Alpha power decreases during center embedding in natural stimuli

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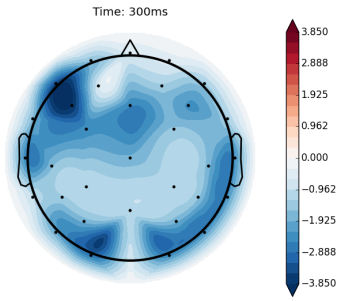
Understanding the role of memory in sentence processing requires clear measures of memory usage. Unfortunately, evaluation of memory effects using reading times is hindered by known frequency confounds. However, decreased EEG oscillations in the alpha band (8–12Hz) have been correlated with attentional focus and memory load [3], and alpha activity has been shown to be relatively uncorrelated with frequency effects [6]. This study uses naturally-occurring narrative sentences to investigate whether decreased power in the alpha band is a reliable indicator of increased linguistic memory load.

Syntactic center-embeddings have long been assumed to create resource demands on linguistic memory [1]. For example, in (1), *both* generates an expectation for *and*, which must be retained until *and* in order to process the conjunction. In (2), *either* generates an expectation of *or*, which must be retained concurrently with the inner expectation of *and*, increasing memory load during the embedded region.

(1) Somehow both $[_1$the filter is dirty$]$ and the flow decreases ...

(2) Either $[_1$both $[_2$the filter is dirty$]$ and the flow decreases $]$ or ...



10 Hz depth 2 - depth 1 (t-vals)

The present study evaluates the effect of this kind of memory usage with a corpus of amateur novels [2], consisting of 32-channel EEG data recorded from 24 subjects as they read 204 narrative sentences using rapid serial visual presentation (RSVP). This use of natural stimuli mitigates the potential for experimentally-constructed stimuli to induce a confound due to unnatural difficulty (lessened ecological validity) compared to naturally-occurring center embeddings. That is, subjects are expected to be less likely to process natural stimuli with non-linguistic heuristics or mechanisms.

The sentences from this corpus were automatically parsed and annotated with embedding depths using a left-corner parser [5], and all words were grouped by their corresponding embedding depth. Time-frequency data were extracted from the EEG signals using a Morlet wavelet transform with a resolution of 1 Hz, and the power at 10Hz was averaged over all words in each embedding condition. Singly-embedded alpha power was subtracted from doubly-embedded alpha power and permuted 1000 times with spatio-temporal threshold-free clustering [4] with $p < 0.01$. Alpha power was significantly lower throughout the duration of each deeper word, and seemed especially affected in the left anterior region (figure shows effect 300 ms post onset).

Results Since alpha power reliably decreases as linguistic memory load increases, alpha power may provide a clean measure of linguistic memory load for future psycholinguistic studies.

References

[1] Noam Chomsky and George A. Miller. Introduction to the formal analysis of natural languages. In *Handbook of Mathematical Psychology*, pages 269–321. Wiley, New York, NY, 1963.

[2] Stefan L. Frank, Leun J. Otten, Giulia Galli, and Gabriella Vigliocco. The ERP response to the amount of information conveyed by words in sentences. *Brain & Language*, 140:1–11, 2015.

[3] Ole Jensen, Mathilde Bonnefond, and Rufin VanRullen. An oscillatory mechanism for prioritizing salient unattended stimuli. *Trends in Cognitive Science*, 16(4):200–206, 2012.

[4] Stephen M. Smith and Thomas E. Nichols. Threshold-free cluster enhancement: Addressing problems of smoothing, threshold dependence and localisation in cluster inference. *NeuroImage*, 44:83–98, 2009.

[5] Marten van Schijndel, Andy Exley, and William Schuler. A model of language processing as hierarchic sequential prediction. *Topics in Cognitive Science*, 5(3):522–540, 2013.

[6] Marten van Schijndel, Brian Murphy, and William Schuler. Evidence of syntactic working memory usage in MEG data. In *Proceedings of CMCL 2015*. Association for Computational Linguistics, 2015.