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BRIEF REPORT

Overlapping dual ERP responses to low cloze probability sentence continuations

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Abstract

In 2005, DeLong, Urbach, and Kutas took advantage of the *a*/*an* English indefinite article phonological alternation and the sensitivities of the N400 ERP component to show that readers can neurally preactivate individual words of a sentence (including nouns and their prenominal indefinite articles) in a graded fashion with a likelihood estimated from the words' offline probabilities as sentence continuations. Here we report an additional finding from that study: a prolonged ERP frontal positivity to less probable noun continuations. We suggest that this positivity is consistent with hypotheses that additional neural processing may be invoked when highly expected continuations are not encountered in the input and speculate briefly on possible functional correlates.

Descriptors: Event-related potentials, Frontal positivity, Language, Sentence processing

Sentence comprehension studies in the past decade have revealed multiple consequences of prediction during language processing, manifest at a number of different linguistic levels and time points (e.g., Federmeier & Kutas, 1999; Kamide, Altmann, & Haywood, 2003; van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005; Wicha, Moreno, & Kutas, 2004). Within event-related brain potential (ERP) research, a primary tool for tracking linguistic anticipation has been the N400—electrical brain activity whose amplitude is reduced to the extent an eliciting item is semantically predictable within accruing context. Along with N400 ERP effects, there have been some reports of later positivities (i.e., LPs, or in some cases referred to as P600s) to semantically improbable or incongruent sentence continuations. For instance, LPs have been detected by Federmeier, Wlotko, De Ochoa-Dewald, and Kutas (2007) to strong sentential constraint violations; by Coulson and Van Petten (2002) to metaphoric sentence endings; by Swick, Kutas, and Knight (1998) to incongruent sentence completions; by Moreno, Federmeier, and Kutas (2002) to English-Spanish code switches and low cloze sentence continuations; by van de Meerendonk, Kolk, Vissers, and Chwilla (2010) to strong but not mild sentential conflicts; and see Kuperberg (2007) for a review of so-called "semantic P600s." Although a common functional link between these positivities has yet to be established, an intriguing possibility is that they reflect some consequence of preactivating information disconfirmed by the actual input stream. Such findings would be important, in part, because the apparent absence of experimental evidence for a consequence to "mispredicting" has constituted a cornerstone of arguments against prediction being a viable language comprehension strategy (e.g., Morris, 2006). However, if neural preactivation is a default processing mechanism, then there must be times when the parser assumes the wrong semantic, syntactic, or phonological trajectory.

The N400 component, however, does not provide such evidence. It correlates linearly with an item's cloze probability but traditionally has proven *insensitive* to degree of constraint violation (Kutas & Hillyard, 1984); responses to low cloze continuations exhibit the same amplitude N400s following both highly and not-at-all constraining contexts. For example, N400 amplitude to *thought* in "*He mailed the letter without a thought*" is not statistically different from that to *wind* in "*He was soothed by the gentle wind*," even though these sentences differ markedly in degree of contextual constraint. In short, the N400 seems to reflect degree of contextual facilitation, but not any consequence of disconfirming context-generated expectancies. Support for a later (post-N400) ERP positivity that might reflect some consequence of expectancy disconfirmation, however, was reported by Federmeier et al. (2007), who observed more positive-going

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ERPs between 500–900 ms post-noun onset to improbable words continuing strongly but not weakly constraining contexts.

Data from DeLong, Urbach, and Kutas (2005) also speak directly to this issue. In that study, participants read sentences of varying constraint that induced expectations for particular consonant or vowel-initial nouns, which ranged from highly probable to unlikely, based on offline cloze probability norming: e.g., "*Dale was very sorry and knew he owed Mary an apology/a check . . .*" (where "*an apology*" is the most likely continuation, and "*a check*" is unlikely). The experimental design supported the conclusion that readers were anticipating specific target nouns online, as inferred from smaller N400s to pretarget noun articles consistent with contextually expected nouns (e.g., *an apology*) compared to inconsistent ones (e.g., *a check*). In addition to cloze probability-graded target article and noun N400 effects, visual inspection indicated that within the noun N400 time window (300–500 ms) the typical N400 pattern (larger ERP negativity for low relative to high cloze nouns) "flipped" over left, lateral, frontal scalp locations. Moreover, this reversal of the cloze probability N400 effect appeared to extend through 500–1200 ms, well beyond the N400 time window. In this report, we test the statistical reliability, topographical distribution, and the sensitivity of this ERP effect to cloze probability (and, indirectly, contextual constraint) manipulations.

Methods

Eighty sentences were continued by relatively expected or unexpected indefinite article/noun pairs (160 total stimuli). Noun targets were normed for cloze probability with sentences truncated following the target indefinite articles (as detailed in DeLong et al., 2005). Targets were sentence medial and congruent, serving as both expected and unexpected continuations in different contexts. Each participant viewed one of two lists (80 sentences each), and contexts and target pairs were used only once per list. Each list contained equal numbers of relatively expected/unexpected, as well as *a*/*an*, targets. Comprehension questions followed one quarter of sentences, with an average correct response rate of 94.6% (range 88%–100%).

Thirty-two University of California, San Diego volunteers (23 women, 9 men) participated for course credit or cash. Participants were right-handed, native English speakers with normal or corrected-to-normal vision, ranging from 18–37 years old (mean, 21 years). Seven participants reported a left-handed parent or sibling.

Testing consisted of a single experimental session, with words presented centrally using rapid serial visual presentation (duration of 200 ms, interstimulus interval of 300 ms). Participants read for comprehension, using hand-held buttons to answer questions.

The electroencephalogram (EEG) was recorded from 26 electrodes arranged geodesically in an electro-cap, each referenced online to the left mastoid. Artifact-contaminated target trials were rejected offline before averaging—on average, 14.1% of noun data. Data were rereferenced offline to the algebraic mean of the left and right mastoids and averaged for each experimental condition, time-locked to the onset of the target noun.

Analyses of variance (ANOVAs) were conducted with two levels of stimulus type (high $\geq$ 50%, low $<$ 50% cloze nouns) and 26 levels of electrode site. Significant interactions were followed up by distributional ANOVAs using 16 representative electrode sites (see Figure 1). All reported ANOVA p-values are after epsilon correction (Huynh-Feldt) for repeated measures with more than one degree of freedom.

We also conducted a new analysis—an alternative to the Pearson product-moment correlations calculated in DeLong et al. (2005)—to investigate the relationship between noun cloze and ERP mean amplitude. Here, we performed repeated measures ordinary least squares regression analyses (Lorch & Myers, 1990) on the 26 scalp channels in both the N400 and LP time windows. The response variable was mean EEG amplitude and the predictor variable (in addition to an intercept term) was target noun cloze probability (ranging from 0%–100%). In each time window, a "t_{max}" permutation procedure (Blair & Karniski, 1993) was used to correct for the 26 multiple comparisons using a family-wise alpha level of 0.05. Five thousand permutations of the data were used to estimate the t_{max} distribution of all possible permutations, which is five times more permutations than the minimum recommend by Manly (1997) for this alpha level. On average, each participant provided 68.2 trials ($SD = 10.2$) for analysis.

Results

We examine effects of cloze probability within the noun N400 (300–500 ms) and a later time window (500–1200 ms). See Figure 1 for ERPs plotted over 26 channels.

ANOVAs with 2 Levels Noun Cloze Probability (High vs. Low) × 26 Electrode Sites

300–500 ms. There was a main effect of Cloze [$F(1,31) = 21.15$, $p < .001$], with mean amplitude of low cloze nouns (0.03 μV) relatively more negative than that of high cloze nouns (1.53 μV). An interaction of Cloze × Electrode [$F(25,775) = 29.16$, $p < .0001$, $\varepsilon = .17$] was followed up with a distributional ANOVA that revealed a 4-way interaction between Cloze (high, low), Hemisphere (left, right), Laterality (lateral, medial) and Anteriority (prefrontal, fronto-central, temporo-parietal, occipital), [$F(3,93) = 4.87$, $p = .010$, $\varepsilon = .72$)], indicating a canonically distributed N400 effect (largest over medial and posterior sites, with a right-lateralized skew). However, at left lateral prefrontal sites the N400 effect reversed, with ERPs to low cloze nouns (1.31 μV) being relatively more *positive* than those to high cloze items (0.53 μV).[1]

500–1200 ms. Responses to low cloze nouns (1.78 μV) were found to be overall significantly more *positive* than to high cloze nouns (1.03 μV), [$F(1,31) = 6.00$, $p = .020$], with Cloze and Electrode site interacting [$F(25,775) = 6.28$, $p < .001$, $\varepsilon = .16$]. Distributional analyses revealed a Cloze × Anteriority × Laterality interaction [$F(3,93) = 17.93$, $p < .0001$, $\varepsilon = .73$]. Medially, low cloze nouns were more positive than high cloze nouns, with progressively larger differences towards the front of the head (0.03, 0.29, 1.07, and 1.78 μV effect sizes at occipital, central, frontal, and prefrontal sites, respectively). Laterally, this effect was smaller (maximal 1.01 μV effect at central sites) and less variable along the anteriority axis.

[1]More temporally fine-grained ANOVAs subdividing the N400 time window into earlier (300–400 ms) and later (400–500 ms) portions revealed that the "reversal" effect was primarily due to increased left anterior positivity for low relative to high cloze nouns in the later portion of the N400.

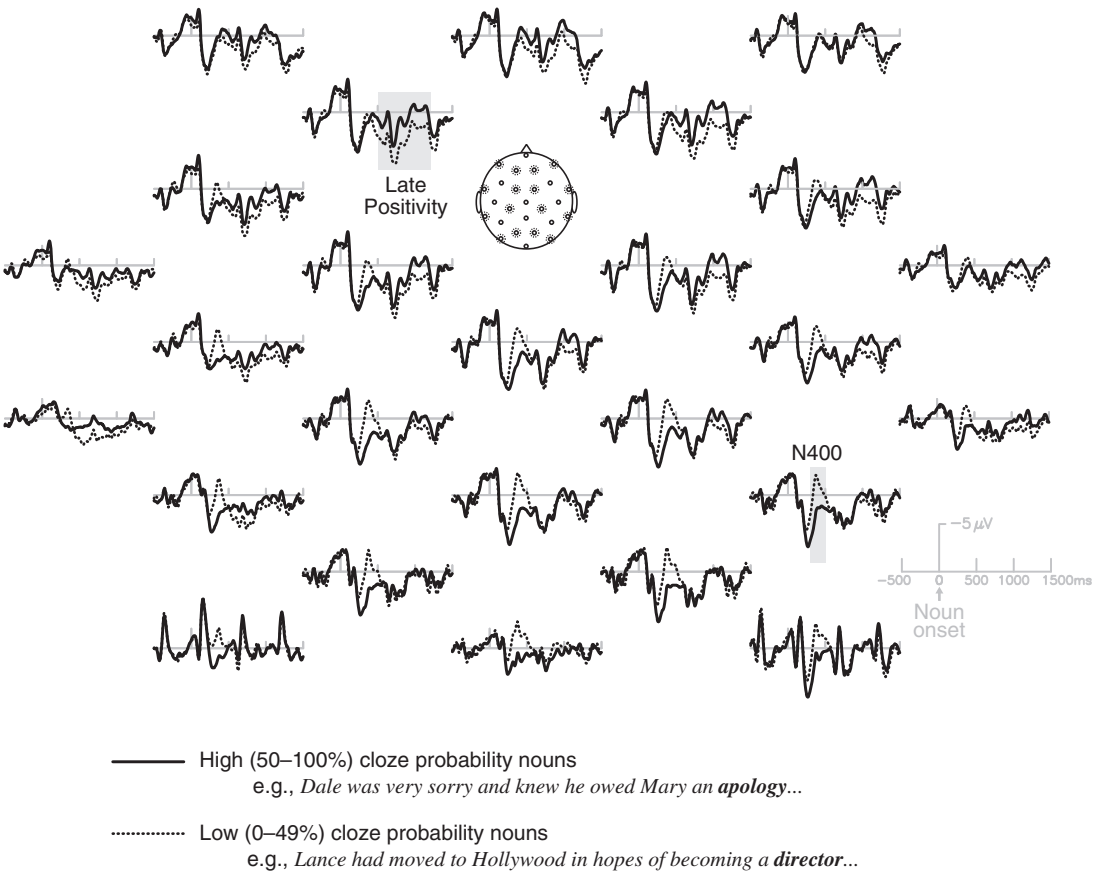

Figure 1. Grand average target nouns sorted on noun cloze probability over all 26 channels. N400 and LP time windows are highlighted over scalp locations where effects are prominent. The 16 electrodes used in distributional analyses are highlighted on the scalp map.

Repeated Measures Regression Analysis of Noun Mean Amplitude with Noun Cloze Probability

300–500 ms. There were significant positive correlations of cloze probability with mean EEG amplitude (more negative ERPs, i.e., larger N400s, with decreasing cloze) at 13 posterior and central electrodes (Figure 2), consistent with the scalp topography of the categorical N400/cloze effects. The analysis also revealed a correlation in the opposite direction at the midline prefrontal electrode. In other words, with decreasing noun cloze, ERP mean amplitude was significantly more *positive* over the most anterior scalp site for this same time window.

500–1200 ms. Like the prefrontal correlation in the N400 time window, between 500–1200 ms there were significant negative correlations of cloze probability with EEG amplitude (increasing mean amplitude ERP positivity with decreasing cloze) at three prefrontal and one left lateral electrode (Figure 2). This ERP pattern suggests that the positivity reflects a similar (albeit opposite polarity) sensitivity to cloze as the N400, except over a different time course and with a different scalp distribution.

Discussion

In DeLong et al. (2005)—a study designed to test for lexical prediction by examining N400s to more and less expected prenominal articles (*a*/*an*)—*post-hoc* examination indicated a late, positive-going ERP effect to subsequent target nouns, which, until now, we had neither analyzed nor reported upon. In the current study, we set out to quantify the sensitivity of this observed positivity to modulations of noun cloze probability. Both categorical ANOVA and regression analyses indicated that, in addition to anticipated linear decreases in noun N400 amplitude with increasing cloze probability posteriorally, there was a reliable prolonged positivity (beginning in the N400 time window and extending through 1200 ms) to unexpected relative to expected nouns, primarily over anterior scalp sites. The mean amplitude of this positivity showed a pattern of negative correlation—i.e., increasing positivity with decreasing cloze—with a spreading distribution across the scalp over time. Like the N400, then, the LP appears to be similarly sensitive to variability in the cloze probability of sententially more or less expected nouns (as determined by offline norms). Questions remain, however, regarding the extent to which the two components reflect the same functional process.

Our interpretation of the LP (concurrent with and following the N400) to contextually less expected nouns might be best informed by comparisons with other positivities in language contexts. LPs accompanying N400s to semantic experimental manipulations have sometimes been remarked upon in the literature. Until recently, however, experimenters have shied away from interpreting them functionally. And at that, such effects have more frequently been observed to incongruent sentence completions, less often to plausible ones, as in the current study.

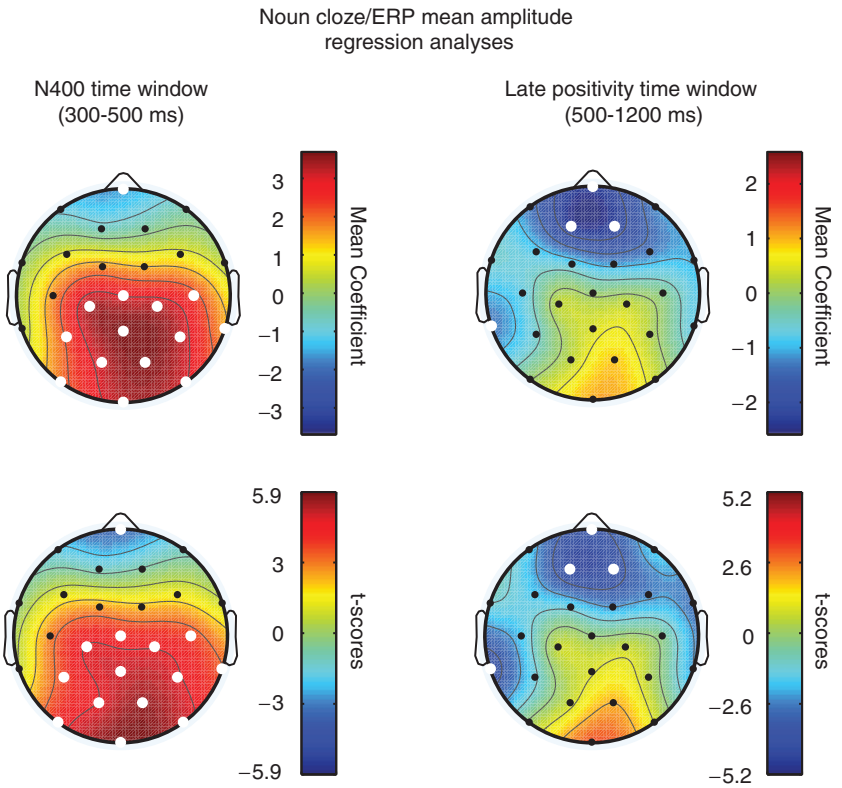

Figure 2. Scalp topographies of noun ERP mean amplitude/cloze probability correlations from repeated measures regression analyses. Redder shading indicates more negative ERP responses with decreasing cloze, and bluer shading indicates increasing ERP positivity with decreasing cloze. The upper topography maps plot slope coefficients at each channel, and the bottom maps visualize the regression coefficients as *t*-scores (i.e., the mean coefficient divided by the standard error of the mean) to give a sense of how reliably the coefficients differ from zero across participants. The *p*-values of significant correlations (indicated by white electrodes) range from 1e–6 $\leq p \leq$ .019 (300–500 ms) and from .003 $\leq p \leq$ .013 (500–1200 ms).

The frontal focus of our LP also contrasts with, for instance, more posterior LPs including P600s to syntactic violations, ambiguities, loci of syntactically driven processing difficulty, as well as the various reports of so-called "semantic P600s"—effects observed to manipulations including animacy violations (Kuperberg, Sitnikova, Caplan, & Holcomb, 2003), semantic verb argument violations (Kim & Osterhout, 2005), and semantic reversals (Kolk, Chwilla, van Herten, & Oor, 2003), to name a few. In the present study, however, there were no "violations" *per se*; all target nouns were congruent continuations, albeit more or less contextually expected.

To our mind, the frontal positivity observed in the current design is most consistent with the 500–900 ms frontal LP observed by Federmeier et al. (2007) to strong, but plausible, sentential constraint violations. Federmeier et al. interpreted this finding as a consequence—perhaps one associated with inhibition or revision—of processing unexpected words that complete highly predictive contexts. While our study did not directly manipulate sentential constraint, the relatively high overall contextual constraint of our sentences (on average, 71%, calculated using the most commonly provided continuations from the sentence norming) combined with the very low cloze noun continuations, mimics the "high constraint violation" condition eliciting the LP in Federmeier et al. (2007). To the extent that our frontal LP indexes processing relating to neural preactivation of information eventually disconfirmed by input, the effect would be expected to correlate with some measure of cloze, constraint, or combination thereof. Our observation of greater LP amplitude to low relative to high cloze nouns is, at minimum, consistent with this proposal. Low expectancy (i.e., low cloze continuations to either weakly or strongly constraining contexts) and high constraint violation (low cloze continuations to highly constraining contexts), however, are different linguistic phenomena, though at times conflated in the literature. Thus, to isolate effects of constraint violation and to determine whether the frontal LP is indeed correlated with one or the other factors (or perhaps to both), further testing—including a full range of contextual constraint and cloze probabilities—is required. A specific piece that our results add to this puzzle is that if our LP and that of Federmeier et al. (2007) are functionally linked, we show that the component's onset can occur relatively early—in some cases, partially overlapping with the N400 time window. Thus, when compared to the remarkably consistent timing of the N400 across linguistic manipulations, the latency of the frontal positivity may be more variable. In the current study, it is possible that this overlap may stem from the potential of the prenominal articles to cue upcoming low cloze nouns. It could be that the brain exhibits a rapid sensitivity to not receiving what it expects, and initiates whatever processing is indexed by the LP at a time point occasionally coincident with the N400 peak. If so, then processing related to, e.g., semantic activation, integration, and/or unification (as indexed by the N400) and processing related to constraint violation (as potentially indexed by the LP) may occur at least partially in parallel. Additionally, this overlap

may help explain, in part, why such positivities have not been more routinely described in other seemingly similar N400 sentence studies, perhaps sometimes getting "swamped" by strong and widespread N400 effects.

To the extent that the prenominal articles signal against receiving anticipated nouns, they themselves might constitute a kind of constraint violation, and elicit an LP. However, although not detailed herein, no such positivity was observed at the articles. One possible reason suggested by our stimulus norming results is that—at least offline—unexpected articles do *not* always diminish comprehenders' expectations for upcoming nouns. In many instances when truncated sentences were normed with unexpected articles (e.g., *a* when *apology* was the contextually expected noun), participants provided continuations comprised of an article phonology-consistent adjective followed by the contextually expected noun (e.g., "... *a heartfelt apology* ..."). Although the current paradigm revealed prediction effects on the N400 at the prenominal article (DeLong et al., 2005), these were accompanied by canonical N400 effects at the ensuing target nouns. This leads us to suggest that the "cue" value of the unexpected article may not be processed as a constraint violation in the same way as low cloze nouns that continue and presumably violate expectations in higher constraint contexts.

In sum, our enhanced frontal positivity to low relative to high cloze nouns is consistent with the hypothesis that there may be a consequence to input disconfirmation of strongly preactivated linguistic trajectories. While a domain-general account of the variety of syntactically/semantically, frontal/centro-parietal, violation/low probability-induced LPs (including our own) would be parsimonious, we cannot be certain that these ERP patterns are members of the same family of components, much less reflect a similar mental process. Theories suggesting that expectancy violations—not (syntactic) rule violations—may trigger LP effects (e.g., van de Meerendonk, Kolk, Chwilla, & Vissers, 2009) hold more appeal given our data; however, the precise nature of a processing consequence (be it conflict monitoring, reanalysis, revision of contextual representations, inhibition, updating of some learning mechanism, or something else) is still a matter that will be best settled by further, careful experimentation. In our own line of research, the logical next step will be to establish whether or not there is a systematic relationship between constraint violation and our frontal LP effects. We believe that graded manipulations of cloze and constraint will shed light on the issue of there being probability-based "costs" to preactivation (reflected in the LP) for unexpected continuations across a range of more and less constraining contexts.

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