men; mean age = 21.6 years, range = 20–29 years) whose data met artifact rejection criteria for inclusion. All members of the final sample reported being right-handed, with an average handedness score of +76.6 (Oldfield, 1971). All reported normal or corrected-to-normal vision, and none had a history of neurological or psychiatric disorders. According to psychological measures, participants scored higher in positive than negative affect state at the time of testing (mean positive = 34.5; mean negative = 12.2; scale, 10–50) (Positive and Negative Affect Schedules—PANAS; Watson *et al.*, 1988). They scored higher on the optimism items than on the pessimism items on the Life Orientation Test LOT-R (mean optimism = 10.3; mean pessimism = 7.2; scale, 3–15) (Scheier *et al.*, 1994).

Materials

A subset of 140 of the 210 emotionally biased sentence frames was selected from the study by Moreno and Vázquez (2011). Negatively biased sentences depicted scenarios in which someone might be pushed off a cliff, suffer a tumour, die and so on; these sentences had a high-CP expected ending (73% on average) as well as a low-CP alternative ending in which the person was rescued, turned out to be misdiagnosed or suddenly recovered. Positively biased sentences prompted the expectation of someone being praised, loved, happy and so on, with the low-CP possibility of being fired, abandoned or dissatisfied. The sentences were selected so that high- and low-CP endings showed similar frequencies of use, lengths and high or low CP values across both positively and negatively biased sentences. Positive and negative contexts were matched for the extent to which they led participants to predict sentence endings. Likewise, when an unexpected ending was selected, its CP in the sentence was also matched across sentence emotionality.

For the purposes of this study, an additional set of 140 emotionally *neutral* sentence frames was created. A CP norming study was conducted with them to determine the most highly expected ending and plausible alternative endings. Fifty-eight students participated in the study by completing one of two lists, each with 70 incomplete sentence frames. Participants (29 per list) were asked to complete each sentence with their most likely expected word and write it down in the first column (Response 1, R1). They were also instructed to provide two alternative endings for the same sentence (R2 and R3). A set of 70 sentences was then selected for inclusion in the ERP experiment; the selection was carried out such that the CP, frequency of use and length of high- and low-expected endings were matched to those of the endings of the emotionally biased sentences selected from Moreno and Vázquez (2011) (Table 1).

The ERP experiment included a final set of 210 sentences: 70 neutral, 70 negatively biased and 70 positively biased. Table 2 shows examples of sentences and their potential endings. During the

Table 1 CPs, frequency of use and word length corresponding to high and low CP endings for each type of sentence

			No. of responses	CPs								Frequency of use		No. of letters	
				High				Low				High	Low	High	Low
				R1	R2	R3	T	R1	R2	R3	T				
Sentence Frame	Negatively biased ($n = 70$)	Mean	31.4	73.2	11.6	2.9	87.7	0.9	4.5	3.9	9.3	162.6	232.6	6.9	7.2
		Range	27–33	97.0–51.5	31.0–0.0	12.1–0.0	100–69.7	10.3–0.0	39.3–0.0	18.2–0.0	48.5–3.0	1420–0	3744–0	10–4	12–4
		s.d.	*2.2*	*12.3*	*6.7*	*2.9*	*8.6*	*2.1*	*6.7*	*4.4*	*9.6*	*251.0*	*616.2*	*1.5*	*2.3*
	Positively biased ($n = 70$)	Mean	31.3	72.9	10.8	3.5	87.2	1.1	4.2	3.9	9.2	156.3	208.7	7.1	6.9
		Range	28–33	97.0–53.	27.3—0.0	12.1–0.0	100–62.1	10.3–0.0	30.3–0.0	27.6–0.0	48.5–3.0	1624–0	3249–0	11–3	12–3
		s.d.	*2.1*	*12.0*	*6.8*	*3.3*	*9.7*	*2.2*	*5.8*	*4.5*	*8.9*	*262.8*	*523.3*	*2.1*	*2.1*
	Emotionally neutral ($n = 70$)	Mean	28.9	76.5	10.9	2.8	90.2	1.2	4.2	4.4	9.8	180.7	207.8	6.9	6.9
		Range	27–29	96.6–51.7	34.5–0.0	13.8–0.0	100–58.6	10.3–0.0	17.2–0.0	13.8–0.0	27.6–3.4	1174–0	3527–0	12–2	13–3
		s.d.	*0.3*	*13.2*	*7.7*	*4.0*	*10.2*	*2.2*	*4.4*	*3.8*	*6.2*	*244.1*	*498.1*	*2.1*	*2.2*

Table 2 Examples of sentences and target endings used in the experiment

		Target word outcome[b]			
	Sentence frame[a]	High-CP ending	CP as R1 (%)	Low-CP ending	CP as R1, R2 or R3 (%)
Negatively biased	En el capítulo no pasó nada de particular y resultó muy . . .	. . . aburrido.	90.9	. . . interesante.	12.1
	There was nothing special about the episode and it turned out to be very . . .	*. . . boring.*		*. . . interesting.*	
	Escribió una carta despidiéndose del mundo y luego se . . .	. . . suicidó	78.8	. . . animó.	3.0
	[He/She] wrote a farewell letter to the world and then . . . [himself/herself] . . .	*. . . committed suicide.*		*. . . cheered up.*	
	Aunque había pasado ya mucho tiempo, todavía me guardaba . . .	. . . rencor.	71.4	. . . aprecio.	7.1
	Although it happened a long time ago, [he/she] still held . . . [against me/me in great]	*. . . [a] grudge.*		*. . . esteem.*	
	Compró un cachorrito por puro capricho y luego lo . . .	. . . abandonó.	57.1	. . . cuidó.	7.1
	[He/She] bought a puppy on a whim and then [he/she] . . . [it/of it]	*. . . abandoned.*		*. . . took care.*	
Positively biased	El príncipe se acercó a la bella durmiente y la . . .	. . . besó.	90.6	. . . mató.	3.1
	The prince approached the sleeping beauty and [he] . . . [her]	*. . . kissed.*		*. . . killed.*	
	Mi jefe vio el trabajo bien hecho y me . . .	. . . felicitó.	79.3	. . . ignoró.	3.4
	My boss saw that the work was well done and [he] [me] . . .	*. . . congratulated.*		*. . . ignored.*	
	Esos detalles conmigo demostraban lo mucho que me . . .	. . . quería.	69.7	. . . envidiaba.	6.1
	Those little thoughtful details revealed how much [he/she] [me] . . .	*. . . loved.*		*. . . envied.*	
	Me daba pereza ir a verle, pero lo hice y me . . .	. . . alegré.	57.6	. . . arrepiento.	9.1
	I was lazy to go see him, but I did it and [I] . . .	*. . . was glad.*		*. . . regret it.*	
Emotionally neutral	Antes de comer te lavas las manos con . . .	. . . jabón.	89.7	. . . esmero.	3.4
	Before eating you wash your hands with	*. . . soap.*		*. . . good care.*	
	Por las mañanas suelo tomar un café con . . .	. . . leche.	79.3	. . . Juan.	3.4
	In the morning I usually have coffee with	*. . . milk.*		*. . . John.*	
	Por la noche, después de la película me voy a . . .	. . . dormir.	69.0	. . . casa.	10.3
	In the evening, after watching the movie I go . . .	*. . . to sleep.*		*. . . home.*	
	Para que los cálculos sean más precisos, necesito recopilar más . . .	. . . información.	58.6	. . . documentación.	6.9
	To make more precise calculations, I need to compile more . . .	*. . . information.*		*. . . documentation.*	

[a]An approximate translation into English is offered in italics.
[b]For each sentence, the CP of the highly expected ending as an R1 response and the global CP of the low-expected ending as a R1-R2-R3 response are shown. The latter is calculated to indicate the likelihood that the low-expected word will enter the reader's mind at any time, either as a preferred response (R1) or as an alternate one (R2 or R3).

electroencephalography (EEG) recording session, we randomly presented each sentence with its high- or a low-expected ending. High-expected endings consisted of the word with the highest CP as R1 in the norming studies. Low-expected endings were always obtained from R2 and R3 responses, and their CP was never more than 10.3% as an R1 (mean CP as an R1 = 1%). We omitted the nonsense ending condition of Moreno and Vázquez (2011). *T*-tests confirmed that CP was higher for the high-expected endings than for the low-expected ones when given as R1 and R2 (Table 3). For responses given as R3, CP was either not significantly different or higher for unexpected than expected endings in the case of emotionally neutral sentences. *T*-tests confirmed matched frequency of use (Sebastián-Gallés *et al.*, 2000) and matched word length between high- and low-CP endings for all sentence types ($P > 0.3$ in all cases). All sentence ending targets were open-class words (46% nouns, 35% verbs, 17% adjectives, 1% adverbs). For 94.3% of sentences, the alternative low-CP ending belonged to the same word class category (e.g. noun, verb, adverb) as the highly expected word target. For example, for the sentence '*At the edge of the cliff someone came from behind and_____ [him] . . .*', the highly expected verb '*pushed*' (79% CP as R1) was replaced by the low-CP verb '*rescued*' (0% as R1; 6% as R2). Across sentences, the R1-R3 CP and global CP of high- and low-expected endings, as well as their length and frequency of use, was not statistically different ($P > 0.08$ in all cases).

For EEG sessions, two experimental lists were constructed such that each ending (high- or low-CP) was assigned to one list. Each subject was randomly assigned to receive one list, such that he/she saw only one version of a sentence. Sentence order within a list was pseudo-randomized, with no more than five sentences of the same bias (neutral, positive or negative) appearing consecutively.

Analysis of valence of alternative responses in the CP norming study

We examined the emotionality of the alternative responses produced by participants in response to the subset of emotionally biased sentences used for the present study. The CPs for endings to these sentences had been determined in the previous study (Moreno and Vázquez, 2011). When responses differed from the high-CP ending, we counted the times that the alternative response was emotionally positive, negative or neutral. Participants were more likely to provide a negative than a neutral or positive response to negatively biased sentences. For example, more participants ended the sentence '*At the edge of the cliff someone came from behind and _____ [him]...*' with '*threw*' than with '*told*' or '*rescued*'. Likewise, participants were more likely to provide a positive than a neutral or negative response to positively biased sentences. This consistency between sentence frame and selected ending emotionality was observed for R1 when the highly expected verb '*pushed*' was not given, as well as for R2 and R3 (Table 4). We take these results to confirm that the emotionally biased sentences in our study biased participants towards a negative or positive outcome, beyond the fact that a particular word ending to the sentence was highly expected.

ERP recording and analysis

Volunteers were tested in a single experimental session. They filled out handedness, vision and health questionnaires and were seated in front of a 17″ computer monitor at a distance of approximately 100 cm. They were pre-exposed to a short set of practice sentences to acclimate them to the reading task. They were informed that, at the end of the session, they would be given a recognition memory test about the sentences they had seen. Sentences were always presented one word at a time in the centre of the screen in black, lower-case, 36-point Arial font on a white background. Each word was presented for 200 ms, except for the final word, which was presented for 500 ms. The inter-stimulus interval was 300 ms. Participants pushed a button to initiate the next sentence. Experimental lists were divided into five blocks of 42 sentences each. Participants proceeded from one block to the next at their own pace.

EEGs were recorded from 31 tin electrodes embedded in an electrocap (Electro-Cap International, Eaton, OH, USA), referenced to the left mastoid. Electrode impedances were kept below 5 kΩ. Signals were amplified with Brain Amps amplifiers (Brain Products, Munich, Germany) at a sampling rate of 250 Hz with a bandpass of 0.01–40 Hz, and re-referenced off-line to the mastoid average. Bipolar horizontal and vertical electrooculograms were recorded to allow artifact rejection and correction.

Data were processed using BrainVision Analyzer software (Brain Products, Munich). After visual inspection of individual data files, the following artifact rejection thresholds were set for a 1500 ms interval: maximal allowed voltage step, 50 μV; minimal and maximal allowed amplitude, ± 100 μV and lowest allowed activity (max-min), 5 μV. EEG raw data from all subjects were scanned and marked using the same artifact rejection criteria. Trials contaminated by eye movements, excessive blink and muscle activity, or amplifier blocking were thus rejected off-line before averaging; approximately 10.5% of trials in each condition were lost. If data for any participant showed an artifact rejection rate higher than 40% per experimental condition, data for that participant were excluded.

The ocular correction method of Gratton *et al.* (1983) was used for remaining participants. A butterworth zero phase filter was applied to the EEG data (low cutoff at 0.1 Hz, time constant = 1.6 s, 24 dB/oct; high cutoff at 20 Hz, 24 dB/oct). The continuous EEG was segmented into 1000 ms epochs starting 100 ms before the onset of the target ending. Artifact-free average waveforms were calculated for each ending (expected, unexpected) in neutral, positively biased and negatively biased sentence frames after subtraction of pre-stimulus baseline.

Table 3 *T*-test comparisons between high- and low-CP endings by type of sentence

	Negatively biased		Positively biased		Emotionally neutral	
	T (69)	*P*	*T* (69)	*P*	*T* (69)	*P*
CP as R1	48.18	0.001	48.06	0.001	46.37	0.001
CP as R2	5.80	0.001	5.57	0.001	6.32	0.001
CP as R3	−1.49	0.14	−0.65	0.52	−2.54	0.01
Global CP	52.56	0.001	49.23	0.001	58.29	0.001
Frequency	−0.87	0.39	−0.88	0.38	−0.44	0.66
Length	−0.94	0.35	0.76	0.45	0.09	0.93

RESULTS

Recognition memory test

The recognition memory test consisted of 42 sentences. Six of these sentences were not included in the experiment (lures), and six came from each of the experimental conditions (i.e. emotionally neutral expected/unexpected; positively biased expected/unexpected and negatively biased expected/unexpected). All sentences were presented accompanied by two endings. Experimental sentences were followed by (i) the actual word that participants saw and (ii) the word from the experimental list to which the participant had not been exposed. Lure sentences were accompanied by two unseen words. Participants were asked to mark which of the two endings they had seen before or indicate that a sentence was completely new. They were generally accurate in detecting the lure sentences and in recognizing previously seen endings for experimental sentences: 85.9% hits (s.d. = 8.3; range = 64.3–97.6), 13.4% errors (s.d. = 7.4; range = 2.4–33.3) and

Table 4 CP norming study: analysis of the valence of alternative responses

Sentence emotionality	HCP R1[a]	Valence of alternative R1[b]			Valence of alternative R2			Valence of alternative R3		
		Positive	Negative	Neutral	Positive	Negative	Neutral	Positive	Negative	Neutral
Negatively biased	23.0	1.6	5.9	0.9	5.6	19.2	2.8	5.5	21.1	3.1
	(4.2)	(2.3)	(4.1)	(2.0)	(4.5)	(6.1)	(4.0)	(4.3)	(5.7)	(4.0)
Positively biased	22.9	6.3	1.7	0.5	19.8	6.6	1.3	20.7	6.7	2.2
	(4.1)	(3.7)	(1.8)	(1.2)	(6.7)	(6.3)	(2.5)	(6.1)	(4.7)	(3.2)

HCP, high cloze probability; R1, R2, R3, most likely response, second most likely response, third most likely response, respectively. Standard deviations are shown in parenthesis.
[a]Mean number of HCP target word responses produced as an R1.
[b]Mean number of positively, negatively or neutrally valenced responses among all alternative R1, R2 and R3 given by participants whenever the target HCP word was not produced.

0.7% omissions (s.d. = 1.3; range = 0–4.7). One-way analysis of variance (ANOVA) on the percentage of hits revealed a main effect of sentence type. Participants were particularly good at detecting newly introduced lure sentences (96.8%), more so than they were at recognizing the endings accompanying any of the already seen experimental sentences [84% on average; $F(3,75) = 11.2$, $P = 0.001$].

An additional three Sentence Type by 2 Endings ANOVA, which excluded performance on the lure sentences, showed that the recognition of endings for each of the three types of experimental sentence (emotionally neutral, positively or negatively biased) was not significantly different ($F(2,50) = 2.30$, $P = 0.11$); the percentage of recognition hits was not significantly different between sentences that had been accompanied by a high- or low-CP ending during the experimental session [$F(1,25) = 0.6$, $P = 0.44$] and the interaction Sentence Type by Ending was not significant ($F(2,50) = 1.07$, $P = 0.34$).

These results suggest that sentences included in the ERP experiment were matched in reading difficulty and/or salience, as there were no subsequent memory effects in recognition test performance.

ERP results

Figure 1 shows the grand average ERPs in response to expected and unexpected outcomes for each type of sentence (emotionally neutral, positively biased, negatively biased). Mean amplitudes were measured in the windows from 250 to 550 ms and from 600 to 900 ms in order to capture N400 and pN400FP effects, respectively. The 70–150 ms and 175–225 ms time windows were selected to explore earlier N1 and P2 modulations.

All repeated-measures ANOVAs included the following within-subject variables: Sentence Emotionality (three levels: negatively biased, positively biased and neutral), Expectancy (two levels: high *vs* low CP), Anteriority (four levels: frontal, fronto-central, centro-parietal and parietal) and Laterality (five levels: left-temporal, left-dorsal, midline, right-dorsal and right-temporal). *F*-tests with more than one degree of freedom in the numerator were adjusted, where appropriate, using the Huynh–Feldt correction.

N1 (70–150 ms)

Main effects were found for Anteriority [$F(3,75) = 6.68$, $P = 0.012$] and Laterality [$F(4,100) = 13.16$, $P < 0.0001$]. N1 amplitude was larger at centro-parietal sites than at frontal and fronto-central sites and larger at fronto-central sites than at frontal ones. It was also larger over lateral locations than over dorsal or midline ones. Significant main effects were not found for the critical variables Sentence Emotionality or Expectancy ($P > 0.58$ in both cases). However, a significant interaction

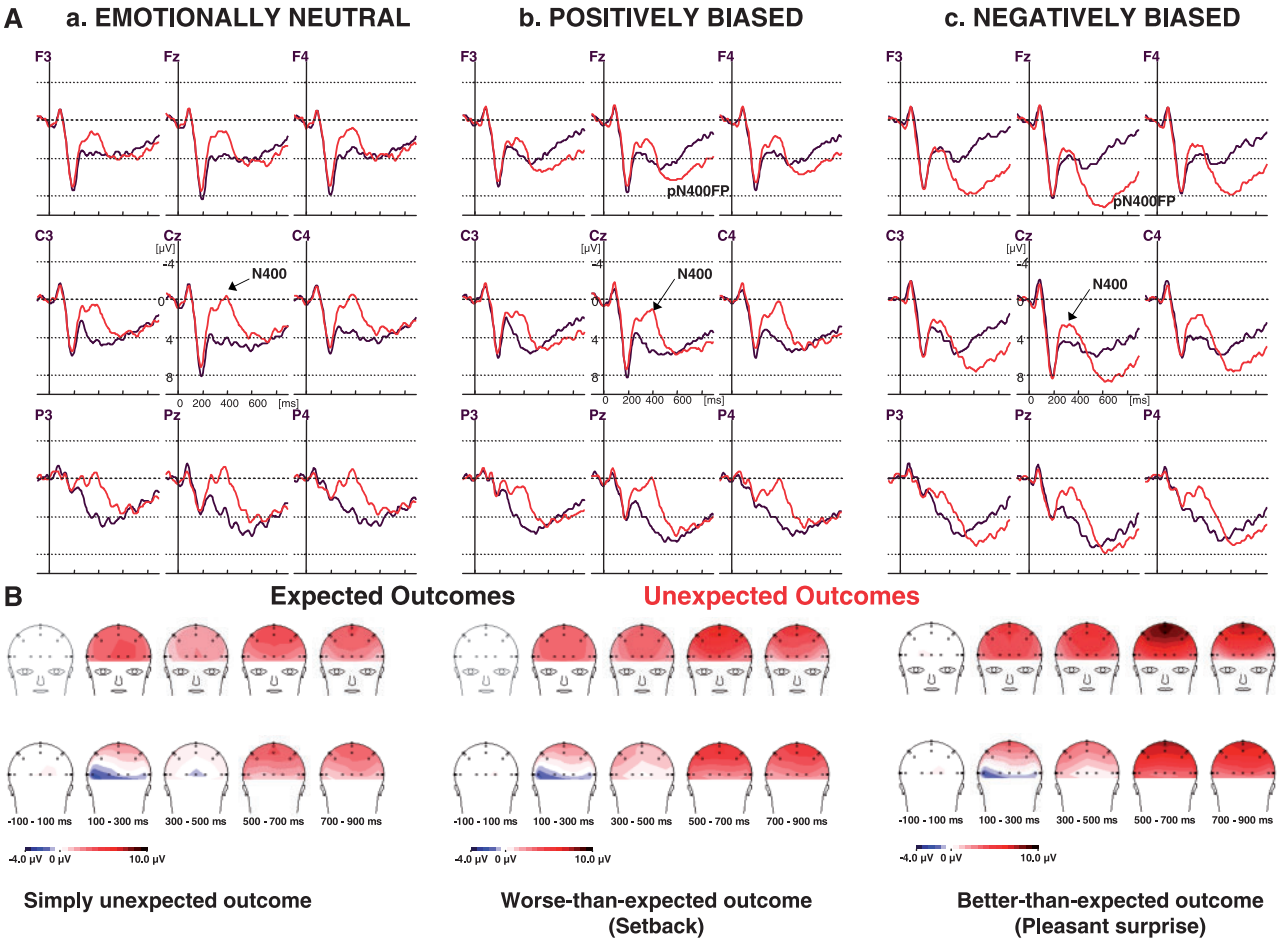

Fig. 1 (**A**) ERP responses to expected (black) and unexpected (red) outcomes within neutral (a), positively biased (b) and negatively biased (c) sentence frames. Responses are plotted for a selection of nine electrodes (three frontal, three central and three parietal). At centro-parietal sites, unexpected outcomes elicited an N400 response under all conditions. In contrast, over frontal sites, N400 was observed for unexpected emotionally neutral outcomes (a), while it appeared smaller for unexpected outcomes in positively biased sentences (b) and it was absent for unexpected outcomes in negatively biased ones (c). A post-N400 frontal positivity (pN400FP) also elicited in response to unexpected outcomes, overlapping with the N400 at frontal scalp sites. Unexpected outcomes in negatively biased sentences (better-than-expected outcomes) elicited a large, diffuse pN400FP (c). (**B**) Topographical maps showing the scalp distribution of voltage amplitude from −100 to 900 ms around word onset, in intervals of 200 ms, in response to each type of unexpected outcome. Left to right: simply unexpected outcome in an emotionally neutral sentence, worse-than-expected outcome in a positively biased sentence and better-than-expected outcome in a negatively biased sentence.

was found for Sentence Emotionality × Expectancy × Laterality [$F(8,200) = 2.58$, $P = 0.032$]. Pairwise *t*-tests revealed that N1 was larger for unexpected outcomes in positively biased sentences (setbacks) than for unexpected outcomes in negatively biased sentences (pleasant surprises) over midline regions ($P = 0.017$) and over right-dorsal regions ($P = 0.026$); ($P > 0.052$ for all other comparisons).

P2 (175–225 ms)

During the P2 time window, main effects were observed for Expectancy [$F(1,25) = 4.55$, $P = 0.043$], Anteriority [$F(3,75) = 205.34$, $P < 0.0001$] and Laterality [$F(4,100) = 163.72$, $P < 0.0001$]. The P2 amplitude was larger for expected endings than for unexpected ones; it gradually decreased in size from frontal to parietal sites, and it was larger at midline sites than at lateral ones. An interaction was observed for Sentence Emotionality × Anteriority [$F(6,150) = 6.82$, $P = 0.002$], such that P2 amplitudes were smaller for positively biased sentences than for negatively biased (over frontal and fronto-central sites) and emotionally neutral ones (over frontal sites) ($P < 0.026$ in all cases). At parietal sites, P2 was larger for negatively and positively biased sentences than for neutral ones ($P = 0.044$ and 0.051, respectively). An interaction was observed for Sentence Emotionality × Laterality [$F(8,200) = 5.06$, $P < 0.0001$], such that P2 amplitudes were larger for negatively biased sentences than for both positively biased and neutral ones at midline and right-dorsal sites ($P < 0.043$ in all cases). Follow up *t*-tests of the interaction Expectancy × Laterality [$F(4,100) = 4.97$, $P < 0.008$] revealed that P2 amplitude was larger for expected sentence endings than for unexpected ones over midline ($P = 0.016$) and right-dorsal ($P = 0.021$) regions.

N400 (250–550 ms)

Consistent with previous findings, word expectancy, as measured by CP in paper-and-pencil tests, strongly affected mean N400 amplitude. Unexpected endings elicited more negative-going N400 potentials than did expected endings [$F(1,25) = 30.97$, $P < 0.0001$] (Figure 1). Overall, endings, whether expected or unexpected, elicited more negative-going voltages in emotionally neutral sentences than in negatively biased ($P < 0.0001$) or positively biased ones (marginal, $P = 0.068$) [$F(2,50) = 10.49$; $P < 0.0001$]. The interaction between Sentence Emotionality and Expectancy was significant [$F(2,50) = 4.48$, $P = 0.016$]. The amplitude difference between expected and unexpected endings was maximal for emotionally neutral sentences (1.8 μV; $F(1,25) = 38.7$, $P < 0.0001$), intermediate for positively biased sentences (1.3 μV; $F(1,25) = 27.9$, $P < 0.0001$) and insignificant for negatively biased sentences (0.4 μV; $F(1,25) = 0.97$, $P = 0.33$).

Expectancy interacted with Anteriority [$F(3,75) = 64.08$, $P < 0.0001$], with maximal amplitude differences between expected and unexpected endings over parietal and centro-parietal sites, typical of an N400 effect. Both Sentence Emotionality and Expectancy interacted with Laterality ($P < 0.0001$), with maximal differences at midline and right dorso-temporal sites. Third- and fourth-order interactions were also significant, suggesting a complex response at different electrode locations.

To further characterize the pattern of the N400 response to expected and unexpected outcomes for each type of sentence, we carried out a separate ANOVA at selected scalp locations where N400 effects typically show their maximal amplitude.[1] Expectancy exerted a strong effect, with unexpected targets eliciting larger N400s than expected ones [$F(1,25) = 71.79$; $P < 0.0001$]. Sentence Emotionality also exerted a main effect [$F(2,50) = 9.38$; $P < 0.0001$]. However, Bonferroni-corrected *post hoc* tests revealed that endings in positively and negatively biased sentences did not differ in N400 amplitude from each other ($P = 0.383$). It was the neutral sentence endings the ones eliciting larger N400 effects than endings in both negatively ($P = 0.001$) and positively biased sentences ($P = 0.036$). The interaction Sentence Emotionality × Expectancy was not significant [$F(2,50) = 1.26$; $P = 0.291$]. The interaction Sentence Emotionality by Expectancy by Electrode was significant [$F(18,450) = 2.56$; $P = 0.019$]. However, due to a possible overlap with subsequent pN400FP effects, analysis of N400 effects at individual electrodes is not reported.

pN400FP (600–900 ms)

ANOVA revealed a main effect for Expectancy [$F(1,25) = 15.79$, $P < 0.001$], with larger pN400FPs for unexpected endings (3.8 μV) than for expected ones (2.5 μV). A main effect was also found for Sentence Emotionality [$F(2,50) = 14.28$, $P < 0.0001$], with larger pN400FPs for endings in negatively biased sentences (3.9 μV) than for endings in positively biased (3 μV; $P = 0.002$) or emotionally neutral ones (2.6 μV; $P = 0.0001$). The pN400FPs for endings in positively biased sentences did not differ significantly from those in neutral sentences ($P = 0.32$). Finally, main effects were observed for both Anteriority [$F(3,75) = 5.61$, $P = 0.021$] and Laterality [$F(4,100) = 62.54$, $P < 0.0001$].

In order to explore the scalp distribution of the pN400FP effect, tests of the interaction Anteriority × Expectancy [$F(3,75) = 19.5$, $P < 0.0001$] revealed that the difference between expected and unexpected endings was maximal in frontal regions (1.8 μV; $P < 0.0001$), intermediate in fronto-central regions (1.6 μV; $P < 0.0001$) and smallest in centro-parietal ones (0.9 μV; $P = 0.011$). It only approached significance in parietal regions (0.6 μV; $P = 0.083$). Pairwise comparisons of the interaction Expectancy × Sentence Emotionality [$F(2,50) = 10.55$; $P < 0.0001$] revealed that across the entire set of electrodes, pN400FP amplitude was significantly larger for unexpected endings than for expected ones in negatively biased sentences ($P < 0.0001$) and positively biased ones ($P = 0.049$), but not in emotionally neutral ones ($P = 0.480$). All interactions of Expectancy and Sentence Emotionality with Anteriority and Laterality factors were significant ($P < 0.004$ in all cases), indicating that modulations depended on the scalp region. Following the Moreno and Vázquez (2011) approach, further tests were carried out at a frontal ROI[2] where pN400FP amplitude was maximal. They confirmed that the larger frontal positivity for unexpected relative to expected endings was significant only for negatively biased ($P < 0.0001$) and positively biased sentences ($P = 0.009$) and not for emotionally neutral ones ($P = 0.244$). Furthermore, the positivity elicited in response to unexpected endings was 2.4 μV larger for negatively biased sentences (pleasant surprises) than for positively biased ones (setbacks) [$F(2,50) = 26.65$, $P < 0.0001$].

Separate ANOVAs for expected and unexpected endings in isolation showed that pN400FP amplitude was similar across sentence emotionality for expected endings [$F(2,50) = 0.09$, $P = 0.915$], while it showed significant differences for unexpected ones [$F(2,50) = 21.44$, $P < 0.0001$]. Similar results were obtained at the narrower frontal ROI for expected endings [$F(2,50) = 0.83$, $P = 0.44$] and for unexpected ones [$F(2,50) = 26.65$, $P = 0.0001$] (Figure 2).

DISCUSSION

This study aimed to explore the processing of emotionally *biased* expected and unexpected word outcomes and compare it with the processing of emotionally *neutral* ones in a language comprehension task. The study focused on the N400 component of the ERP, which indexes semantic processing difficulty, and on the pN400FP effect,

[1]Electrodes included: TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4 and P8.

[2]The frontal ROI included electrodes F3, Fz, F4, FC3, FCz and FC4.

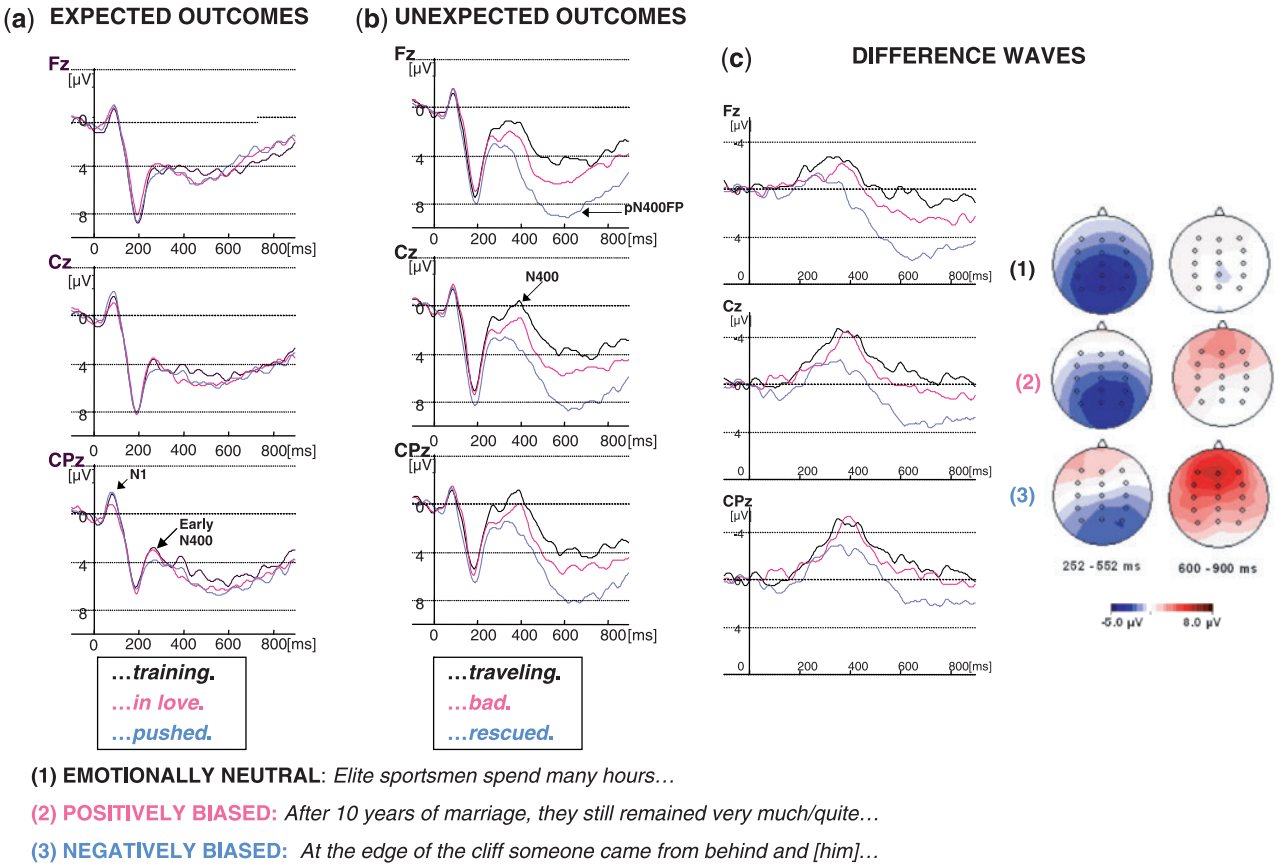

Fig. 2 ERP responses to expected (**a**) and unexpected (**b**) outcomes are plotted for three midline electrodes (front to back: Fz, Cz, CPz). Difference brainwaves (unexpected — expected ERP responses) are shown in column (**c**). ERP responses to expected outcomes barely differed across sentence type, with the exception of some early deviations over Cz and CPz at the N1 peak and early in the N400 time window (**a**). ERP responses to unexpected outcomes showed a biphasic pattern featuring an N400 response that seemed to overlap with large and long-lasting pN400FP (**b**). Difference waves in column (**c**) indicate a smaller difference in N400 between highly expected and unexpected word outcomes for negatively biased sentences than for other types of sentence. However, negatively biased sentences also show the largest pN400FP effect. Topographic maps on the right show the scalp distribution of N400 (252–552 ms) and P600 (600–900 ms) effects for each type of sentence.

which has been linked to the need to inhibit or revise a previously held prediction (Federmeier, 2007).

In a previous study (Moreno and Vázquez, 2011), unexpected outcomes in emotionally biased sentences elicited N400 and pN400FP effects, both when the sentences biased the reader to expect a positive outcome and when they biased him/her to expect a negative one. Both N400 and pN400FP in that study were unaffected by the direction of the emotional switch, i.e. whether the unexpected word outcome was better than expected (pleasant surprise) or worse than expected (setback). N400 was instead modulated in response to the fulfilment of a strong expectation: N400 was smaller in response to highly expected *negative* word outcomes than to highly expected *positive* ones. The effect was limited to a midline posterior scalp region. This result suggested that participants might be adjusting the strength of their positive or negative predictions to different extents.

This study explored how expectation might modulate N400 and pN400FP effects when emotionally *unbiased* sentences were also present. In that scenario, unexpected outcomes also elicited both a larger N400 and a larger pN400FP than expected ones. However, ERP responses differed depending on whether emotional content was attached to the sentence. Unexpected, emotionally *neutral* outcomes gave rise to a large and widely distributed N400 that was significant even at frontal electrode sites, failing to elicit pN400FP effects. Pleasant surprises and setbacks elicited N400 effects localized to posterior scalp locations and pN400FP effects. The latter effect was, in addition, significantly larger for pleasant surprises than for setbacks. Thus, we found a differential processing of emotionally loaded and unloaded expectations at the level of N400 and pN400FP effects. The N400 results are difficult to interpret due to the temporal overlap between N400 and pN400FP signals for unexpected endings, which show opposite polarity.

Thus, the results of this study differ from those of the related previous work (Moreno and Vázquez, 2011), where N400 and pN400FP modulations were unaffected by the direction of the emotional switch. We believe that this discrepancy can be attributed to differences in the experimental context. This study includes emotionally *neutral* sentences and it does not include implausible (nonsense) endings. Thus, all unexpected endings in this study had low CP while remaining plausible, whereas 33% of sentences in the previous study ended with a totally implausible ending. Moreover, the probability of encountering a highly expected ending differed between the two studies. In the previous study, the probability of encountering a highly expected word was only 33%, since an equal proportion of sentences featured the highly expected word, an unexpected word or a nonsense word. In contrast, the probability of encountering a highly expected ending in this study was 50%, since half of the sentences ended with an unexpected, low-CP word and the other half ended with the most highly expected word. This may have led readers to adopt a more predictive strategy during the reading comprehension task in the present study (see Roehm *et al.*, 2007, for P300 ERP effects being influenced by individual processing strategies beyond stimulus constraints and experimental task). According to current views on the functional

interpretation of pN400FP effects (Kutas *et al.*, 2011), our finding that pN400FP was larger in response to unexpected pleasant surprises than in response to unexpected setbacks may mean that, when the level of prediction is high, more cognitive resources are needed to override a 'secretly' held negative prediction than to override a positive one.

Whatever the correct interpretation of pN400FP may be, our results may serve as evidence against the hypothesis that it indexes the realization of an incorrect prediction merely at the lexical level (Van Petten and Luka, 2012). Even though our unexpected *neutral* endings were as lexically unexpected as the unexpected pleasant surprises and setbacks (offline-measured CP values of 1% as an R1 and 4% as an R2 or R3), they did not elicit significant pN400FP effects. Thus, whatever the nature of the reviewing, updating or inhibitory process that pN400FP is indexing, it is modulated not only by whether the real ending lexically matches the reader's prediction but also by whether the reader's prediction is emotionally neutral, positive or negative. This conclusion is consistent with other studies suggesting that the pN400FP effect is not a simple index of unexpectedness or mismatch (Federmeier *et al.*, 2010).

A recent study has suggested an inverse correlation between the so-called 'naturality' of adjective-noun pairs and the amplitude of a frontally distributed late positivity, similar to the pN400FP analysed here (Molinaro *et al.*, 2012). According to the monitoring theory of language perception (van de Meerendonk *et al.*, 2010), the conflict between an expected and unexpected linguistic event must be sufficiently strong to trigger a reanalysis that manifests as post-N400 positivity distributed parietally instead of frontally (P600 effect). We suggest that post-N400 late positivities, whether parietally or frontally distributed, are sensitive to degrees of conflict, 'naturality' and/or emotional connotations of unexpected albeit plausible lexical events. Future studies should determine what factors determine whether the post-N400 positivity manifests primarily in frontal or parietal regions.

In addition to N400 and pN400FP, this study examined the early ERP components N1 and P2, also shown to be affected during the processing of linguistic emotional content. Consistent with previous work (Scott *et al.*, 2009; Leon *et al.*, 2010), our results show that N1 and P2 are sensitive to the manipulation of emotional variables. N1 potentials have been linked to capture of attention in non-linguistic tasks (Gable and Harmon-Jones, 2012). In our study, the finding that N1 amplitude increased for unexpected setbacks relative to unexpected pleasant surprises may be interpreted as a capture of attention. Similarly, Leon *et al.* (2010) reported larger N1 for words emotionally inconsistent to prior discourse than for emotionally consistent ones. N1 effects, however, should be interpreted with caution, since early ERP modulations occurring before lexical access is complete are controversial.

The role of P2 effects in language studies is not yet fully understood. Our results are consistent with the notion that P2 effects reflect the matching of a visual input with expectation (Wlotko and Federmeier, 2007). However, the P2 studies suggesting such a link used a split visual field presentation paradigm (Federmeier, 2007). For right visual field presentations (i.e. left hemisphere initial advantage), P2 amplitudes were larger for expected word outcomes than for unexpected ones (Wlotko and Federmeier, 2007). We obtained similar results over midline and right hemisphere scalp regions while using a central visual field presentation. Nonetheless, the significance of our finding is difficult to determine, since it may have been driven by the direction of the subsequent opposite polarity N400 effect, which was smaller for highly expected word outcomes than for low-expected ones.

In conclusion, our experimental design presumably encouraged the reader to make a prediction about the most likely upcoming word ending (a 73% word CP; 50% chance of an accurate prediction); predictions, if made, turned out to be fulfilled or needed to be reconsidered in order to face an unexpected outcome. In light of current views on the interpretation of N400 effects, when those predictions were fulfilled, either it was relatively easier to integrate highly expected negative than neutral outcomes into the sentence context (integration view) or participants were more accurate, faster or more willing to make pessimistic than emotionally neutral predictions (prediction view). With regard to the N400 responses to unexpected rather than highly expected outcomes, our results may be contaminated by subsequent pN400FP effects that were elicited only in response to emotional and not for neutral unexpected endings, being also larger for pleasant surprises than for setbacks. Based on one of the currently held views on pN400FP effects (Federmeier, 2007), if we defined the effect as directly proportional to the effort required to override a prediction, our results suggest that it takes more effort to override a negative or pessimistic prediction than to override an emotionally neutral or optimistic one. In any event, our present results and those of our previous study (Moreno and Vázquez, 2011) suggest that, as long as emotion is involved, brainwave responses are sensitive to the overall probability that a potential prediction is right. It appears to take more effort to override an emotionally loaded prediction when that prediction is very likely to be correct.

The inferences that we draw from our results may be constrained by the fact that we used a sentence-ending target word experimental design. We opted for a sentence-ending position in order to create a very strong contextual constraint. We reasoned that words at the final position in the sentence would reveal more precisely their degree of expectancy, i.e. whether they were strongly or weakly expected. Future studies should seek to examine expectancy effects for embedded emotional target words.

Future studies should also help clarify under what circumstances people are more or less capable of integrating emotional outcomes into prior context, or are more or less willing to predict future emotional outcomes. These studies should seek to identify the brain signatures associated with the processing of happy and unhappy turns of events in language comprehension tasks. Perhaps this work will ultimately enable us to connect the mechanisms of emotional language comprehension with the study of more general human emotion regulatory processes.

Conflict of Interest

None declared.

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