Cortical Processing of Arithmetic and Simple Sentences in an Auditory Attention Task

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Introduction
Cortical Processing of Arithmetic and Language
- May rely on both shared and task specific mechanisms (Analth & Dehaene 2016, 2019).
- Language processing predominately activites left temporal areas (Mesulam 2007).
- Arithmetic processing activites bilateral parietal areas, as well as occipital, temporal and frontal areas (Dehaene et al. 2003).

Isolocular Stimulus Paradigm
- Pioneered by Ding et al., 2019.
- 4 word spoken sentences presented at fixed rhythmic word and sentence rates.
- Neural activity tracks the word rate, which is also the dominant acoustic rate.
- Neural activity also tracks the sentence rate, which is not present in the acoustics.
- Hierarchical tracking of sentence structures

Methods
MEG data was collected from 22 young subjects listening to two simultaneous speakers, dictionly presented. The speakers were of opposite sex and alternated between spoken sentences and equations.

Stimulus Design
- Fixed word, symbol, sentence, equation rates.
- Word, symbol, phrase, sentence presents in stimulus spectrum (1d sentence, equation phrase not present).
- Example sentence: "kids like sweet food".
- Example equation: "three plus five is eight".
- Subjects were asked to attend to one speaker and detect deviates (incorrect equations or meaningless sentences).

Frequency Domain Analysis
- Analyzed MEG responses at the frequencies of interest after subtracting a baseline of neighboring 5 frequency bands on either side.
- MEG frequency response peaks were source localized using minimum norm estimation (Gramfort et al., 2014).

Temporal Response Functions (TRFs)
Investigated response functions; selecting source localized TRFs estimated with boosting (David et al., 2007) using Edbrain (Brindiak et al., 2020)
- Least squares estimation of envelopes, word, symbol, sentence & equation TRFs to regress out auditory responses.

Linear Decoders at each voxel trained on dynamics of MEG responses to detect if subject attended to equations or sentences

Selective Attention: Cocktail party paradigm
- Attention to one of two simultaneous speakers
- Attention modulates linguistic responses.
- Sentence tracking of isochronous speech occurs primarily only for attended speech (acoustic tracking occurs regardless of attention) (Ding et al., 2018).

We use an isochronous Speech Cocktail Party Paradigm with fixed word, symbol, sentence and equation rates.

Results
Frequency Analysis
- Attention modulates frequency responses
- Frequency tracking of isochronous speech occurs primarily only for attended speech (acoustic tracking occurs regardless of attention) (Ding et al., 2018).

We use an isochronous Speech Cocktail Party Paradigm with fixed word, symbol, sentence and equation rates.

Research questions
- Does isochronous speech affect the in sinar of language processing in the frequency domain?
- Does equation and sentence level processing show shared or distinct cortical networks?
- Can the cocktail party paradigm further differentiate between these networks?

Cortical response patterns
- Word/symbol: bilateral auditory areas
- Sentences: left temporal areas (consistent with language processing)
- Equations: bilateral parietal areas (consistent with arithmetic processing)
- Spatial patterns (may indicate language processing, arithmetic fact retrieval)
- Occlusal areas (may indicate visualization)

Unique cortical networks are involved in sentence and equation processing.

Behavioral Correlations
- Neural responses are correlated with behavioral accuracy in relevant detection task.
- Sentence and equation rate responses only correlated when attended.
- Spatial patterns of significant correlations are consistent with language and arithmetic processing for each task.

Indicates that neural responses may be linked to comprehension or calculations

Spatialtemporal Dynamics of Cortical Processing
- TRFs reveal distinct spatiotemporal patterns of arithmetic and sentence processing.

Decoding Attention from Neural Response Dynamics
- Linear Decoders trained on the response dynamics at each source voxel.
- Decoding of attention condition (sentences or equations) significantly above chance.
- Highest decoding accuracy in superior parietal areas consistent with arithmetic processing.

Decoding attention from cortical responses reveals distinct areas with equation vs sentence responses.

Discussion & Conclusions
- Auditory responses occur regardless of attention, while sentence and equation responses occur only when attended.
- Sentence and equation processing involves cortical networks that are both shared (left temporal) and distinct (bilateral parietal and occlusal areas for equations).
- Dynamics of language and equation processing involve distinct spatiotemporal patterns.
- Superior parietal areas are most important for decoding attention to sentences vs equations.
- Cortical networks involved in arithmetic and language processing naturally segregate during selective attention.
- Attentional sentence and equation responses are correlated with behavior, and may be linked to comprehension or calculations.

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References

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