



Electrophysiological Correlates of Processing Causal Relationships between Sentences

Gina R. Kuperberg*§, David Caplan||, Marianna Eddy||§, Jordana Cotton*, Phillip J. Holcomb§

*Department of Psychiatry, Massachusetts General Hospital, Bldg 149, 13th Street, Charlestown, MA 02129, USA;

||Neuropsychology Laboratory, Department of Neurology, VBK 827, Massachusetts General Hospital, Boston, MA 02114;

§Neurocognition Laboratory, Department of Psychology, Tufts University, Medford, MA 02155.



Introduction

Causal relationships between events are essential for the coherence of narrative text [6]. Establishing causal coherence sometimes requires the generation of a causal inference – information that is not explicitly stated in the text [5,9].

Highly connected statements are recalled more often than statements with few causal connections [1,2,3,4, 7]. However, if subjects incurred an online semantic processing cost in an association with every possible causal inference, this could overwhelm their overall processing capacity.

Electrophysiologically, the cost of establishing coherence during online comprehension is reflected by a larger N400 to words that are unconnected (versus connected) to their preceding discourse context [8]. In the current study, we measured ERPs as subjects read three types of three-sentence discourse scenarios and tried to connect the final sentence with its preceding context.

Logic of Design and Predictions

The attempt to link a completely unrelated sentence with its preceding context would incur a semantic processing cost, manifest by an N400 effect to critical words in this sentence.

The causal inferences were generated and incurred a semantic processing cost during word-by-word reading, critical words in the final sentence of the inference condition (versus the related condition) would also elicit an N400 effect.

Subjects' ratings of how difficult it was to connect the final sentence with its preceding context would predict the semantic processing cost incurred during online reading, as reflected by the amplitude of the N400 on critical words in the final sentence.

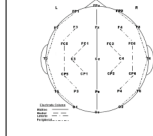
3 main experimental conditions

Condition	Explanation	Example
(1) Contextually congruent condition	The final sentence is congruous with its preceding context.	<i>"Mark and John were having an argument. Mark began to hit John hard. The next morning John had many bruises."</i>
(2) Inference condition	Instead of the final sentence being directly related with its context, it is indirectly related such that the reader needs to make an inference to connect the second and final sentences.	<i>"Mark and John were having an argument. Mark got more and more upset. The next morning John had many bruises."</i>
(3) Unrelated condition	The first two sentences are replaced by sentences from another scenario in another list. The final sentence now becomes incongruous with its preceding context.	<i>"Mark and John were gambling at the casino. They won every game of blackjack. The next morning John had many bruises."</i>

240 scenarios (80 of each of the three experimental conditions) presented to each participant in three lists. Critical words (CWs) were determined by asking twelve other participants (four per list) to rate the relatedness of the sentences and to indicate the word that helped them make that decision. Approximately 50% critical words were sentence-final words.

Participants and Data Acquisition

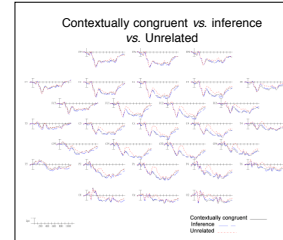
- Fifteen right-handed participants.
- Three main experimental conditions.
- First two sentences were presented successively (3.4 seconds each, ISI:100msec). The third sentence was presented word by word (500msec, 100msec ISI).
- Task: to press one of three buttons depending on how difficult it was to connect the final sentence with its preceding context.



EEG measured with twenty-nine active tin electrodes, continuously sampled at 200 Hz and amplified with a bandpass of 0.01 to 40 Hz.

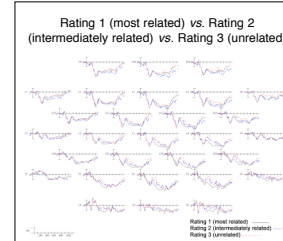
Results

A. Original Conditions

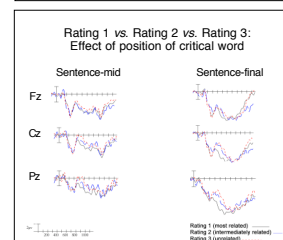


- Bilaterally distributed N400 effect elicited by CWs that were unrelated (versus congruent) with preceding context.
- No N400 effect elicited by CWs in sentences requiring inferences to connect to preceding context.

B. Participants' ratings

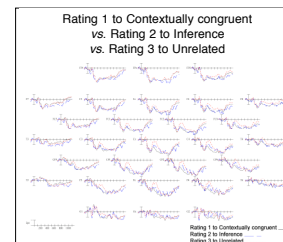


- Bilaterally distributed N400 effect elicited by CWs that subjects rated as most difficult (versus easiest) to connect to the preceding context.
- Smaller, right-lateralized N400 effect and late, sustained positivity effect (at the most anterior electrodes) were elicited by CWs that were rated as intermediately difficult (versus easiest) to connect to the preceding context.



- Similar effects were elicited by CWs that occurred at the end and before the end of the final sentence.

C. Original condition and participants' ratings



- These effects were also seen when we examine ERPs to subjects' ratings within the original three conditions.

- It is therefore unlikely that the right-lateralized N400 effect and the late, anterior positivity effects to rating 2 (vs. rating 1) were due to differences in lexico-semantic relationships between individual words, as such relationships were matched across the contextually congruent and inference conditions.

Summary and Discussion

A semantic processing cost was not necessarily incurred online as subjects read sentences that could be connected to their preceding context by generating a causal inference.

? A failure to generate causal inferences online.
? Online inference generation is not associated with a cost in semantic integration.

A right-lateralized N400 effect, was, however, generated in processing inference-requiring sentences that subjects subsequently classified as being intermediately (versus easy) to connect to their preceding context. This was associated with a late anterior positivity effect.

? The N400 effect reflects an online semantic processing cost in a subset of inference-requiring scenarios.
? The late anterior positivity effect might reflect the cost of online inference generation in these scenarios.

References

- [1] Fletcher, C.R. and Bloom, C.P., Journal of Memory and Language, 27 (1988) 235-244.
- [2] Goldman, S.R. and Varnhagen, C.K., Journal of Memory and Language, 25 (1986) 401-418.
- [3] Keenan, J.M., Ballet, S.D. and Brown, P., Journal of Verbal Learning and Verbal Behavior, 23 (1984) 115-126.
- [4] Myers, J.L., Shinjo, M. and Duffy, S.A., Journal of Memory and Language, 26 (1987) 453-465.
- [5] Singer, M. In M.A. Gernsbacher (Ed.), Handbook of Psycholinguistics, Academic Press, San Diego, 1994, pp. 479-510.
- [6] Thorndyke, P.W., Cognitive Psychology, 9 (1977) 77-110.
- [7] Trabasso, T. and Van den Broek, P.W., Journal of Memory and Language, 24 (1985) 612-630.
- [8] van Berkum, J.J.A., Hagoot, P. and Brown, C.M., Journal of Cognitive Neuroscience, 11 (1999) 657-671.
- [9] van den Broek, P. In M.A. Gernsbacher (Ed.), Handbook of Psycholinguistics, Academic Press, San Diego, 1994, pp. 539-583.

Acknowledgments

Gina R. Kuperberg is currently supported by NIMH (K23 MH02034). Part of this work was supported by grants from NIDCD to David Caplan (DC02146) and NICHD to Phillip Holcomb (HD25889) and by the Institute for Mental Illness and Neuroscience Discovery (MIND).

Figure A

Contextually congruent vs. inference vs. Unrelated

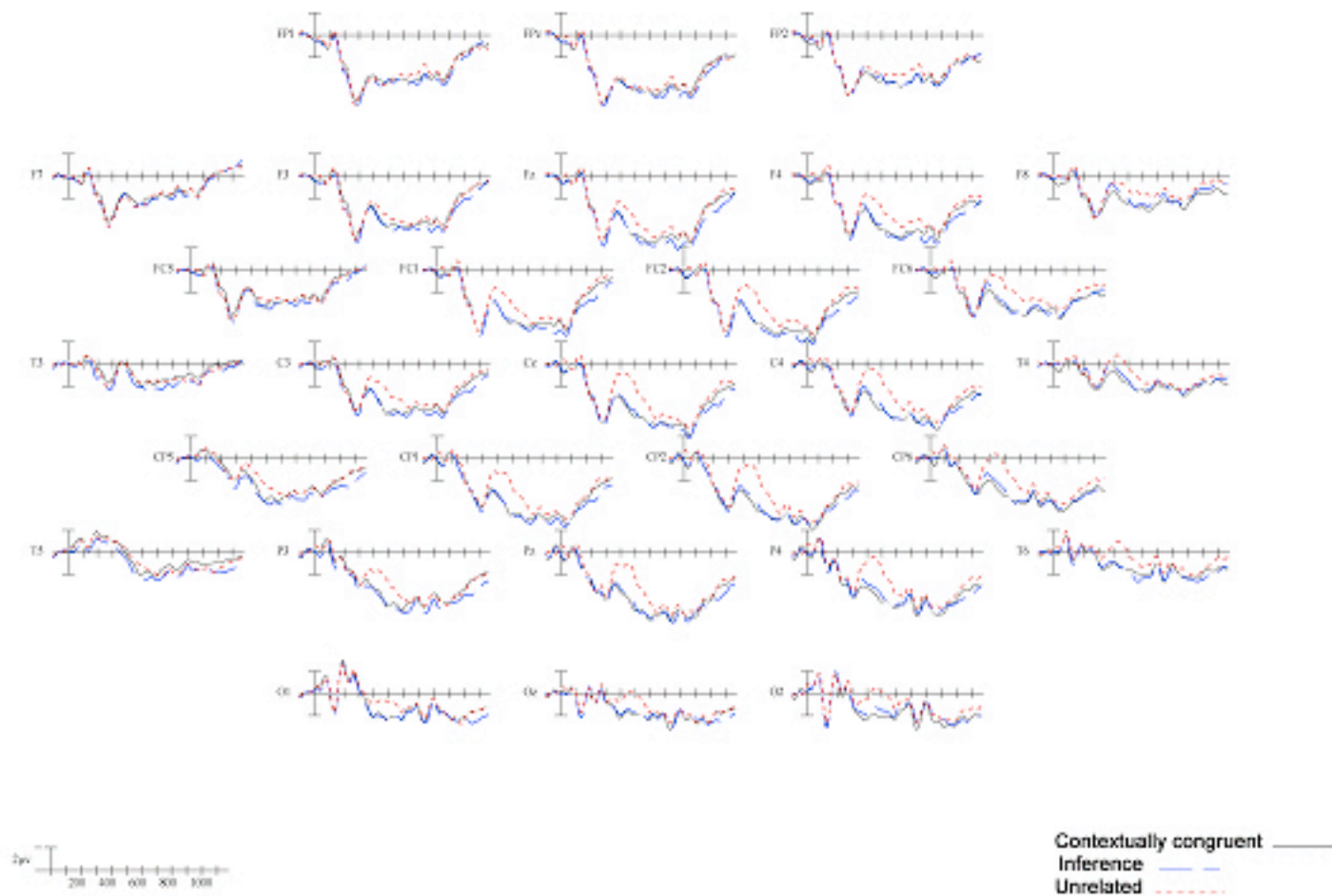
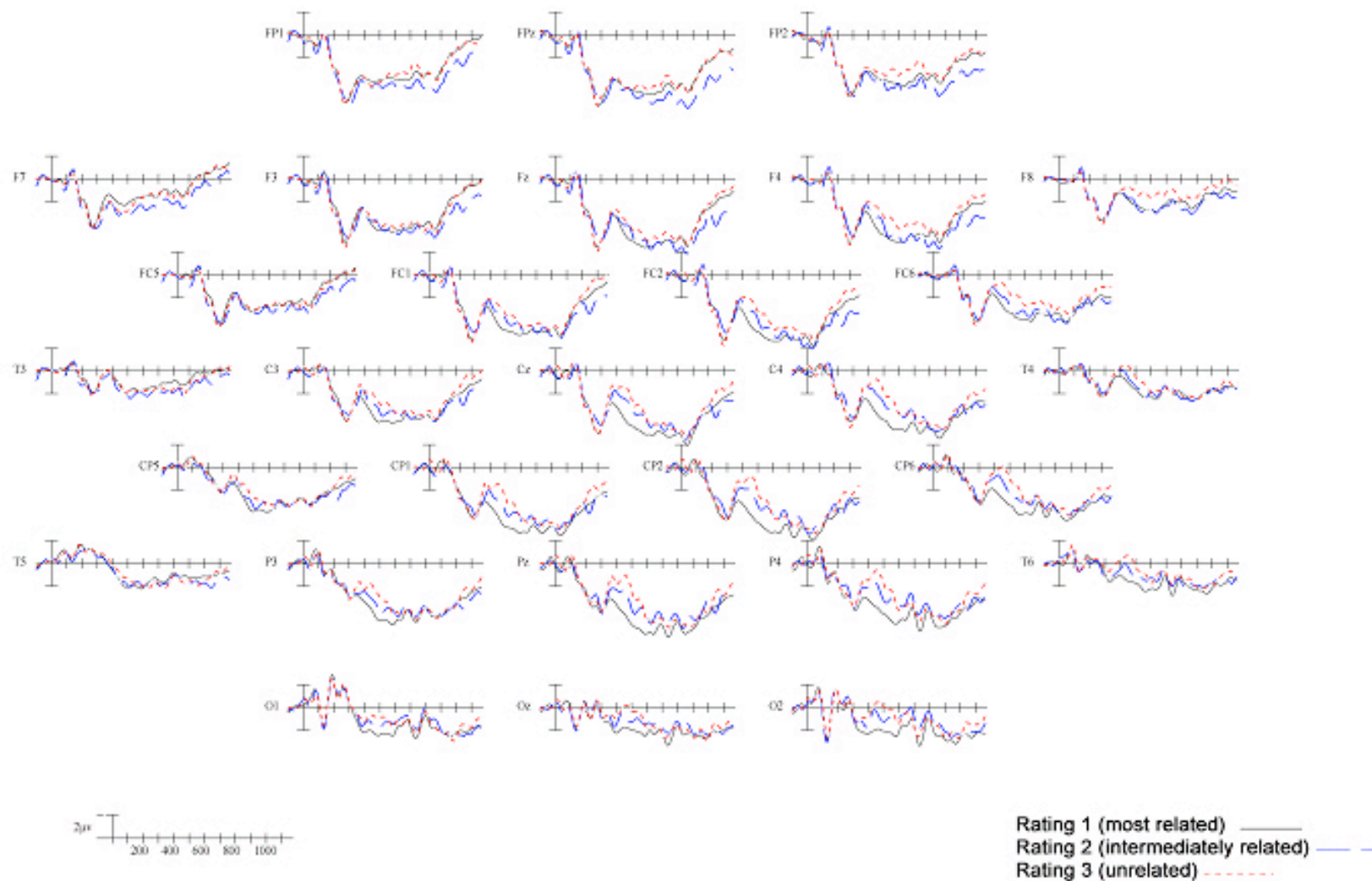


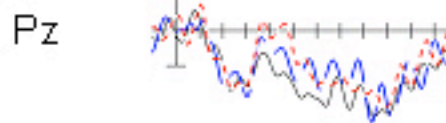
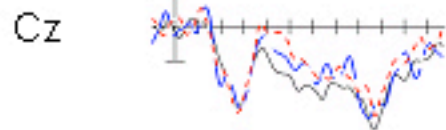
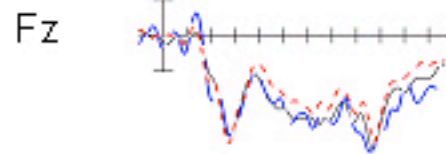
Figure B

Rating 1 (most related) vs. Rating 2 (intermediately related) vs. Rating 3 (unrelated)

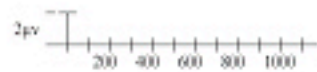
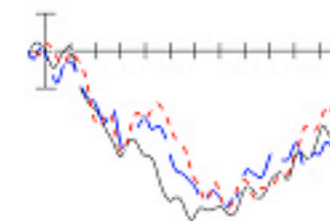
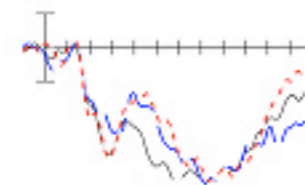
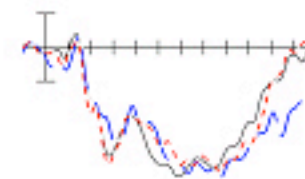


Rating 1 vs. Rating 2 vs. Rating 3: Effect of position of critical word

Sentence-mid



Sentence-final



Rating 1 (most related) ———
Rating 2 (intermediately related) - - -
Rating 3 (unrelated)

Figure C

Rating 1 to Contextually congruent vs. Rating 2 to Inference vs. Rating 3 to Unrelated

