Will the glass be half full or half empty? Brain potentials and emotional expectations

Eva M. Moreno [a,*], Carmelo Vázquez [b]

[a] Human Brain Mapping Unit, Instituto Pluridisciplinar, Universidad Complutense de Madrid, Paseo Juan XXIII, 1, 28040 Madrid, Spain
[b] School of Psychology, Universidad Complutense de Madrid, Campus de Somosaguas, 28223 Madrid, Spain

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ABSTRACT

Brainwave responses to words in context depend on semantic and world-knowledge expectations. Using the N400 component of event-related potentials as an index of word expectation, we explored brain responses to negatively and positively biased sentence frames randomly presented with their emotionally matched highly expected outcome or with violations that included switches to unexpected emotionally opposite outcomes or nonsense. Nonsense elicited large N400 responses regardless of the bias of the preceding sentence frame. Unexpected emotionally opposite outcomes elicited smaller than nonsense N400 responses and subsequent post-N400 frontal positivities, both unaffected by sentence frame bias. Over a midline-posterior scalp region, expected positive outcomes elicited larger N400 responses than negative ones, despite a high and matched word probability. Our study reveals that brains respond to unexpected emotional outcomes regardless of the direction of the emotional switch and hints at the possibility that the strength of positive and negative expectations may be adjusted before experiencing unexpected events.

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Our species is endowed with both a tendency to expect positive outcomes for unknown future events, and a heightened sensitivity to negative outcomes (Cacioppo and Gardner, 1999; Vaish et al., 2008). People tend to have a stable, overall pessimistic or optimistic outlook in life (Scheier and Carver, 1985, 1987; Scheier et al., 1994). This appears to be crucial in determining affective responses, as *expectations* about what "might have been" play an important role in how people feel about what actually occurred. In fact, good and bad outcomes feel better or worse, respectively, when they are *unexpected* than when expected (Shepperd and McNulty, 2002). Interestingly, our tendency to make optimistic predictions about improbable bad outcomes (e.g. failing an exam) shift over time when feedback is anticipated in the near future, and when the outcome is uncontrollable (Carroll et al., 2006; Sweeny et al., 2006; Sweeny and Shepperd, 2007). Trying to avoid the disappointment of an unexpected bad outcome by anticipating troubles (Golub et al., 2009) or by using defensive pessimism strategies (Norem and Chang, 2002) may be adaptive. Nevertheless, the fact that most people exhibit positive illusions, including an unrealistic optimism about the future (Taylor and Brown, 1988), raises an intriguing question: can individuals avoid harboring good expectations even on the millisecond timescale of brainwave responses?

This question can be approached by analyzing the event-related potential (ERP), which allows examination of brain responses to expected and unexpected linguistic events with millisecond resolution. This technique has the additional advantage of not requiring overt responses or tasks beyond silently reading for comprehension. According to ERP studies, expectations in fact play an important role in language comprehension tasks. Thus, unexpected linguistic events such as a word that does not semantically fit in its sentence frame (e.g. the word city in the sentence *He shaved off his mustache and city*) elicit greater negativity at around 400 ms post-word onset than does a predictable, appropriate word such as beard (Kutas and Hillyard, 1980a, 1980b). The amplitude of the N400 component of the ERP is sensitive to the nature of the semantic relationship between any actual word and the word(s) that can be *expected* to complete the given sentence frame (Federmeier and Kutas, 1999). The *expected* completion of a sentence frame contains those words with the highest Cloze Probability (CP) in that context. The CP of a word in a given context refers to the percentage of individuals that choose it to complete the given sentence frame in a paper-and-pencil sentence completion task (Taylor, 1953). Brainwave analyses then reveal that N400 is smallest following words with high CP; intermediate or large following words that are, respectively, related or unrelated to the highest-CP completion; and largest following nonsense words (Kutas, 1987; Kutas and

* Corresponding author. Tel.: +34 91 394 32 61; fax: +34 91 394 32 64.
E-mail addresses: emmoreno@pluri.ucm.es (E.M. Moreno), cvazquez@psi.ucm.es (C. Vázquez).

Hillyard, 1984; Kutas et al., 1984). The fact that N400 depends on a word's semantic relationship to the expected completion indicates that individuals use knowledge stored in long-term memory to make online predictions about upcoming words (Federmeier and Kutas, 1999; Kutas and Federmeier, 2000). Other studies provide further evidence of an upcoming word prediction model (DeLong et al., 2005; Kutas et al., 2011; Van Berkum et al., 2005; Wicha et al., 2004). The N400 is also sensitive to violations of true facts from our world knowledge (Hagoort et al., 2004; Hald et al., 2007). For example, in the sentence 'The Dutch trains are white and very crowded' the word 'white' elicits an N400 response as it violates a known fact for Dutch speakers (i.e. Dutch trains are yellow). Interestingly, the N400 amplitude in response to a false statement is as large as the one in response to a nonsense word (e.g. 'sour' in the previous example).

Although psycholinguistic research has mainly explored affectively neutral knowledge (Van Berkum et al., 2009), a large part of our world knowledge consists of experiences about what outcomes go with what types of emotional events. Indeed, messages devoid of emotional meaning may be the exception rather than the rule in everyday linguistic experience. One would be surprised to hear that after being left by her boyfriend, a woman reacted by flirting rather than by 'crying' or 'getting depressed'. There is, in some sense, a world knowledge that has to do with emotional rather than emotionally detached facts about the world. This knowledge reflects how likely we think it is that sad or happy events lead to sad or happy consequences. In fact, this orderly view of the emotional world is broken only under exceptional circumstances, such as severe traumatic experiences (Janoff-Bulman, 1989).

Making strong predictions about upcoming words in a sentence, however, may also carry a processing cost in situations in which those predictions prove false. An increased post-N400 frontal positivity (pN400FP) is observed between 500 and 900 ms over frontal electrode sites during the processing of unexpected word endings in highly constraining contexts (Federmeier et al., 2007). A similar but longer lasting pN400FP (500–1200 ms) has also recently been reported in response to strongly expected sentence continuations that go unfulfilled (DeLong et al., 2011). Therefore, while a small N400 response indicates the benefit of a fulfilled word expectation, the pN400FP effect has been proposed to reflect the consequences of processing a word that violates a prediction (Federmeier et al., 2007). In contrast to the long history of studies on N400 effects (Kutas and Federmeier, 2011) the pN400FP effect has only recently been regarded as a potential functionally independent ERP response linked to disconfirmation of strongly made predictions (DeLong et al., 2011).

The outcome of an incoming emotional message may not be under control in a passive reading task. Nevertheless, the brain may implement mechanisms to cope with negative and positive outcomes from incoming messages. People might anticipate happy and sad endings based on their emotional world knowledge, though these may also involve certain adaptive strategies. Adopting an optimistic or pessimistic strategy will alter expectations and therefore the ease or difficulty of semantic processing in a language comprehension task. We should be able to detect these alterations as changes in brainwave signatures (i.e. N400 and pN400FP) in response to expected and unexpected good and bad outcomes. Thus, tracing brainwaves in language comprehension tasks can provide information on how we prepare ourselves to process emotionally loaded information.

Studies of the processing of single emotional words have reported an early ERP (200–300 ms) arousal effect (pleasant and unpleasant versus neutral words) over left occipito-temporal electrodes (Kissler et al., 2007). The word's valence discrimination is reported to occur later, with pleasant word stimuli eliciting both a smaller N400 and a larger late positivity response than unpleasant

word stimuli (Herbert et al., 2008). However, a recent picture-word priming study found N400 to be insensitive to emotion (Kissler and Koessler, 2011). ERP studies investigating the time course of processing single affective stimuli have given mixed results that depend on the type of stimuli (pictures, faces, words) and the type of task, e.g. reading for comprehension, memorization, lexical decision-making, and evaluation of emotional content (Fischler and Bradley, 2006; Kissler et al., 2006).

Only a few studies have examined ERP responses to emotional words in whole-sentence contexts. The early posterior negativity found in single word studies was not found, whereas a posterior late positivity discriminated between negative and neutral words (Bayer et al., 2010). Other studies examining N400 effects found that the amplitude of the N400 did not differ between negative and positive words (Holt et al., 2008), or that it was larger for negative words than for positive and neutral words (De Pascalis et al., 2009). In the latter study, the CP of target words, a strong determinant of N400 amplitude in sentence paradigms, was not reported. In the study by Holt et al. (2008), emotional and neutral words were all low-CP (2% on average) embedded in emotionally neutral contexts.

In tasks using emotional prosody (happy or sad intonation) to provide a context for subsequent processing of negative and positive words (e.g. 'success' or 'failure'), a larger N400 amplitude was found in response to words whose valence mismatched the prosody of the preceding sentence (Schirmer et al., 2002). A recent study also revealed that emotional prosodic expectancy violations elicit a right-lateralized, positive-going ERP effect, while combined semantic/prosodic expectancy violations elicit an early negativity ERP effect (Paulmann and Kotz, 2008).

Finally, some ERP studies have shown that an individual's current mood is crucial during information processing. Experimental mood inductions can make "happy" people more likely to accept some unexpected sentence endings (Federmeier et al., 2001) or make people in pessimistic moods more biased towards expectations of negative outcomes (Chung et al., 1996). Our study does not externally induce a mood; rather, it explores brainwave responses to the processing of fulfilled and unfulfilled positive and negative expectations during a sentence comprehension task. We aim to relate our findings to potential strategies that we may use to prepare ourselves for pleasant 'surprises' and 'setbacks'. Thus, our experimental design included negatively and positively biased sentence frames with a highly expected congruent ending, a nonsense ending, or an ending that is less expected and emotionally opposite to the expected one. In ERP studies, syntactically anomalous words presented at sentence-ending positions have been reported to elicit an increased negativity over anterior electrode sites between 300 and 500 ms relative to when the same anomalies appear in sentence-embedded positions (Osterhout, 1997). This effect has been considered to be driven by wrap-up processes that are potentially triggered at the end of sentences. However, words in context also tend to elicit smaller N400 responses as their predictability increases over the course of a sentence (Kutas and Federmeier, 2000). For the purposes of our study it is critical to induce a strong negative or positive expectation from the incoming message in order to be able to explore the response to its fulfilment or its violation. Thus, target words in our study appear at a point in the sentence in which ample semantic constraint has been built-up (i.e. sentence-final position), such that expectations are most likely entrenched.

We anticipate that N400 responses will be graded by expectancy, that is, by the CP of the target word ending; N400 amplitudes will be largest in response to nonsense endings, smaller in response to low-probability emotionally opposite endings, and smallest in response to highly probable emotionally congruent endings. Thus, fulfilled expectations will generate reduced