Cortical Processing of Arithmetic and Simple Sentences, in an Auditory Attention Task, Linked to Behavior

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preprint available \url{https://doi.org/10.1101/2021.01.31.429030}
The Neural Basis of Arithmetic and Language Processing

Numerical processing bilateral parietal areas

Adapted from Dehaene et. al. 2003
The Neural Basis of Arithmetic and Language Processing

Numerical processing
bilateral parietal areas

Language processing
left temporal areas

Adapted from Hickock & Poeppel (2010)

Adapted from Dehaene et. al. 2003
Motivation

Processing of arithmetic and language during cocktail party
Motivation

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- Cortical areas involved?
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- Cortical areas involved?
- Dynamics of cortical processing?
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- Impact of selective attention?
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Recorded MEG from 22 subjects (avg. 22.6 years)
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Methods: Isochronous Speech Paradigm

Adapted from Ding et al., Nature Neuroscience (2016)
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How about responses to equations?
Methods: Isochronous Speech Paradigm

How about responses to equations?
Difference between sentence and equation tracking?

Adapted from Ding et al., Nature Neuroscience (2016)
Methods: Stimuli

- Synthesized male and female speakers
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- Language stimuli:
  - 4 word sentences
Methods: Stimuli

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  - Word rate 2.67 Hz
  - Sentence rate 0.67 Hz
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- Arithmetic stimuli:
  - 5 symbol equations
Methods: Stimuli

- Synthesized male and female speakers

- Language stimuli:
  - 4 word sentences
  - Word rate 2.67 Hz
  - Sentence rate 0.67 Hz

- Arithmetic stimuli:
  - 5 symbol equations
  - Symbol rate 2.78 Hz
  - Equation rate 0.56 Hz
Methods: Stimuli

- Synthesized male and female speakers
- Language stimuli:
  - 4 word sentences
  - Word rate 2.67 Hz
  - Sentence rate 0.67 Hz

- Arithmetic stimuli:
  - 5 symbol equations
  - Symbol rate 2.78 Hz
  - Equation rate 0.56 Hz

Cortical Processing of Arithmetic and Simple Sentences, in an Auditory Attention Task, Linked to Behavior
Results: Cortical Tracking of Sentences and Equations

Tracking of Acoustic Rates
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Tracking of Acoustic Rates

- Word (2.67 Hz) and symbol (2.78 Hz) rates
- For both attended and unattended speech
Results: Cortical Tracking of Sentences and Equations

Tracking of Acoustic Rates

- Word (2.67 Hz) and symbol (2.78 Hz) rates
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Results: Cortical 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 cortex
Results: Cortical Tracking of Sentences and Equations

**Tracking of Sentence Rate (0.67 Hz)**

**Tracking of Equation Rate (0.56 Hz)**
Results: Cortical Tracking of Sentences and Equations

**Tracking of Sentence Rate (0.67 Hz)**
- Only for attended speech

**Tracking of Equation Rate (0.56 Hz)**
- Only for attended speech
Results: Cortical Tracking of Sentences and Equations

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
Results: Cortical Tracking of Sentences and Equations

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
Results: Behavior Correlates with Neural Tracking

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

Behavioral Accuracy vs. Cortical Tracking
Results: Behavior Correlates with Neural Tracking

Only attended sentence and equation rates are correlated

Neural tracking may reflect improved comprehension or correct calculations
Results: Behavior Correlates with Neural Tracking

Only attended sentence and equation rates are correlated

Neural tracking may reflect improved comprehension or correct calculations
Results: TRF Analysis

Dynamics of Arithmetic and Language Processing

Temporal Response Functions (TRFs)

Adapted from Brodbeck and Simon (2020)
Results: TRF Analysis

Joint TRF with many predictors. Regress out low-level auditory processing.

- foreground

- sentence

- word

- word

- word

- word

- word

- word

- word

- word

- word

- stimulus

- envelope
Results: TRF Analysis

Joint TRF with many predictors. Regress out low-level auditory processing

forefront

sentence sentence

word word word word word word word word word

stimulus

envelope

word onset

sent. onset
Results: TRF Analysis

Joint TRF with many predictors. Regress out low-level auditory processing.
Results: TRF Analysis

Joint TRF with many predictors. Regress out low-level auditory processing

foreground

sentence

word

word

word

word

word

word

word

word

stimulus

envelope

word

onset

sentence

onset

equation

onset

background

equation

sym.

onset

sym.

sym.

sym.

sym.

sym.

sym.

sym.

sym.
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Results: TRF Analysis

Sentence TRFs

- Mostly left hemisphere
- Temporal areas
Results: TRF Analysis

**Sentence TRFs**
- Mostly left hemisphere
- Temporal areas

**Equation TRFs**
- More bilateral
- Temporal, motor, and parietal areas
Cortical Processing of Arithmetic and Simple Sentences, in an Auditory Attention Task, Linked to Behavior

Results: TRF Analysis

Sentence TRFs
• Mostly left hemisphere
• Temporal areas

Equation TRFs
• More bilateral
• Temporal, motor and parietal areas

Selective attention highlights differences in dynamics
Results: Decoder Analysis

Decoding based on the MEG sensor topography at each time point.
Results: Decoder Analysis

Decoding based on the dynamics at each cortical voxel

Math vs. Language

Attend **math** last symbol responses vs. Attend **language** last word responses
Results: Decoder Analysis

Decoding based on the dynamics at each cortical voxel

foreground vs. background sentence responses

foreground vs. background equation responses
Conclusions

- Equation & Sentence tracking only for foreground
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- Differences in localization
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- Correlated with behavior
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- TRFs reveal differences in dynamics
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- Reliable decoding of attentional state
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- TRFs reveal differences in dynamics
- Reliable decoding of attentional state

Selective attention highlights these distinct processes
Cortical tracking may be related to improved comprehension or calculations

Preprint available on biorxiv

https://doi.org/10.1101/2021.01.31.429030
Acknowledgements

This work was funded by DARPA (N660011824024), NSF (SMA-1734892 and DGE-1449815), and NIH (R01-DC014085)

Advisor
• Jonathan Z. Simon

Co-authors
• Neha H. Joshi
• Mohsen Rezaeizadeh

CSSL lab
• Lien Decruy
• Dushyanthi Karunathilake
• Christian Brodbeck (alumnus)
• Alessandro Presacco (alumnus)
• Peng Zan (alumnus)

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https://doi.org/10.1101/2021.01.31.429030