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A network analysis of phonemic perception in normals and aphasic stroke patients using Dynamic Causal Modeling

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Outline

- **Introduction: Aphasia and MMN**
- **Objectives**
- **Stimuli**
- **MEG experiment**
- **DCM analysis**
- **Summary**

Introduction

Aphasia

Aphasia is an impairment of language ability following brain damage typically as a result of stroke. This affects talking, reading, understanding and/or writing.

Wernicke's aphasia: patients tend to speak fluently, but their speech often degenerates into seemingly random, very hard to follow "streams of consciousness", which may be peppered with non-words or made up words.

Wernicke's aphasics often fails to provide good answers to questions posed to them, suggesting that they do not really understand the speech of their interviewers.

It is caused by lesions to posterior region of the left superior temporal gyrus (STG)

Mismatch Negativity (MMN)

MMN is a negative peak that occurs after an unpredictable change in the acoustic environment, e.g. when deviant sounds are embedded in a stream of repeating sounds, or standards ([Näätänen et al., 2007](#)).

Latency: 150-250 ms after change onset.

Sources: interactive fronto-temporal network including primary and secondary auditory cortex and right inferior frontal gyrus ([Alho, 1995](#); [Opitz et al., 2002](#)).

Interpretation: MMN is thought to reflect updating of an internal model of the acoustic input: register change & update

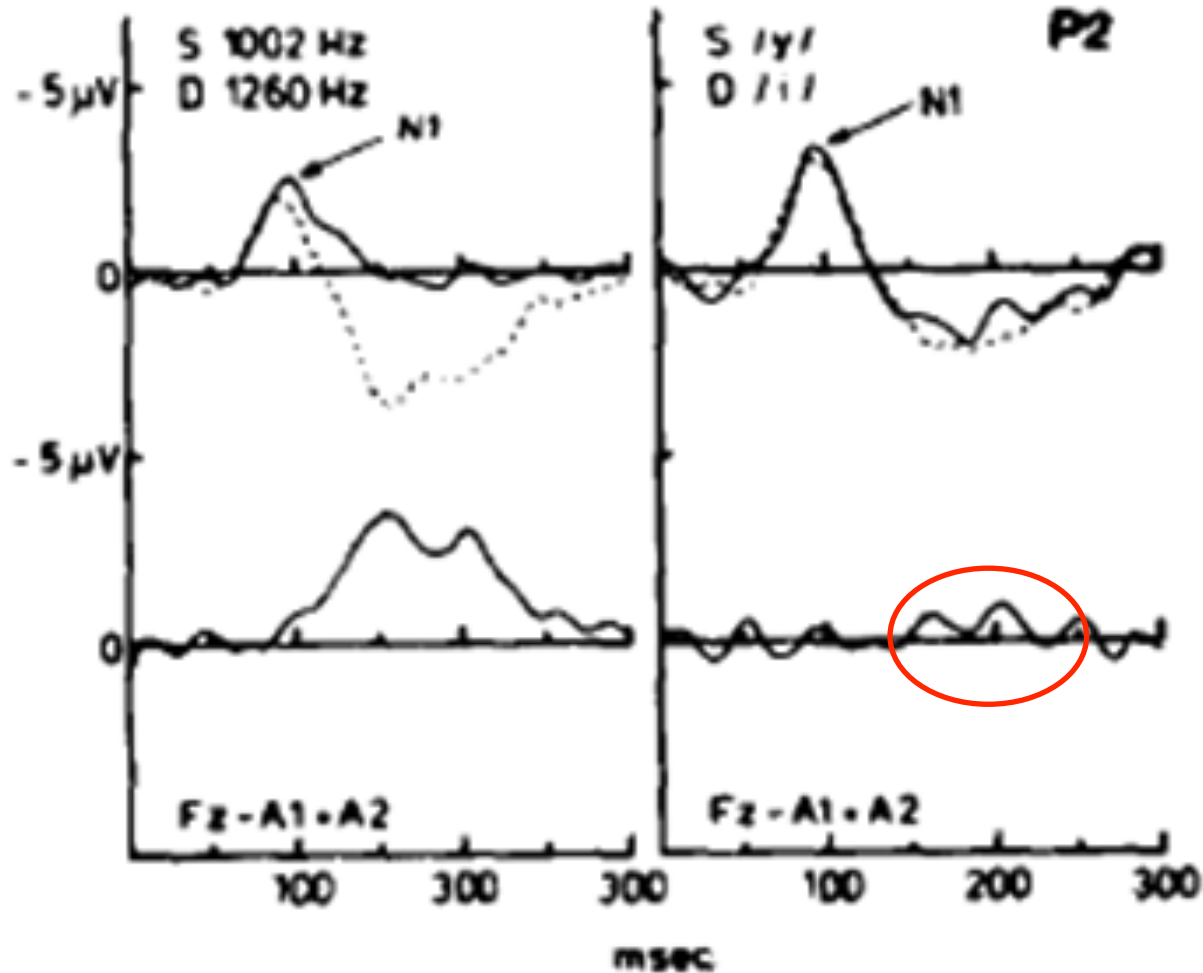
Aphasia and MMN

Pure Tones

Speech

ERPs ->

MMN ->



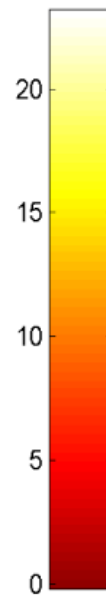
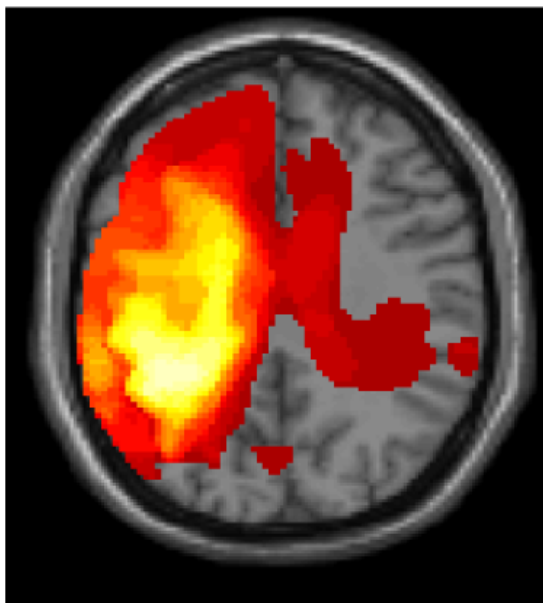
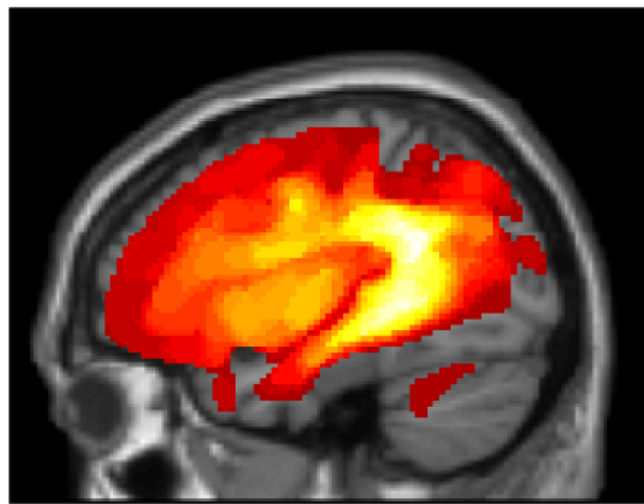
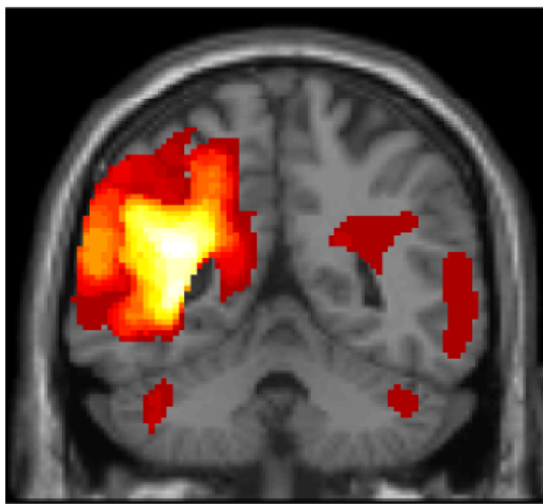
Objectives

Aims of the study

- Characterize speech perception in controls and aphasics using MEG, in source space.
- Investigate causal architecture of speech network in both groups using DCM of evoked MEG responses.
- Develop a neural index of speech recovery in terms of connection strengths of underlying connections of the speech network.

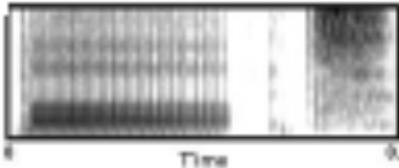




Lesion Particle Map

- 25 aphas
- 17 health



Stimuli

Stimuli

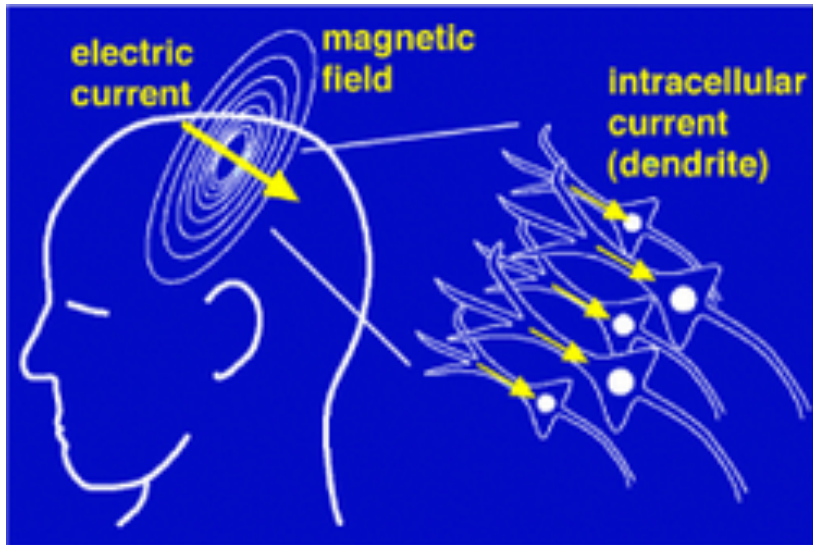
Vowel Stimulus	Percept	<div>Vowels</div> 	Formant F1 (Hz)	Frequencies F2 (Hz)	Distance from Standard (ERB)
STD	"Bart"		628	1014	0
D1	"Bart"		565	1144	1.16
D2	"Burt"		507	1287	2.32
D3	"Beat"		237	2522	9.30

Stimuli: CVC words with different frequencies of F1 and F2 formants
D1: **acoustic deviant** (within same vowel category)
D2 and D3: **phonemic deviants** (perceived as different vowel type)

MEG experiment

MEG

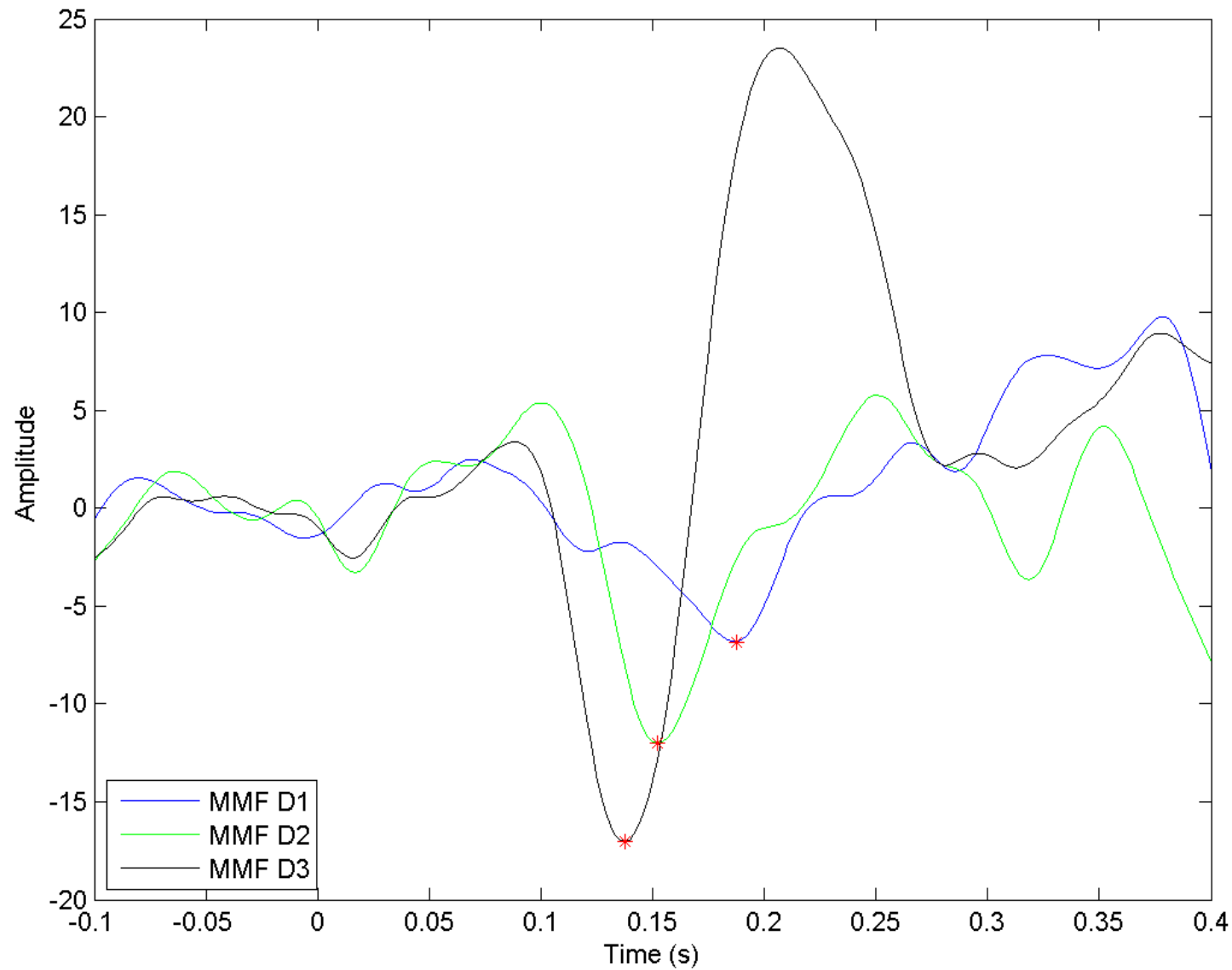
MEG measures tiny magnetic fields produced by the electrical activity of dendrites of cortical pyramidal cells during synaptic transmission.



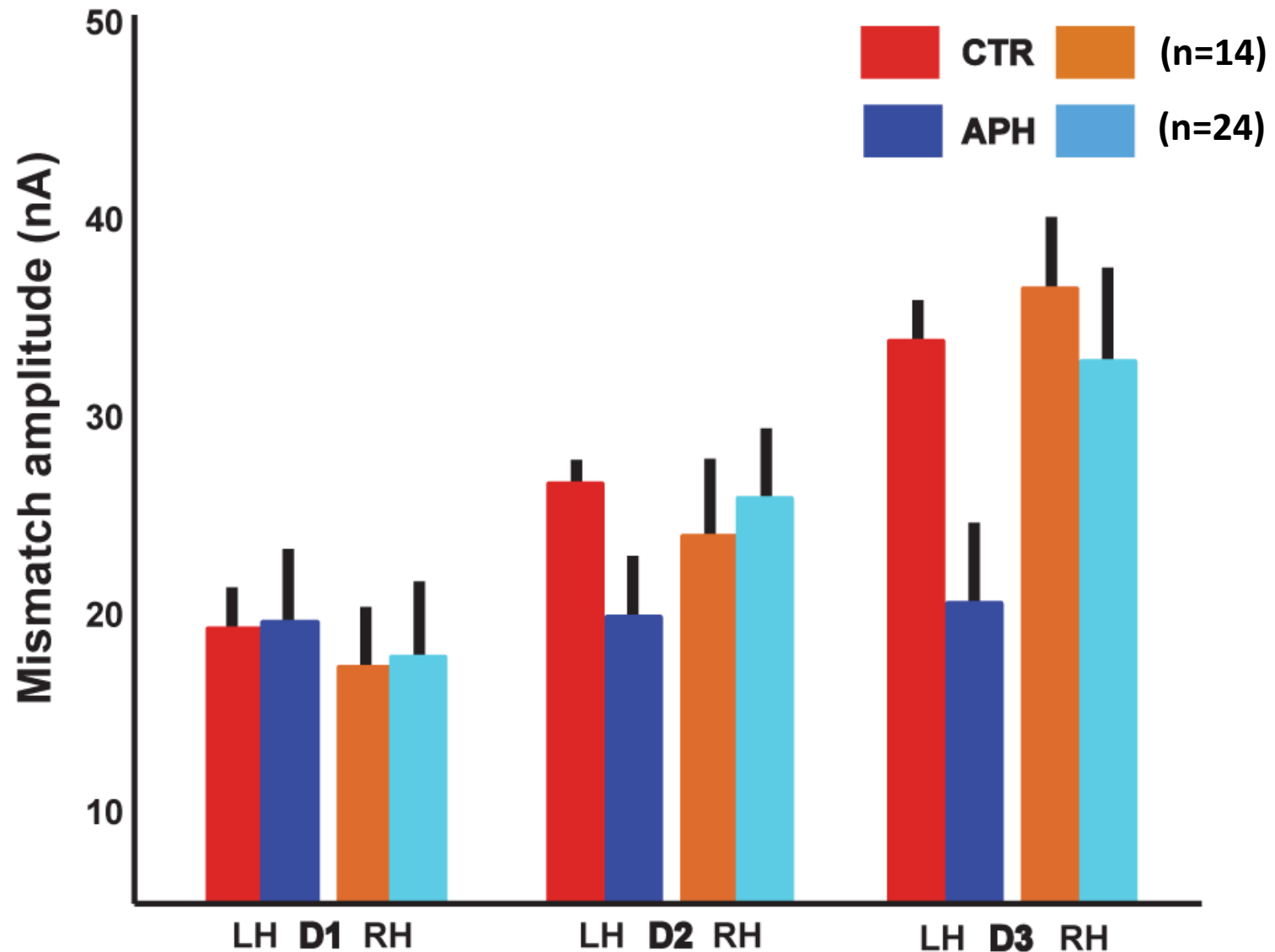
MEG Source localization

- Sources localized using **Variational-Bayes Equivalent Current Dipole** ([Kiebel et al., 2008](#)).
- It uses nonlinear optimization to test the strength of different dipole models based on pre-specified constraints on the position and moments of the dipoles.
- Evaluates the log evidence in favour of each model based on an optimization between goodness of fit and model complexity.
- Run for 100 iterations (models) for each model configuration (e.g. 2 vs. 4 dipole configurations) and the model with the maximum model evidence is chosen as the winning model.
- For aphasics, care taken that dipoles lie outside their lesions.

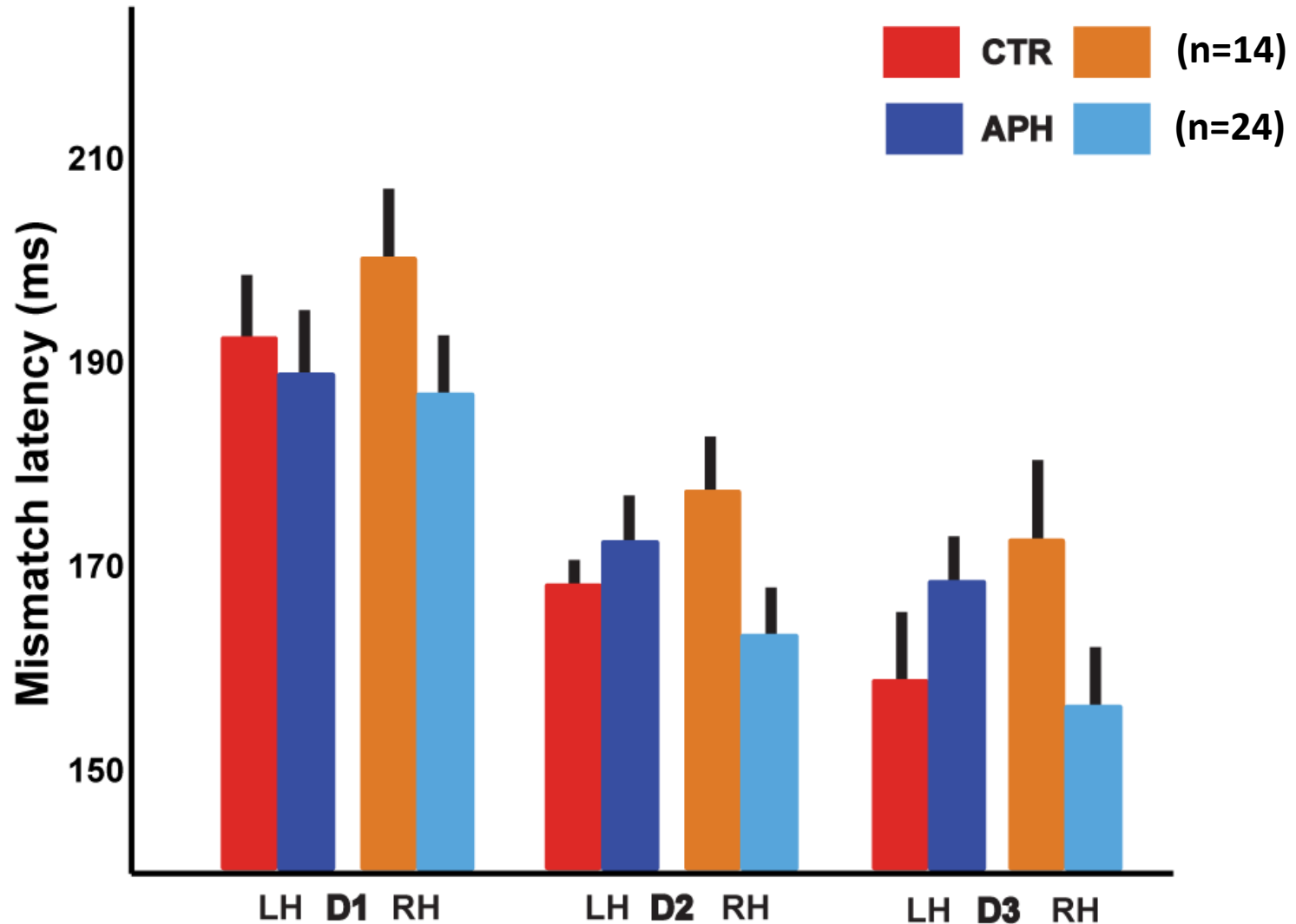
Source-space MMN responses



Source-space MMN amplitudes



Source-space MMN latency



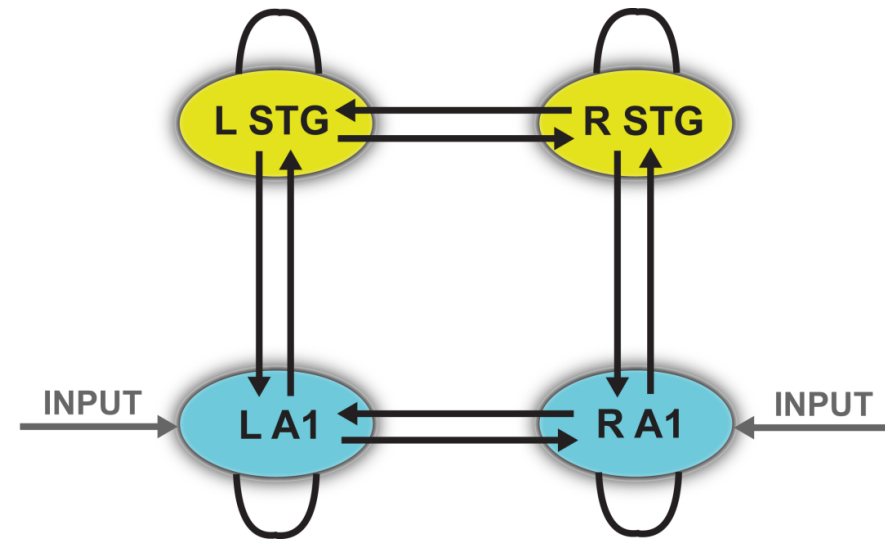
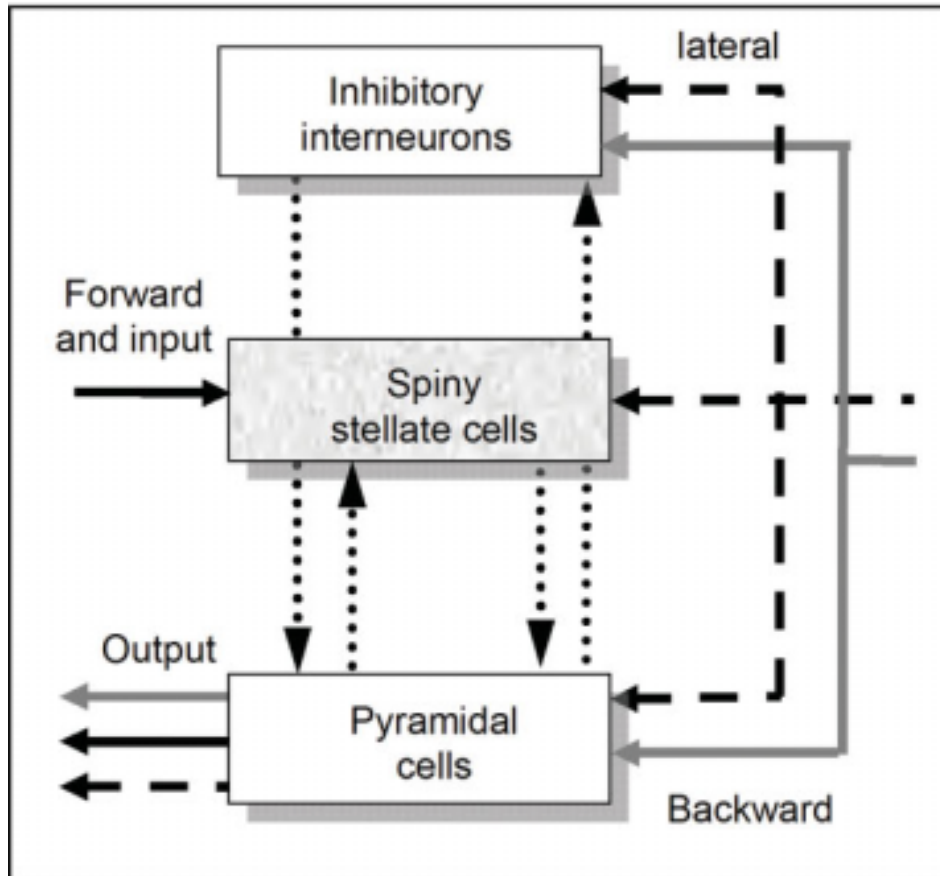
MEG summary

- Aphasics **do** show robust MMN responses to speech stimuli.
 - However, no significant difference between D1/D2/D3 amplitudes in left hemisphere.
 - Right hemisphere MMN responses for speech are as robust as controls' left hemisphere MMN responses.
- > **Adaptation of phonemic processing from LH to RH**
- **Limitations of previous work:**
 - based on ERPs
 - sensor-level data; few electrodes and poor spatial resolution
 - stimuli not sophisticated enough to look at graded deviant responses across phonemic boundaries

Dynamic Causal Modelling

DCM for evoked MEG

Neural mass model



Jansen and Rit, 1995

Felleman & Van Essen, 1991

DCM for MEG

- MEG data specified in terms of its ECDs (0-300 ms at source)
- Specify different models that can explain the data
- **Bayesian inversion** of multiple models for each dataset, which provides a posterior distribution.
- **Bayesian model selection:** Select best model based on highest model evidence.
- **Bayesian model averaging:** Infer parameters of the best model(s), using their posterior distributions.

DCM analysis

- **Predictive coding:** (Friston, 2005)

Prediction error = Predictions - Sensory input

- **Self-connections:**

sensitivity or precision of neural response to sensory input

- **Forward connections:**

bottom-up propagation of prediction error from lower to higher level of the hierarchical system

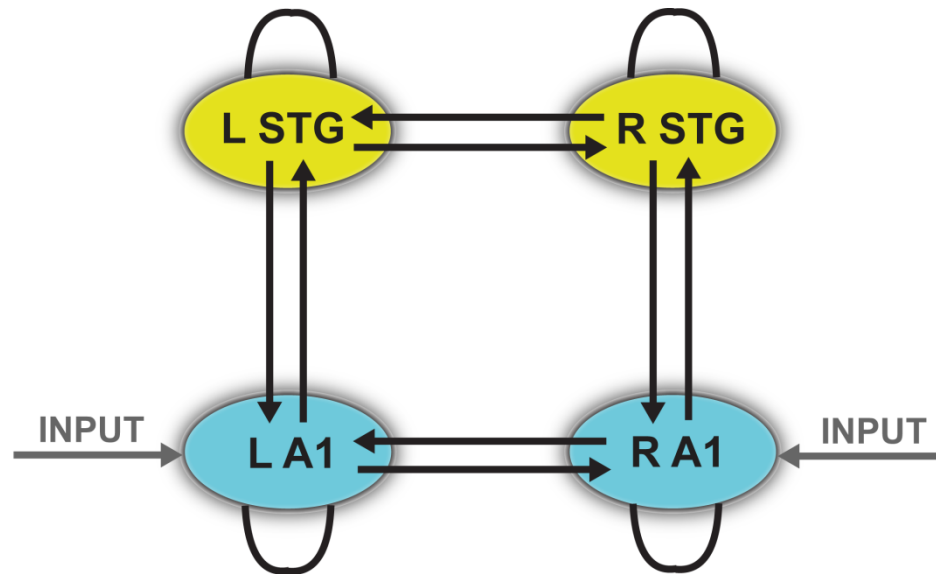
- **Backward connections:**

top-down predictions from higher to lower levels.

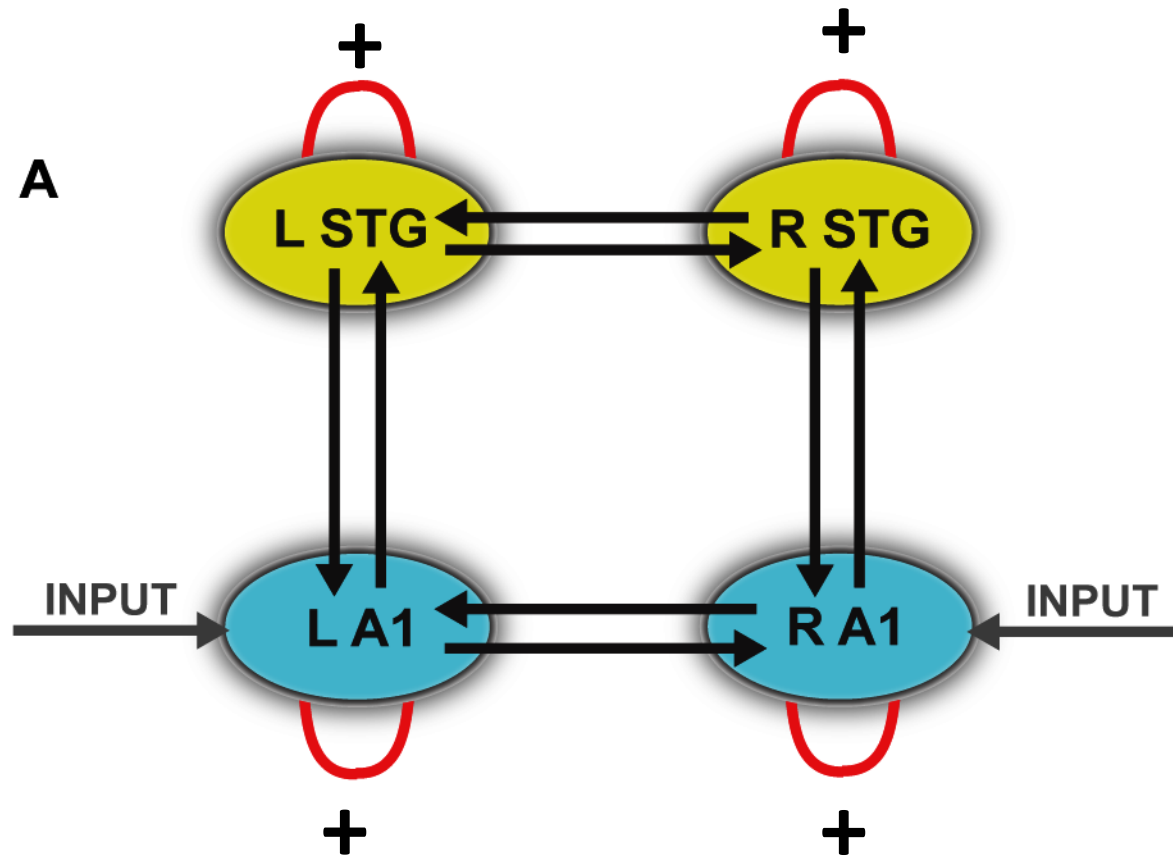
DCM analysis

Aim: To investigate modulation of the connections as a function of **phonemic deviancy: (D3 and D2) vs. D1**

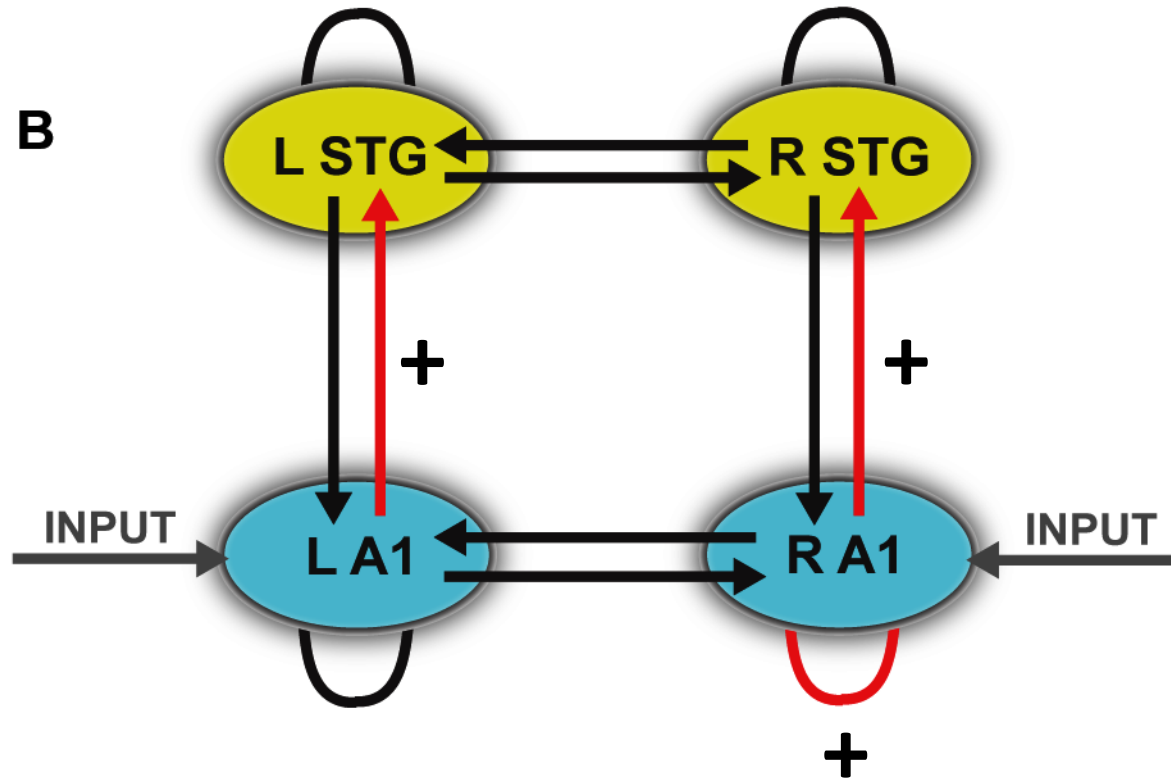
Models: 12 connections between A1 and STG were modelled, yielding 255 models for each participant.



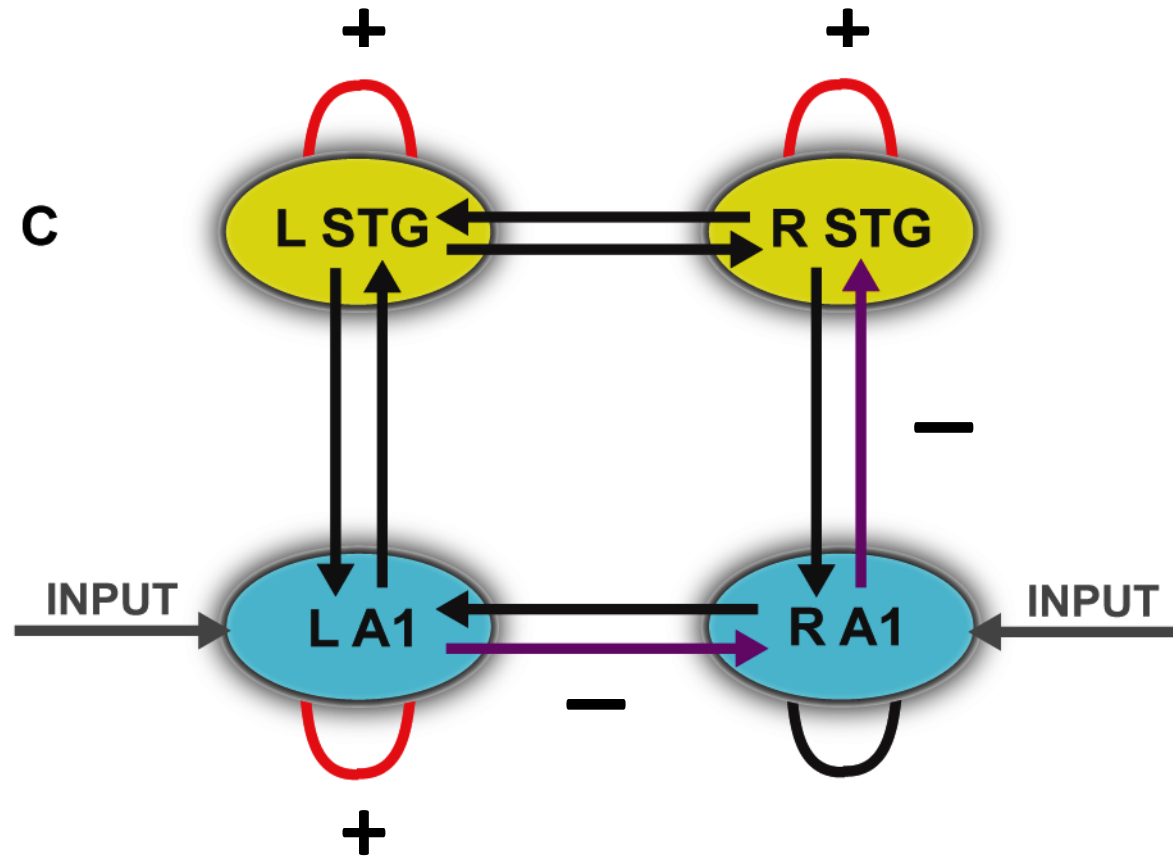
Controls



Aphasics



Controls vs. Aphasics



DCM summary

- Aphasics lack modulated self-connections in L A1, L STG, & R STG
 - > decreased sensitivity to phonemic input at these nodes
 - > impaired phonemic processing at higher hierarchical level (STG)
- Aphasics show increased modulation of forward connections from R A1 to R STG, i.e., from lower to higher level of the hierarchy.
 - > greater phonemic prediction error in the system
 - > consistent with a predictive coding account
- Aphasics show increased modulation of lateral connection from L A1 to R A1 and modulated self-connection at R A1.
 - > adaptation of phonemic analysis from left to right hemisphere

Overall summary

- Aphasics show robust speech MMNs contrary to previous reports
- MEG results in aphasics suggest impaired left hemisphere phonemic processing and compensation in the right hemisphere
- DCM of MEG responses provides a predictive coding explanation where aphasics show increased phonemic prediction errors.
- A robust paradigm that provides an index of aphasics' speech comprehension and recovery in terms of connection strengths between the underlying connections of the speech network.

Acknowledgments

Guillaume Flandin, FIL (technical support)

UCL Research Computing (parallel computing help)

Wellcome Trust, UK (funding)

Questions?

Further work

Longitudinal design:

Effect of phonological therapy

Effect of drug treatment (donepezil: AChesterase inhibitor)

Test change in effective connectivity, correlation with behaviour

Previously...

