The neural basis of arithmetic may be dissociated from that of language.

What are the cortical areas and dynamics involved in neural processing of spoken arithmetic and language?

How does selective attention impact these processes?

We investigate MEG responses to spoken arithmetic and language in a cocktail party paradigm.
Methods

22 subjects (avg. 22.6 yrs) native English speakers.

Stimuli:
- Synthesized 4 word sentences and 5 symbol equations.
- Male and female speakers.
- Lang: Word 2.67 Hz, Sentence 0.67 Hz,
- Math: Symbol 2.78 Hz, Equation 0.56 Hz

Experiment:
- Diotic presentation of mixed speech.
- 6 mins single speaker
- 7.2 mins cocktail party

Preprocessing: TSPCA, SNS, 0.3-40 Hz, ICA

Source localization: MNE using a volume source space with 12 mm voxel spacing

Temporal Response Functions (TRFs): Using the Boosting algorithm

Decoders: Logistic Regression with 5-fold cv.

Statistical tests: Permutation tests with TFCE

Stimulus Structure

Mix spectrum has both acoustic rates, but not sentence or equation rates.

Spectrum
Neural Tracking of Sentences and Equations

Tracking of Acoustic Rates
- Word (2.67 Hz) and symbol (2.78 Hz) rates
- For both attended and unattended speech
- Bilateral auditory areas

Tracking of Sentence Rate (0.67 Hz)
- Only for attended speech
- Left temporal areas linked to language
- Significantly left lateralized

Tracking of Equation Rate (0.56 Hz)
- Only for attended speech
- Parietal and occipital areas linked to arithmetic
- Overlaps with language areas
- Significantly different to sentence tracking

Background sentence and equation rate responses
Behavior Correlates with Neural Tracking

Behavior: outlier detection task
- Mathematically incorrect equations (‘one plus one is ten’)
- Semantically meaningless sentences (‘big boats eat cake’)

Correlation with cortical distribution of response frequency power
- Only attended sentence and equation rates are correlated
- Single speaker equation tracking is not correlated, perhaps due to several subjects performing at ceiling

Neural tracking may reflect comprehension
Dynamics of Cortical Processing: Temporal Response Functions (TRFs)

Temporal Response Functions (TRFs):
- Models the impulse response of the neural system to continuous stimuli
- TRFs fit using Boosting for:
  - speech envelopes
  - word and symbol onsets
  - sentence and equation onsets
- Minimal effect of auditory responses on sentence and equation TRFs

Spatiotemporal Patterns
- Differences in math and language processing around 1000-1600 ms
- Attentional modulation during math in parietal areas

Attentional modulation of TRFs highlights arithmetic and linguistic processing regions.
Decoding Arithmetic and Linguistic Processing from MEG Responses

**Linear Decoders**
- Decoders at each time point using sensor topography (left-top panel)
- Decoders at each voxel using dynamics at that voxel (other panels)

**Math vs. Language**
- Can be decoded from both sensor topographies and dynamics
- Discriminability best in IPS and superior parietal areas

**Decoding Attention**
- During math: Parietal
- During language: left temporal and bilateral superior parietal
Conclusions

Neural tracking of equations and sentences only for attended speech

Acoustic rates are tracked regardless of attention

Tracking of equations in both arithmetic and linguistic areas
- Sentences: left temporal areas
- Equations: parietal, occipital and temporal areas

Behavioral performance correlates with neural tracking
- For sentence and equation tracking only when attended
- May reflect comprehension

Dynamics of cortical processing revealed by TRFs
- Selective attention highlights differences between arithmetic and linguistic processing
- Further work needed to investigate these dynamics

Decoding math vs. language from neural responses
IPS/superior parietal areas are most discriminative

Decoding attentional state from neural responses
- During language: left temporal and bilateral superior parietal areas
- During math: bilateral parietal areas
Thank You

References


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