Alpha power decreases during center embedding in natural stimuli

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Introduction

EEG oscillations in the alpha band (8–12Hz) are correlated with attentional focus and memory load [3] and uncorrelated with frequency effects [8]. This study shows that decreased alpha-band power is correlated with increased linguistic memory load in naturally-occurring sentences.

EEG oscillatory power

$$P_{f_{s,i}(T)} = \frac{1}{T}\int_{t\in T} |f_{s,i}(t)|^2 \, \mathrm{d}t \qquad (1)$$

The amount of energy contained in a signal, S, in a given time period, T, at frequency f_i.

Alpha power

Alpha brainwaves (8-12 Hz) inhibit other neural signals [4].

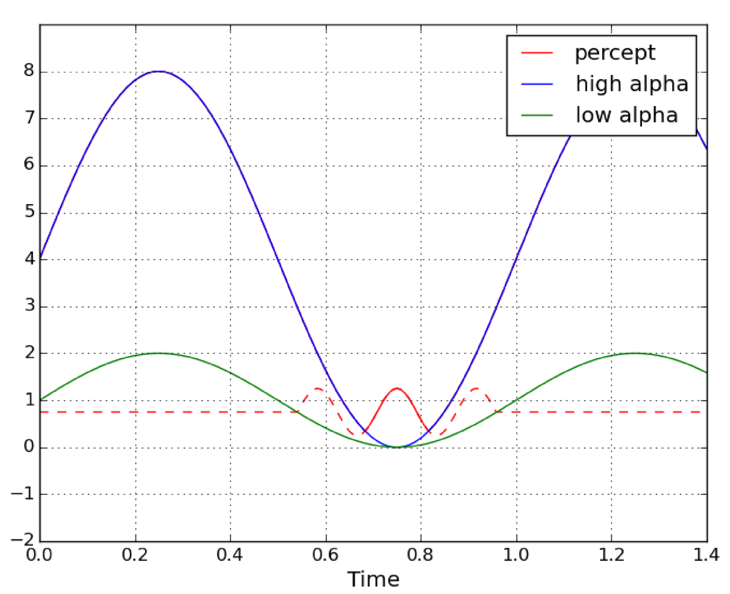

Figure 1 : Schematic of alpha inhibition. Green and blue lines are possible alpha wave states, red is a gamma-band percept signal that has more opportunity to fire (dashed) when alpha has lower power.

The more power expended on alpha waves, the less other signals can fire. Thus, we expect alpha power should decrease with more memory load since the brain will need to keep more signals activated in linguistic working memory.

Previous work found that alpha is uncorrelated with typical linguistic confounds but may correlate with linguistic memory load [8].

Factor	p-value
Unigram	0.6480
Bigram	0.7762
Trigram†	0.3817
PCFG Surprisal	0.3295
Sentence Position	0.4628
Embedding Depth†	0.0046

Table 1 : Previous findings: significance of predictor fit to alpha wave coherence. †Included from final evaluation in [8].

But these previous findings relied on a complex measure of MEG (not EEG) and on fewer subjects.

Measuring memory load

(1) Somehow both [the filter is dirty] and the flow decreases … (load = 1)

(2) Either [both [the filter is dirty] and the flow decreases] or … (load = 2; load = 1)

During sentence processing, words generate expectations which must be maintained in order to correctly comprehend the sentence. For example, 'either' generates an expectation of 'or', which helps a reader correctly bind the conjunct at the appropriate level in the sentence. When these expectations are nested, greater memory load is required to maintain multiple simultaneous expectations.

Experiment

Data

Publicly available corpus of EEG data from reading randomized narrative sentences [2]
- 24 subjects
- 32-channel EEG
- 204 English sentences from amateur novels
- RSVP (SOA: $190 + 20 \cdot nchar + 390$ ms)
- 50% followed by comprehension questions

Preprocessing
- Resample at 100 Hz
- Band-pass filter 0.05 Hz – 25 Hz
- Re-reference to average mastoid signal
- Use WICA [1] to remove eye artifacts from EEG
- Parse sentences with left-corner parser [7] to find embedding depths (i.e. memory load)

Significance testing

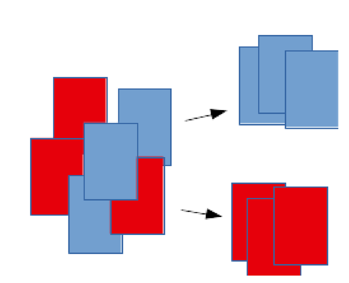

Figure 2 : Group data by condition

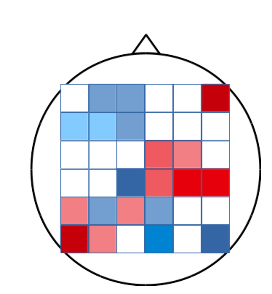

Figure 3 : Differences between conditions (t-test)

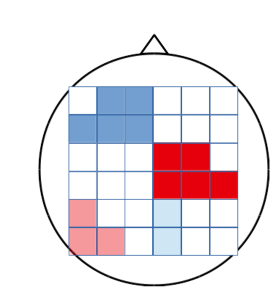

Figure 4 : TFCE to cluster differences

Words are grouped by condition and the difference is tested. This process is repeated for 1000 permutations. Threshold-Free Cluster Enhancement (TFCE, [6]) helps localize effects in time and space while correcting for multiple comparisons. Optimal TFCE parameterization recommendations ($E = 1$, $H = 2/3$) are adopted from [5]. Overall $p < 0.01$.

Results (10 Hz)

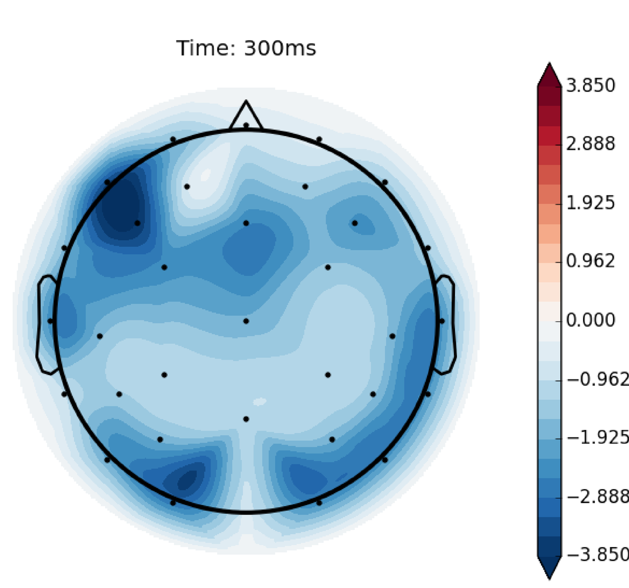

Figure 5 : Power (depth 2 - depth 1; 300 ms)

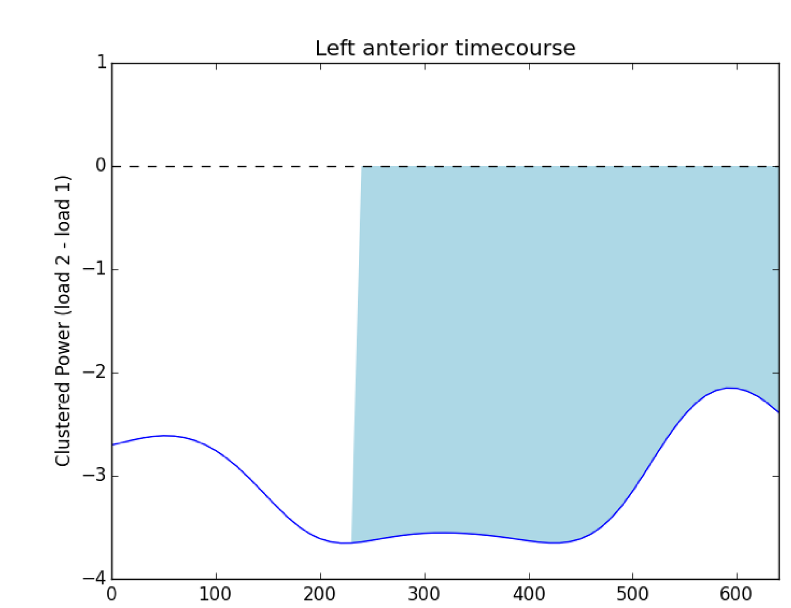

Figure 6 : Timecourse of left anterior (sensor M10-49)

Alpha power is significantly lower when memory load is higher. The effect seems strongest in the left anterior of the brain. Figure 6 plots power difference over time at the dark spot in the left anterior in Figure 5. The shaded region is significant.

Conclusion

Alpha power decreases in EEG as memory load increases, which suggests that alpha power may provide a relatively clean measure of linguistic memory load for future psycholinguistic experiments.

Follow-Up Studies: Non-narrative text

We've started two simultaneous follow-up studies in German and English using experimentally-constructed stimuli with Vera Demberg and Per Sederberg, respectively. Although the correlation between alpha power and memory load has not yet been observed in the follow-up data, one reason might be that the follow-up studies have half the number of subjects as the present study. Another possible reason might be that the constructed follow-up stimuli only test a single construction type and this correlation may not show up during processing of that construction. We will explore these possibilities in the future.

References

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