
**PROBING FOR EARLY SEMANTIC ACTIVITY IN THE EVENT-RELATED
POTENTIAL: A NEW PARAMETRIC APPROACH**

Joseph Dien¹, Gwen A. Frishkoff², Arleen Cerbone¹, and Don M. Tucker^{2,3}

¹Department of Psychology
Tulane University

²Institute of Cognitive and Decision Sciences
Department of Psychology
University of Oregon

³Electrical Geodesics, Inc.
Eugene, Oregon

Dien, J., Frishkoff, G. A., Cerbone, A., and Tucker, D. M. (2003). Parametric event-related potential analysis of expectancy and meaningfulness: Evidence for parallel mechanisms in word comprehension. *Cognitive Brain Research*, 15:137-153. ([https://doi.org/10.1016/S0926-6410\(02\)00147-7](https://doi.org/10.1016/S0926-6410(02)00147-7))

© 2003. This manuscript version is made available under the CC-BY-NC-ND 4.0 license <http://creativecommons.org/licenses/by-nc-nd/4.0/>

Abstract

Electrophysiological data have traditionally shown semantic effects no earlier than about 200 ms. after stimulus presentation (peaking at about 300 or 400 ms.) Using novel analysis techniques, this report shows that word meaning may be accessed as early as 150 ms. after word onset (peaking at about 200 ms.) when a word is incongruent with a preceding sentence stem. Semantic processing is thus argued to start sooner than previously demonstrated. Source localization techniques suggest involvement of the left hemisphere visual word form region and possibly the right cerebellum.

Language is central to higher cognition. So important is language function that brain surgeons routinely map the cortical language regions to minimize damage from surgery, often at the expense of other cortical functions. In spite of its importance, the time course and neural substrates of language remain poorly characterized, and existing data suggest competing hypotheses. For example, estimates from event-related potentials (ERPs) and regional cerebral blood flow (rCBF) methods indicate that analysis of the visual word form begins at around 125 ms. (1), while semantic access is initiated at around 200 ms. Eye movement studies, however, suggest that semantic access may be initiated within the first 100–150 ms (2). In addition, it is disputed where semantic analysis begins: both the middle and anterior temporal lobes (3, 4) and the left frontal regions (5) have been implicated. Using novel ERP analysis strategies and an unusually large sample size (78 participants), the current study helps resolve these discrepancies with evidence that semantic analysis begins with a burst of activity that starts around 150 ms. and peaks at about 200 ms., consistent with eye-tracking data. Dipole modeling suggests two such concurrent activations, one in the left hemisphere fusiform gyrus visual word form region and another apparently emanating from the right neocerebellum.

Experimental Design

The present study made use of a standard semantic incongruity paradigm (6), in which participants were asked to read sentences presented one word at a time, with no task other than to understand what they were reading. The last word was either semantically congruent (e.g., *New York is a very busy city.*) or incongruent (e.g., *The mole lived in a hole in the tax.*). A trial began with a central fixation mark (a '+' sign), which appeared for 900 ms. Each word was displayed for 105 ms. and was immediately replaced by the fixation mark. After a 900 ms. inter-word interval, the next word appeared. A period marked the end of each sentence.

Electroencephalographic (EEG) recording began 184 ms. before onset of the last word, and data were collected for a total of 2,048 ms.

Subjects completed a block of 10 practice trials, followed by four blocks (30 trials each) of experimental trials. Each block was evenly divided between trials with congruous and incongruous sentence endings. Stimuli were sentences selected from those used by Kutas and Hillyard (1980). Congruous and incongruous words were matched in length and frequency of occurrence in the English language (7).

Subjects and EEG Recording

Seventy-eight right-handed native English speaking University of Oregon undergraduates were recruited from the department subject pool (37 males and 41 females; mean age 22). Data from twenty-three participants were presented in an earlier report, which contains more detailed information about the experiment (7). Electroencephalographic (EEG) data were collected with the Geodesic Sensor Net from 64 recording sites, plus a right-mastoid reference sensor, and were low-pass filtered at 30 Hz and bandstopped from 7.5 to 8.5 Hz to eliminate aliasing [of the video monitor field](#). The data were then re-referenced to the average reference (8), which produces an estimate of the activity at the reference site, generating a 65th recording site.

Conventional ERP studies require averaging over a large number of similar trials in order to boost the signal-to-noise ratio. This procedure has the drawback of obscuring parametric stimulus differences by collapsing individual trials into a few general categories. In order to conduct parametric analyses of the data, a novel item-averaging approach was therefore applied, taking advantage of the large sample size in this study. Instead of the usual procedure of generating two averaged ERPs for each subject (congruent versus incongruent endings), 120

separate sentence averages were generated, collapsing over subjects instead of over sentences. This procedure permits the computation of correlations between individual sentence parameters and their associated ERPs. As will be seen, it also facilitates source localization.

Principal Components Analysis

Large datasets present a challenge for analysis due to excessive multiple comparisons (65 channels x 125 time points = 8,125 possible comparisons). A standard technique is to use principal component analysis (PCA) to reduce dimensionality to a manageable degree (9). In the present study, variables consisted of the voltage readings at each of 125 time points (160 ms. pre-stimulus and 840 ms. post-stimulus); the 7,800 observations consisted of recordings from the 65 sensors for each the 120 sentences. The relational matrix was the sum-of-squares-cross-products matrix. Promax rotation was used to rotate to a simple structure (10). The factor scores were rescaled to microvolts by multiplying the scores by the factor loading and the standard deviation of the peak time point (10).

The parallel test, which takes into account how many factors are expected purely by chance (10), indicated that nine factors should be retained, accounting for 91% of the variance. Only the first five appeared to correspond to coherent ERP components (listed with factor peak times), namely, the P1 (112 ms.), the N2 (208 ms.), the N3 and P1r (328 ms.), the P3/N4 (432 ms.), and the P600 (672 ms.). Only the analyses of the first two factors will be reported here, since later activity is not directly relevant to this report. Findings regarding the N3 and the P3/N4 are described elsewhere (11). Conventional ANOVA analyses failed to indicate the presence of any semantic effects prior to the N3.

Stimulus Norming

Parametric data on the individual stimulus sentences were gathered so that more sensitive analyses could be performed. Norming data were collected via Mac HyperCard stacks from 44 Tulane University undergraduates (25 males and 19 females; mean age 19). The participants rated five stimulus parameters on seven-point scales, of which only two proved to be relevant (Table 1). First, subjects were presented with the sentence stem and asked to anticipate the ending. They then pressed a button to see the final word and rated how unexpected it was. Unexpectedness of the sentence ending ~~should~~ was assessed to help control for the effect of expectancy on visual word form and semantic processing. Second, subjects viewed the entire sentence and were asked to rate how meaningful the sentence as a whole was. This judgment was assumed to index postlexical (sentence-level) semantic analysis.

	Unexpectedness	Meaningfulness
Congruous	3.43(0.18)	6.53(0.26)
Incongruous	4.32(0.18)	2.1(0.48)

Table 1. Norming results for the 120 sentence stimuli. Ratings were seven-point scales ranging from low (1) to high (7). Numbers in parentheses represent standard deviations.

Correlational Analysis

An important limitation of the PCA procedure is that it tends to conflate ERP components that have similar time courses. For example, in the present report the N3 and the P1r are described by the same factor since they both peak at about 300 ms., even though they are

separate components with distinct scalp topographies. This occurs because a PCA conducted on the time points defines factors according to a particular time course without taking other factors, such as topography, into account. One way of addressing this limitation is to use a two-stage procedure in which a second PCA is applied, decomposing each temporal factor into further factors defined, this second time, by scalp topographies (12). While a useful procedure, it may not be fully effective since spatial PCAs are limited by volume conduction (10).

The parametric strategy described in this report makes it possible to separate temporally similar components using experimental variance. The first step is to determine which, if any, parameters correlate with components embedded in each factor. Since it may not be known in advance which channel best indexes each underlying component, the simplest procedure is to correlate the parameter of interest with the factor scores of every channel separately. For this analysis, the seven periocular channels were dropped since they are likely to have ocular artifacts. In addition, computing 58 different correlations, one for each channel, risks seriously inflated Type I error rates. This can be controlled using a Bonferroni correction, resulting in an alpha of .00086 to be considered significant. While excessively conservative (the Bonferroni correction treats each test as an independent source of error, when in fact each time point is highly correlated with neighboring time points), this correction provides confidence in the present results.

Correlations were computed between each parameter and the factor scores corresponding to each channel for both the P1 and N2 factors. No channels were significant for both conditions combined ($n = 120$). When the congruous and incongruous conditions were examined separately ($n = 60$), the N2 was found to be significantly correlated with meaningfulness and with unexpectedness for the incongruous conditions only (Figure 1). The dramatic difference illustrated in the scatterplots suggests that the semantic system responds in a different fashion when the ending is incongruous, even though the difference is not readily apparent from a simple main effects comparison. While the incongruent sentences included a

number of syntactic violations, dropping these violations from the analysis did not substantively change the results. Cloze probabilities (available only for congruous endings) did not correlate with the P1 or N2.

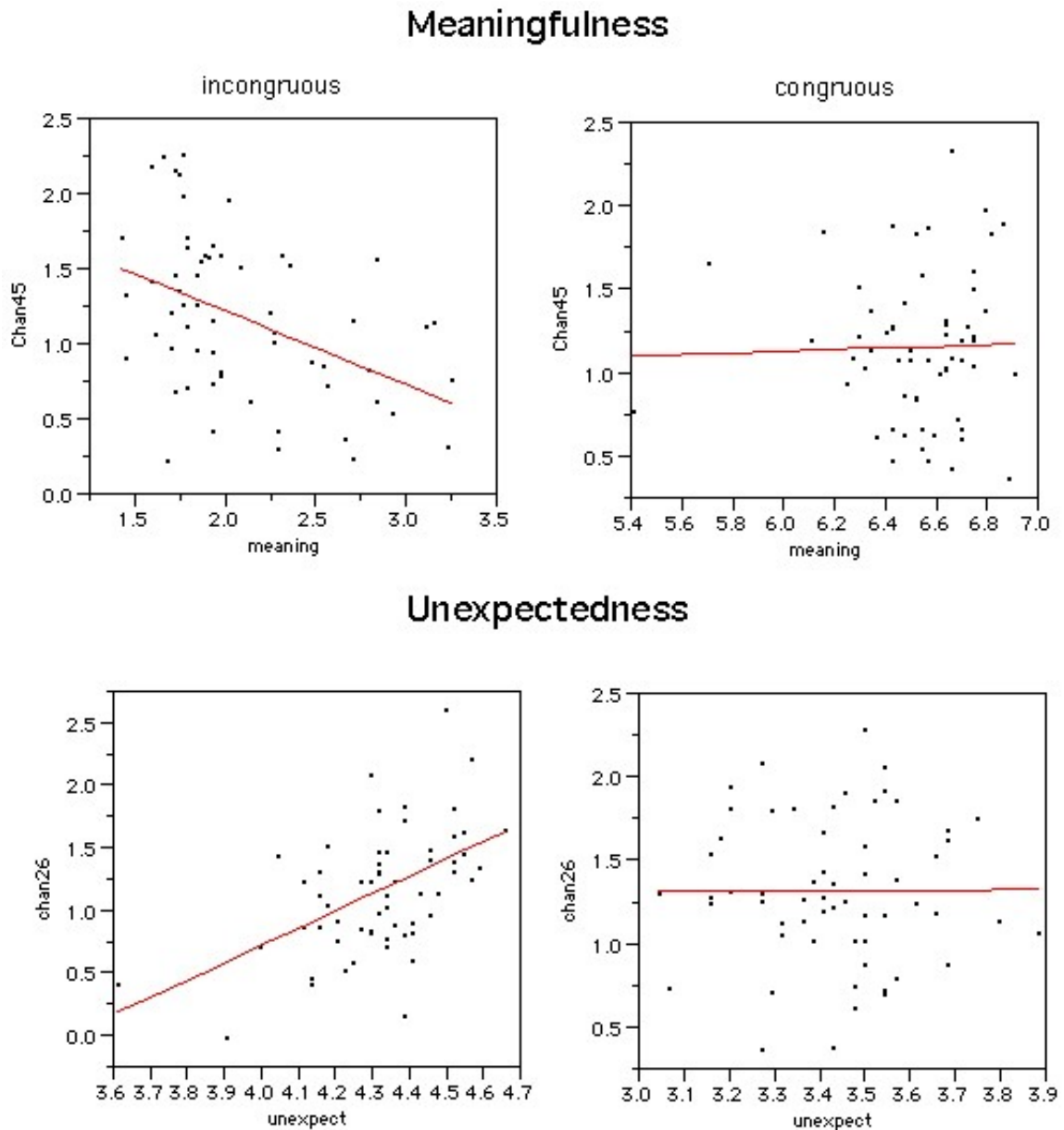


Figure 1. Scatterplots of Meaningfulness and Unexpectedness parameters and the channels with which they correlate most highly (red line indicates best linear fit). The parameters are in

the original metric. The channels are the factor scores (standardized across the entire dataset) for the N2 factor.

For the incongruous condition, the more meaningful sentences produced smaller N2 effects ($r = -.44$ just inferior to T6). This could mean that less semantic processing is necessary when a word has already been partially activated by automatic spreading activation from close semantic associates (13). In contrast, the more unexpected the ending, the larger the was N2 effect ($r = .51$ just anterior to P3). Even after dropping the two extreme low unexpectedness points, the correlation remains high at an r of $.42$. This may be showing that consciously expected stimuli require less processing (14). While the two parameters are correlated ($-.29$ for incongruous endings), the divergent topographies of the correlations (meaningfulness N2 right-lateralized, unexpectedness N2 left-lateralized) suggest that these reflect two separate components that are conflated in the N2 factor. These two components shall henceforth be labeled the N2m (for meaningfulness N2) and the N2u (for unexpectedness N2).

Source Localization Analysis

These two putative N2 components can be further characterized by mapping their scalp topographies. As described elsewhere, factor scores can be rescaled to microvolts by multiplying them by the standard deviation and the factor loading of the time point of interest, such as the peak (10). In short, Pearson correlations are computed by taking the covariance between two variables and then dividing it by the product of the standard deviations. This latter operation standardizes the resulting number, removing the unit scaling. Such correlations can be rescaled by multiplying them by the corresponding standard deviations, reversing this step. This operation yields the portion of the voltage readings at that time point attributable to (i.e., predicted by) the factor of interest. Following the same derivation (15), one can generate the scalp voltage map predicted by the parameter of interest (in this case,

meaningfulness or unexpectedness). The resulting values represent the portion of the recorded voltage that is attributable to the correlated activity. Finally, since the two parameters are moderately negatively correlated ($-.29$), a map of the meaningfulness effects may indirectly include some of the effects of unexpectedness as well, and vice versa. Since unexpectedness is predicted to affect both the visual word form operation and lexical access, whereas meaningfulness is predicted to affect only lexical access, it makes sense to partial out meaningfulness from unexpectedness, maximizing its relation to visual word form effects. While one could partial out unexpectedness from meaningfulness as well, the two partialled measures would then no longer be orthogonal (they would be correlated at $.29$).

Overall, this set of procedures proved highly successful, enabling us effectively to separate the left and right hemisphere N2 activations, as well as sharply refining the topography of these effects and eliminating N2 activity unrelated to the activity of interest. In this way, the quality of the analysis was greatly improved (Figure 2).

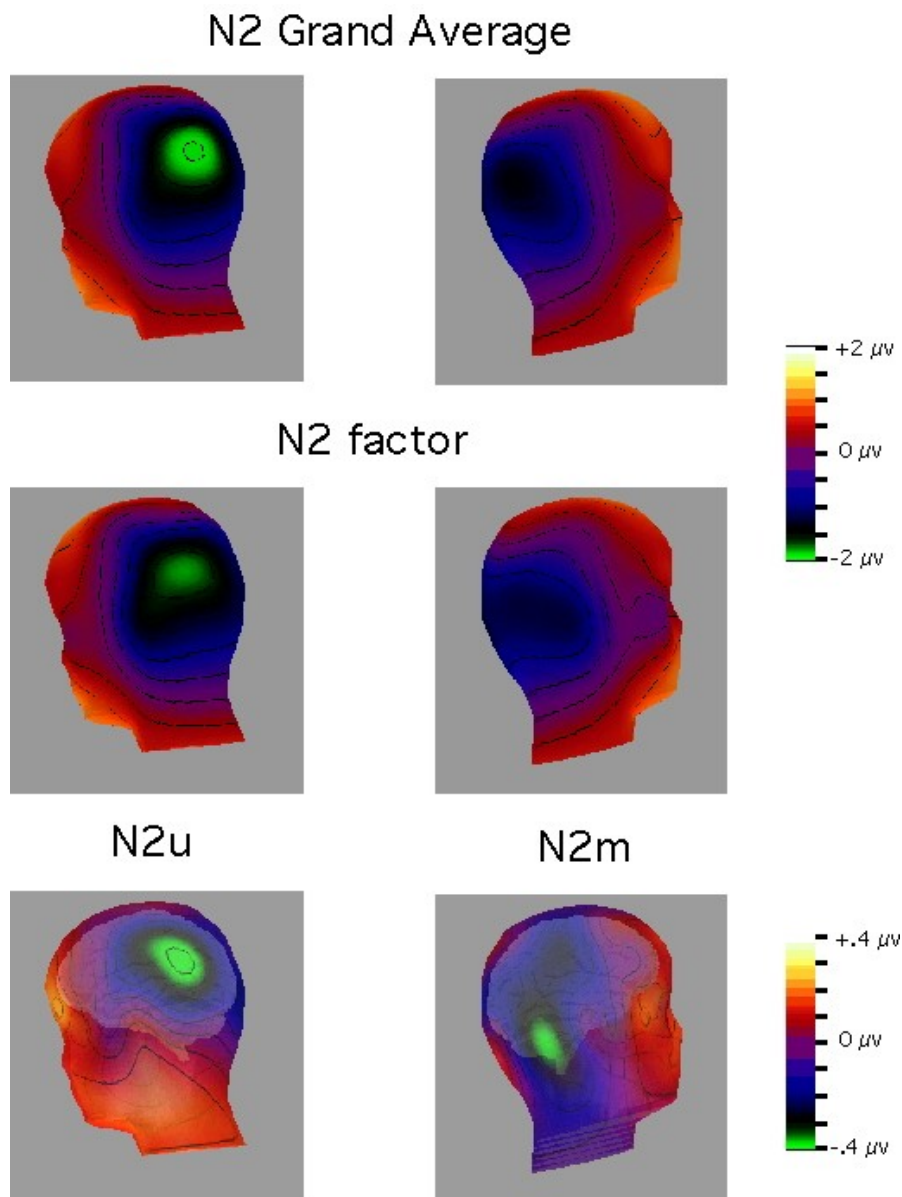
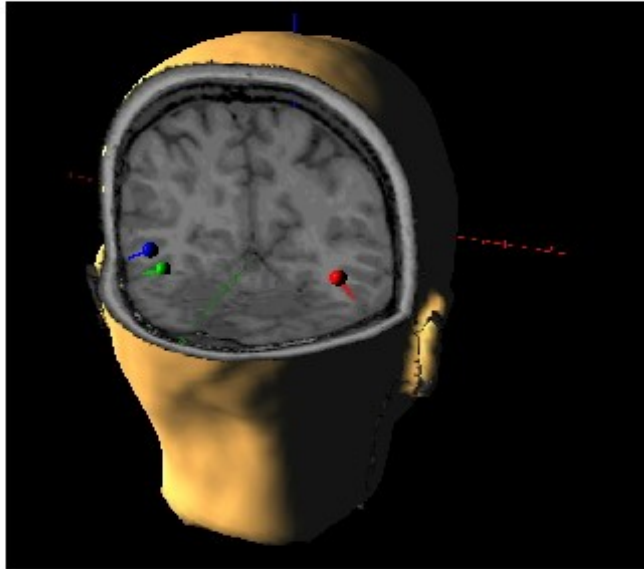


Figure 2. Scalp topographies of N2. The top row shows the scalp topography of the N2 to incongruous endings at 208 ms. The second row show the N2 topography as captured by the N2 factor. The maps on the bottom row represent the topography of the correlations between the respective parameters (residualized unexpectedness and meaningfulness) and the N2 factor scores. Correlations were rescaled into the microvolt metric appropriate for the peak of the N2 factor at 208 ms. The scale for the bottom row indicates the amplitude of the N2 response per standard deviation of the parameter.

It is further possible to take the resulting scalp topographies and perform source localization analyses as shown in Figure 3. BESA99, version 1.12 (16), was applied to the two datasets, using a four-shell ellipsoidal head model, symmetrical dipoles with initial position determined by regional source scans, energy criterion turned on to minimize interaction between dipoles, and minimum-distance criterion activated to avoid solutions with closely spaced dipoles. The seven periocular channels were dropped to minimize the effect of ocular artifacts. Results suggested that the N2m topography was consistent with a right-lateralized cerebellar source. This solution accounted for 82% of the total variance. The addition of another pair of dipoles, which migrated to the parietal region, accounted for only an additional 5%. The N2u topography was consistent with a left-lateralized fusiform gyrus source. This solution accounted for 83% of the total variance. The addition of another pair of dipoles, which migrated to the eyes, accounted for another 7% of the variance. The resulting dipole solutions were converted to a Talairach (17) coordinate system and rendered using Brain Voyager 2000.

N2u Dipole Solution



N2m Dipole Solution

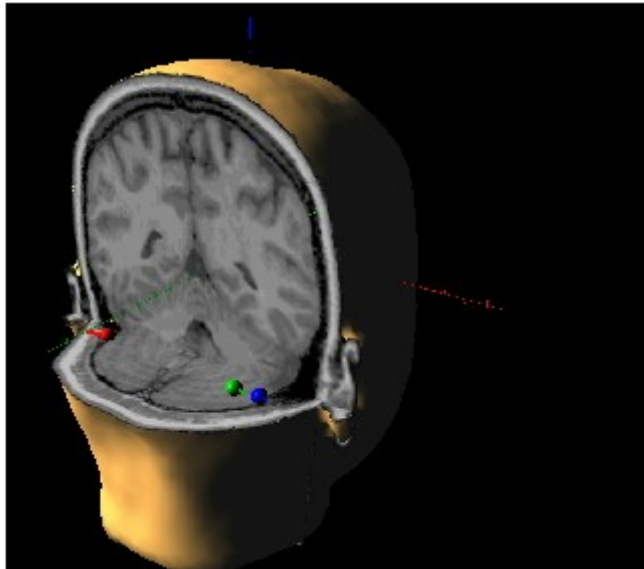


Figure 3. Source localization results of the N2u and N2m effects. The blue dipole is the primary source. The red dipole is the symmetrical position in the other hemisphere. The green dipole indicates the position of activity identified in previous rCBF studies (the orientation of the dipole is arbitrary since hemodynamic data does not have an inherent orientation) that may be the sources of the N2m (18) and N2u (19) effects.

Discussion

This report demonstrates how novel parametric strategies, namely item averaging and correlational factor analysis, make it possible to perform powerful analyses of ERPs, including greatly refined source localization solutions. It also demonstrates that even apparently unitary ERP components, such as the posterior N2, can have multiple generators that require careful experimental analysis to emerge as distinct components of the scalp ERP.

The distinction between meaningfulness and unexpectedness proved analysis. A might expect these two measures to reflect the same processes. oncepts would be expected and expected concepts would be expected because they meaningful. A counter-example is the meaningful but unexpected ending in the sentence “Dan caught the ball with his *mustard*.” be anticipated in advance to be more activated than that of meaningless ending, and yet endinggenerate a meaningful humorous. that the N2m amplitude reflects effort to generate a meaningful interpretation. By this account, the N2m would only indirectly reflect semantic priming insofar as unprimed stimuli could be

Unexpectedness, on the other hand, priming by definition. cording to current theories, although whether automatic and controlled remains (c.f., 20).ocalization analysis suggests that the N2u reflect priming at the visual word form level. end result of visual word form analysis (21)-holistic word recognition, or more specifically, the organization of letter-shape primitives into cohesive visual word-forms. The fusiform gyrus region has been thought to mediate this - since it activation in response to visually presented words (19), and since inactivation of this region results in letter-by-letter read “pure alexia” (22). The p further suggest that expected, and hence primed, words require less processing and hence decrease acti of the fusiform gyrus, consistent with other neuroimaging studies (23). In general, source localization methods for ERPs suffer from a number of ambiguities, collectively termed the “inverse problem,” and

convergent validation is therefore critical. In addition to being consistent with rCBF studies, the N2u solution matches well with previous results from intracranial recordings (which do not suffer from the inverse problem), where the fusiform gyrus region also had peak activations to word-like stimuli in a similar paradigm at about 200 ms. (4).

The N2m solution, which localized to the right cerebellum, is quite plausible but less well grounded experimentally and should be seen as tentative. As seen in Figure 3, the solution corresponds closely to the right cerebellar activation found in a massive functional magnetic resonance imaging (fMRI) study of language-related regions (18) and has also been observed in earlier studies, although not necessarily in the same part of the cerebellum (24). To date, however, no rCBF or cerebellar intracranial ERP studies have been published using the present paradigm. The strongest theoretical support for this localization is that cortical language activations have been primarily left-lateralized in the cortex and right-lateralized in the cerebellum (each cerebellum is connected to the contralateral hemisphere). Although to our knowledge EEG studies have not previously been able to directly relate scalp recordings to the cerebellum (or indeed any source locations at all for the posterior N2), several magnetoencephalography studies have reported doing so (25), suggesting that EEG should also be recordable at the scalp. While traditionally considered a motor-related structure, it has become increasingly clear that the cerebellum has an important role in such cognitive functions as language (26) and can result in serious impairment to language functions when lesioned (27). Without convergent evidence in the same paradigm, as available for the N2u solution, caution must be exercised, especially since the N2m was recorded at the edge of the scalp montage where coverage is incomplete. Nonetheless, the right cerebellum is known to be responsive to language stimuli, and further investigation is [therefore](#) warranted.

~~If the cerebellar source location is confirmed, the time course of the observed effects would indicate that the right cerebellum and the left visual-word form region operate in synchrony. This is plausible since each cerebellum is associated with the contralateral~~

cortical hemisphere and since the cerebellum has extensive connections with the cortex (28). It seems unlikely that the cerebellum is itself the site of semantic analysis. Rather, the cerebellum is likely to participate in an extended semantic network, although the specific contributions of the cerebellum to semantic processing are not well understood. A relevant model suggests that the cerebellum helps mediate shifts in attention (29); perhaps this includes shifts in semantic space the process of trying to generate a meaningful interpretation. This report leaves open the question of whether semantic analysis begins in the frontal or temporal cortex. In this regard, it is interesting to note that the cerebellum appears to be especially connected to frontal regions, such that cerebellar patients often have the same symptoms as frontal patients (26). We suggest that the left frontal cortex and right cerebellum may operate in conjunction with the fusiform cortex as a coordinated network, representing a combination of top-down and bottom-up influences in the initial stages of semantic processing, although further studies are needed to test this hypothesis.

In summary, these results reveal that semantic analysis of written words begins earlier and can be localized more accurately than previously demonstrated using event-related potentials. A previous study (30) reported electrophysiological responses to pictures of task-relevant animals starting at about 150 ms., but such a task could be performed using presemantic features unique to animal forms. The present results are free from this ambiguity, since congruous and incongruous sentence endings differ only with respect to semantics. Moreover, the present analysis has enabled us to propose source generators, in addition to providing new evidence on the time course of early semantic processing.

References and Notes

1. P. E. Compton, P. Grossenbacher, M. I. Posner, D. M. Tucker, *Journal of Cognitive Neuroscience* **3**, 304-312 (1991).
2. S. C. Sereno, K. Rayner, M. I. Posner, *Neuroreport* **9**, 2195-2200 (1998).
3. M. Kutas, *Psychophysiology* **34**, 383-398 (1997); H. Damasio, T. J. Grabowski, D. Tranel, R. D. Hichwa, A. R. Damasio, *Nature* **380**, 499-505 (1996).
4. A. C. Nobre, T. Allison, G. McCarthy, *Nature* **372**, 260-263 (1994).
5. M. I. Posner, Y. G. Abdullaev, *NeuroReport* **10**, R12-R23 (1999); A. Z. Snyder, Y. G. Abdullaev, M. I. Posner, M. E. Raichle, *Proceedings of the National Academy of Sciences* **92**, 1689-1693 (1995); Y. G. Abdullaev, N. P. Bechtereva, *International Journal of Psychophysiology* **14**, 167-177 (1993).
6. M. Kutas, S. M. Hillyard, *Science* **207**, 203-205 (1980).
7. T. Curran, D. M. Tucker, M. Kutas, M. I. Posner, *Electroencephalography and Clinical Neurophysiology* **88**, 188-209 (1993).
8. J. Dien, *Behavioral Research Methods, Instruments, and Computers* **30**, 34-43 (1998).
9. E. Donchin, E. Heffley, in *Multidisciplinary perspectives in event-related potential research (EPA 600/9-77-043)* D. Otto, Ed. (U.S. Government Printing Office, Washington, DC, 1979) pp. 555-572.
10. J. Dien, *Brain Topography* **11**, 43-55 (1998).
11. J. Dien, G. A. Frishkoff, D. M. Tucker, *Brain & Cognition*, (in press).
12. K. M. Spencer, J. Dien, M. Donchin, *Psychophysiology* **36**, 409-414 (1999).
13. A. M. Collins, E. F. Loftus, *Psychological Review* **82**, 407-428 (1975).
14. J. H. Neely, *Journal of Experimental Psychology: General* **106**, 226-254 (1977).

15. For each channel: (1) $Z_f = rZ_m$, where Z_f is the factor-related voltage (standardized), r is the correlation between the parameter and the factor-related voltages, and Z_m is the parameter (standardized). Since: (2) $Z_f = (F - \mu) / \sigma$ where F is the factor-related voltage, σ is the standard deviation of F and μ is the mean of F . Rearranged, this is: (3) $(F - \mu) = \sigma Z_f$ substituting in (1) produces: (4) $F - \mu = \sigma r Z_m$ or (5) $F = \sigma r Z_m + \mu$. If one arbitrarily chooses a Z-score of 1 for the parameter (the magnitude of the parameter is irrelevant to the source localization procedure), the appropriate scalp voltage values are readily generated for each channel and which can then be submitted to a source localization algorithm.

16. M. Scherg, P. Berg, *Brain Electromagnetic Source Analysis user manual* (MEGIS GmbH, Munich, 1996).

17. J. Talairach, P. Tournoux, *A co-planar stereotaxic atlas of a human brain* (Thieme, Stuttgart, 1988).

18. J. R. Binder *et al.*, *Journal of Neuroscience* **17**, 353-362 (1997).

19. L. Cohen *et al.*, *Brain* **123**, 291-307 (2000).

20. J. H. Neely, in *Basic processes in reading: Visual word recognition* D. Besner, G. W. Humphreys, Eds. (Lawrence Erlbaum Associates, Hillsdale, NJ, 1991) pp. 264-336.

21. G. M. Reicher, *Journal of Experimental Psychology* **81**, 275-280 (1969).

22. A. I. Tröster *et al.*, *Neuropsychiatry, Neuropsychology, and Behavioral Neurology* **9**, 209-217 (1996).

23. J. D. E. Gabrieli, J. E. Desmond, J. B. Demb, A. D. Wagner, *Psychological Science* **7**, 278-283 (1996).

24. S. E. Petersen, P. T. Fox, M. I. Posner, M. Mintun, M. E. Raichle, *Journal of Cognitive Neuroscience* **1**, 153-170 (1989); J. V. Pardo, P. T. Fox, *Human Brain Mapping* **1**, 57-68 (1993); M. E. Raichle *et al.*, *Cerebral Cortex* **4**, 8-26 (1994).

25. C. D. Tesche, J. Karhu, *Brain Research* **744**, 23-31 (1997); C. D. Tesche, J. J. T. Karhu, *Human Brain Mapping* **9**, 119-142 (2000); V. Jousmäki, M. Hämäläinen, R. Hari, *NeuroReport* **7**, 2961-2964 (1996).

26. J. D. Schmahmann, *Human Brain Mapping* **4**, 174-198 (1996).
27. N. Gordon, *European Journal of Disorders of Communication* **31**, 359-367 (1996).
28. H. C. Leiner, A. L. Leiner, R. S. Dow, *Human Brain Mapping* **2**, 244-254 (1995).
29. T. H. Le, J. V. Pardo, X. Hu, *Journal of Neurophysiology* **79**, 1535-1548 (1998); N. A. Akshoomoff, E. Courchesne, *Journal of Cognitive Neuroscience* **6**, 388-399 (1994).
30. S. Thorpe, D. Fize, C. Marlot, *Nature* **381**, 520-522 (1996).

Acknowledgements

The preparation of this manuscript was partially supported by a Tulane Council of Research Summer Fellowship and a National Institutes of Mental Health grant MH11751. Thanks to Tim Curran, and Mike Posner for their helpful comments on an earlier version of this manuscript.