EVIDENCE OF SYNTACTIC WORKING MEMORY USAGE IN MEG DATA

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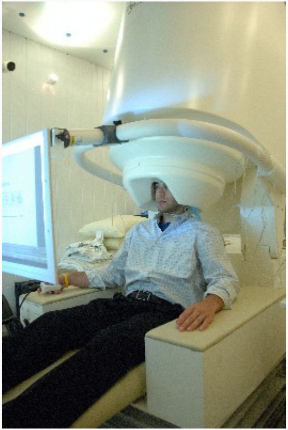
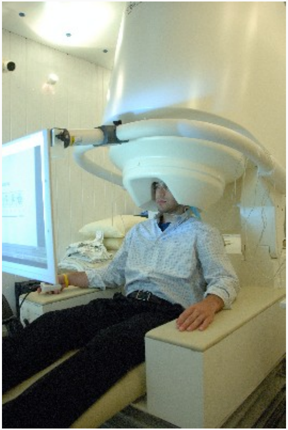
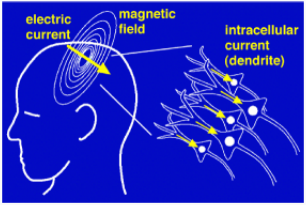
Reading times are low dimensionality and strongly affected by frequency effects.

We find a measure of memory load unaffected by frequency effects.

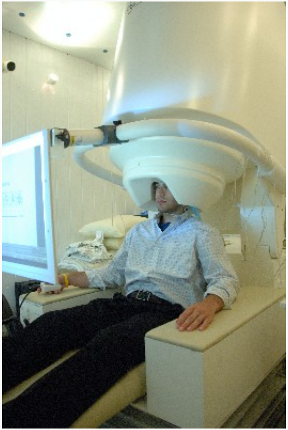
WHAT IS MEG?

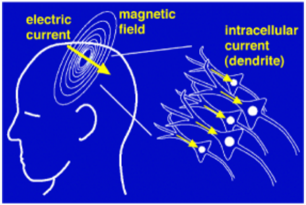





electric
current
magnetic
field
intracellular
current
(dendrite)

WHAT IS MEG?





102 locations

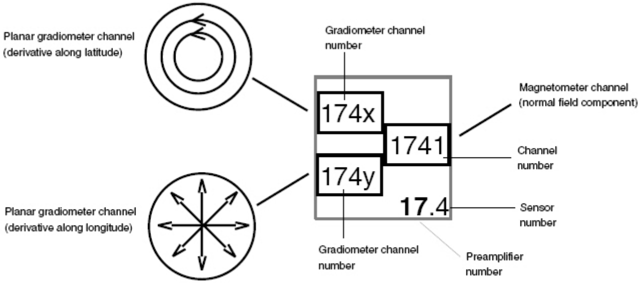
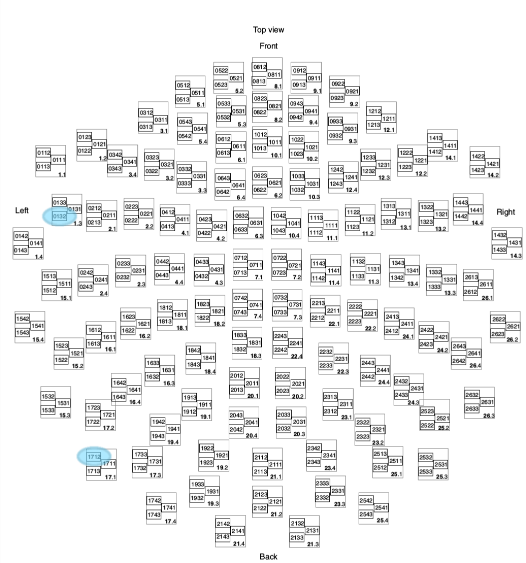
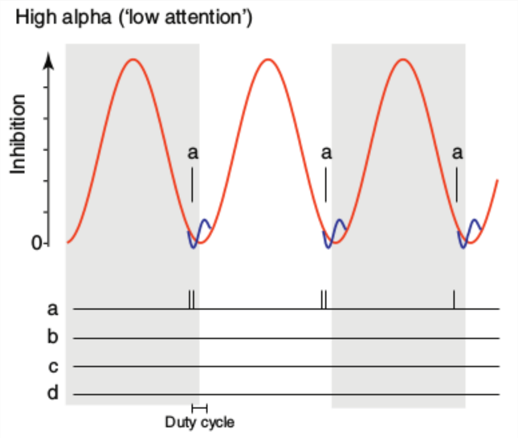


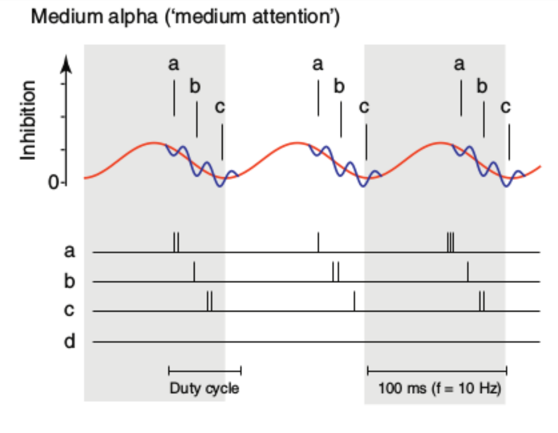
Figure 1.8.b. Naming convention. Depending on location, x=2 and y=3 or vice versa, refer to Fig. 1.8.a.

3 sensors per location


Top view
Front
Left
Right
Back



Jensen et al., (2012)



Jensen et al., (2012)

SENSOR CONNECTIVITY

Connectivity is neural communication

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This study measures connectivity with *spectral coherence*.

$$\text{coherence}(x, y) = \frac{\mathrm{E}[S_{xy}]}{\sqrt{\mathrm{E}[S_{xx}] \cdot \mathrm{E}[S_{yy}]}}$$

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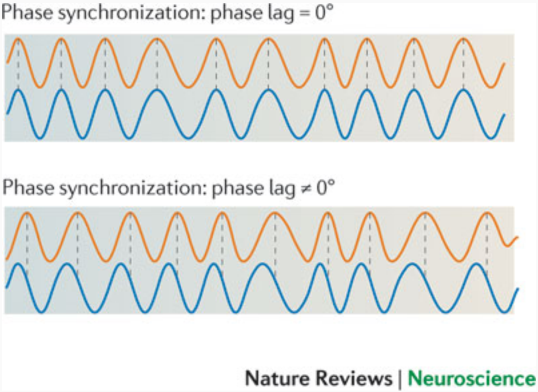
SPECTRAL COHERENCE

$$\text{coherence}(x, y) = \frac{\mathrm{E}[S_{xy}]}{\sqrt{\mathrm{E}[S_{xx}] \cdot \mathrm{E}[S_{yy}]}} \begin{array}{l} \leftarrow \text{cross-correlation} \\ \leftarrow \text{autocorrelations} \end{array}$$

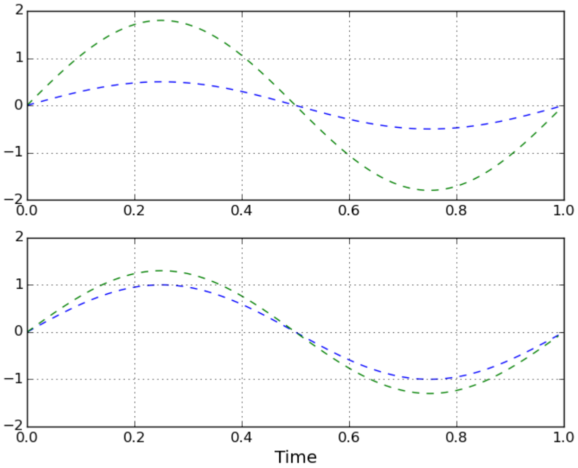
Amount of connectivity not caused by chance

SPECTRAL COHERENCE: PHASE SYNCHRONY



Fell & Axmacher (2011)

SPECTRAL COHERENCE: POWER SIMILARITY



Collected 2 years ago at CMU

AUDIOBOOK MEG CORPUS

Collected 2 years ago at CMU

3 subjects

Collected 2 years ago at CMU

3 subjects

Heart of Darkness, ch. 2

12,342 words

80 (8 x 10) minutes

Synched with parallel audio recording and forced alignment

Collected 2 years ago at CMU

3 subjects

Heart of Darkness, ch. 2
12,342 words
80 (8 x 10) minutes
Synched with parallel audio recording
and forced alignment

306-channel Elekta Neuromag, CMU
Movement/noise correction: SSP, SSS, tSSS
Band-pass filtered 0.01–50 Hz
Downsampled to 125 Hz
Visually scanned for muscle artifacts; none found

*d*1 The cart broke.

*d*2 that the man bought

*d*1 The cart broke.
*d*2 that the man bought

Depth annotations:
van Schijndel et al., (2013) parser
Nguyen et al., (2012) Generalized Categorial Grammar (GCG)

Remove words:

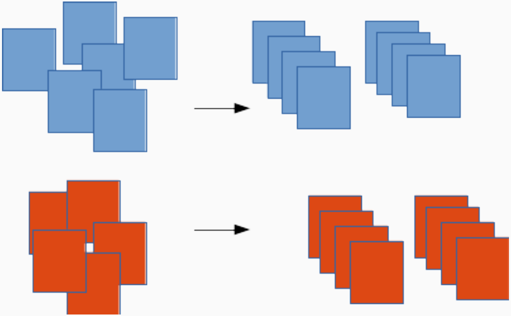
- in short or long sentences ($<$4 or $>$50 words)
- that follow a word at another depth
- that fail to parse

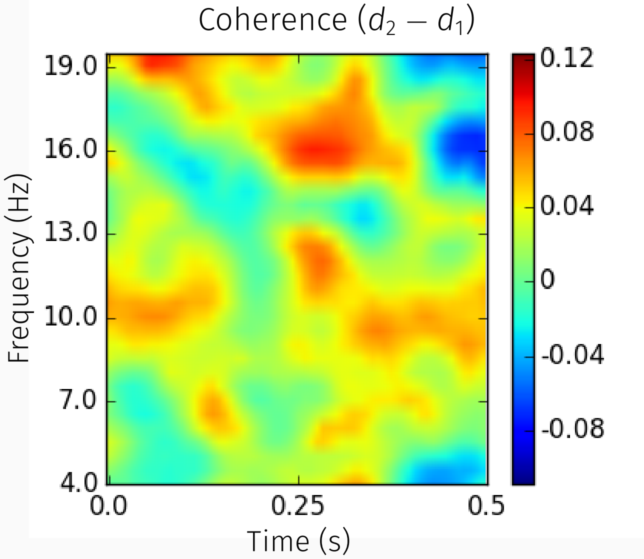
Partition data:

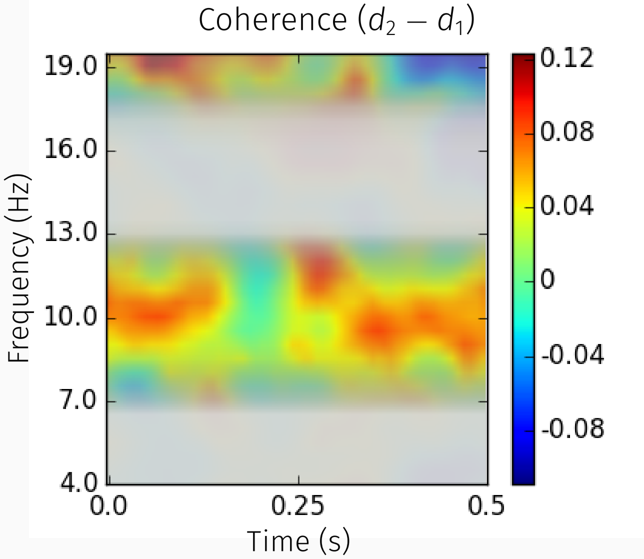
- Dev set: One third of corpus
- Test set: Two thirds of corpus

COMPUTE COHERENCE

- Group by factor
- Compute coherence over subsets of 4 epochs




Coherence ($d_2 - d_1$)
19.0
16.0
13.0
10.0
7.0
4.0
Frequency (Hz)
0.0
0.25
0.5
Time (s)
0.12
0.08
0.04
0
-0.04
-0.08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POSSIBLE CONFOUNDS?

Sentence position

Sentence position

Unigram, Bigram, Trigram: COCA logprobs

Sentence position

Unigram, Bigram, Trigram: COCA logprobs

PCFG surprisal: parser output

Factor	p-value
Unigram	0.941
Bigram	0.257
Trigram	0.073
PCFG Surprisal	0.482
Sentence Position	0.031
Depth	0.005

Depth 1 (40 items)   Depth 2 (1118 items)

TEST RESULTS

Factor	p-value
Unigram	0.6480
Bigram	0.7762
Trigram	0.0264
PCFG Surprisal	0.3295
Sentence Position	0.4628
Depth	0.00002

Depth 1 (86 items)   Depth 2 (2142 items)

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Unigram	0.6480
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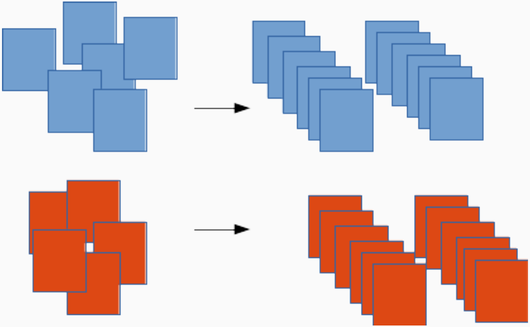
Bonferroni correction removes trigrams, but …

- Group by factor
- Compute coherence over subsets of 6 epochs



Factor	p-value
Trigram	0.3817
Depth	0.0046

Depth 1 (57 items) Depth 2 (1428 items)

- Memory load is reflected in MEG connectivity
- Common confounds do not pose a problem in MEG α connectivity

FUTURE WORK

- Can we see integration cost?
- Can we see storage cost?
- Can we see similarity interference?
- Can we see sentence processing operations?

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- The anonymous reviewers
- Roberto Zamparelli, University of Trento
- National Science Foundation (DGE-1343012)
- University of Pittsburgh Medical Center MEG Seed Fund
- National Institutes of Health CRCNS (5R01HD075328-02)

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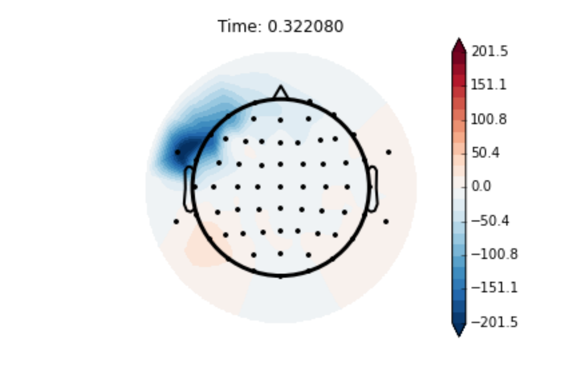
  Suggests finding due to increased synchrony
- Coherence decreases between d_2 and d_3
- Likely due to observed power decrease in left anterior

EEG $d_3 - d_2$ (6 subjects)



DEV RESULTS

Factor	Coef	p-value
Unigram	$5.1 \cdot 10^{-5}$	0.941
Bigram	$5.6 \cdot 10^{-4}$	0.257
Trigram	$4.3 \cdot 10^{-4}$	0.073
PCFG Surprisal	$2.8 \cdot 10^{-4}$	0.482
Sentence Position	$-5.1 \cdot 10^{-4}$	0.031
Depth	$3.6 \cdot 10^{-2}$	0.005

Depth 1 (40 items) Depth 2 (1118 items)

Factor	Coef	p-value
Unigram	$-2.2 \cdot 10^{-4}$	0.6480
Bigram	$-9.8 \cdot 10^{-5}$	0.7762
Trigram	$3.7 \cdot 10^{-4}$	0.0264
PCFG Surprisal	$2.9 \cdot 10^{-4}$	0.3295
Sentence Position	$1.3 \cdot 10^{-4}$	0.4628
Depth	$4.6 \cdot 10^{-2}$	0.00002

Depth 1 (86 items)   Depth 2 (2142 items)

Factor	Coef	p-value
Trigram	$1.6 \cdot 10^{-4}$	0.3817
Depth	$3.2 \cdot 10^{-2}$	0.0046

Depth 1 (57 items)   Depth 2 (1428 items)