MRC Cognition and Brain Sciences Unit

Cambridge University Hospitals NHS
NHS Foundation Trust

Hierarchical Auditory Prediction

I predict, therefore I am

Srivas Chennu *PhD*

UNIVERSITY OF CAMBRIDGE

Background

The Bayesian brain

generates predictions about the sensorium

Is evolutionarily driven to make better and cleverer predictions

Hierarchy of increasing complexity

Each perceptual level makes predictions

And learns from its mistakes (prediction error)

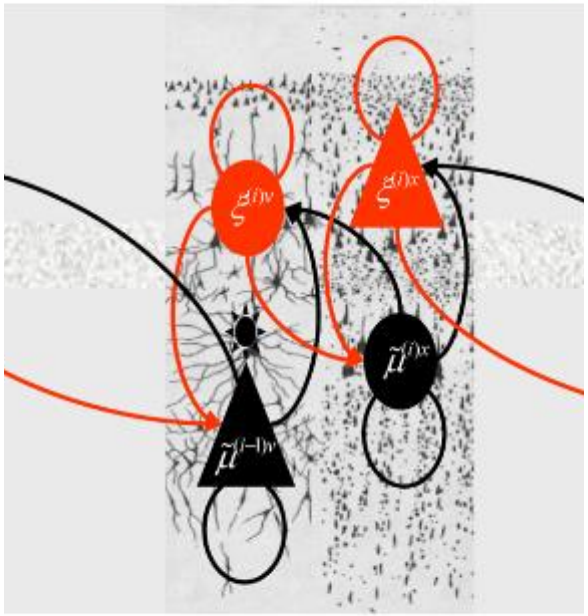
Current thinking

Maybe the brain is *Bayes-optimal*

$$p(beliefs_{new}) = p(data_{new}) \acute{} p(beliefs_{old})$$

Hierarchical Auditory Prediction

Forward prediction error



Layers I-III: Encode pred. err. and cause EEG

Stimulus

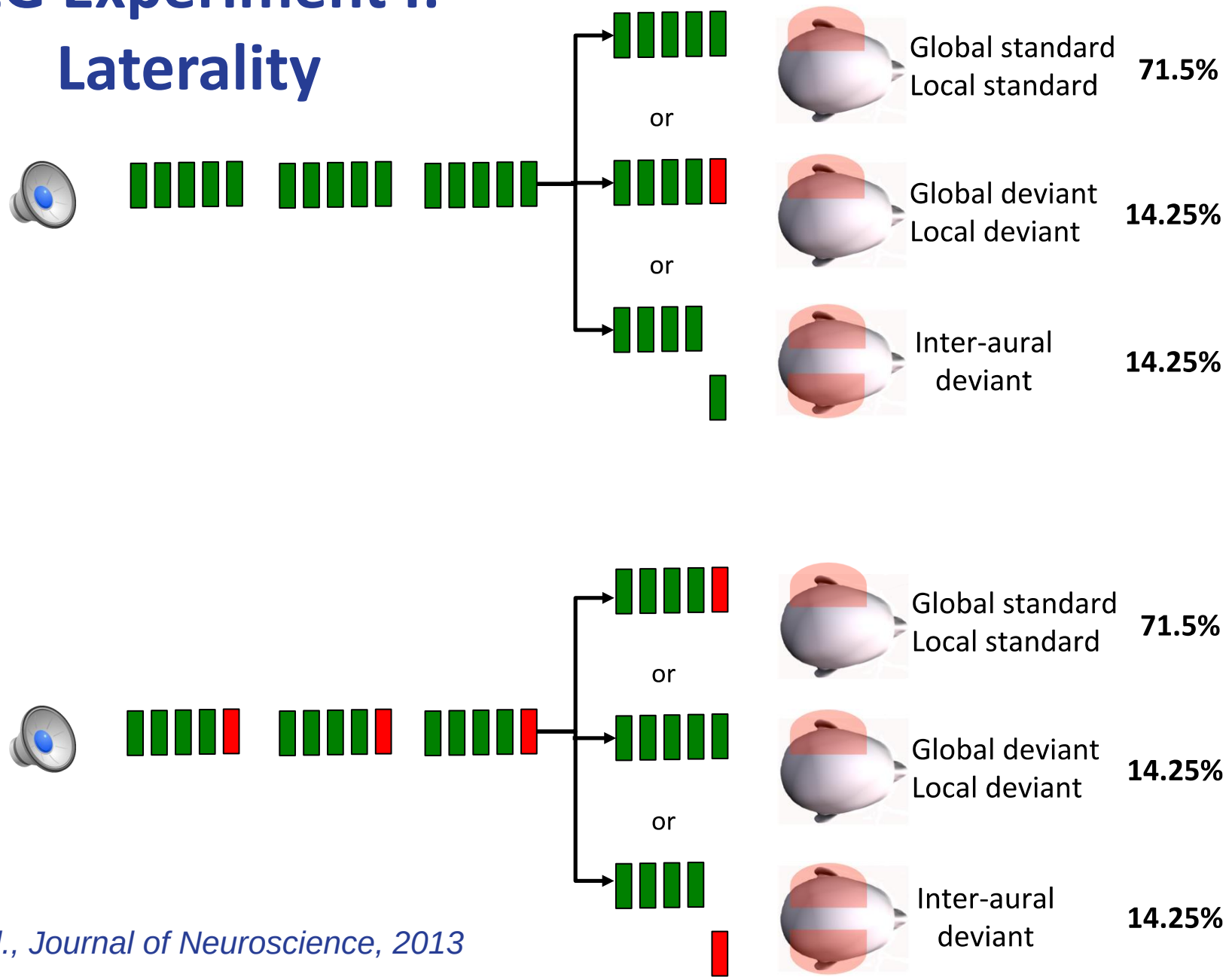
Layers V-VI: Encode predictions

Backward predictions

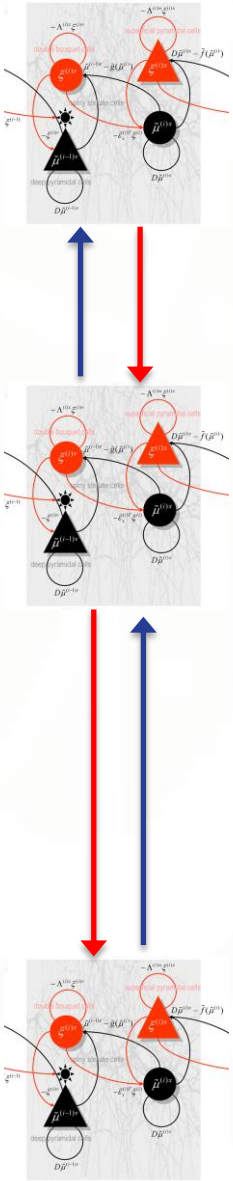
Attention is the precision of prediction

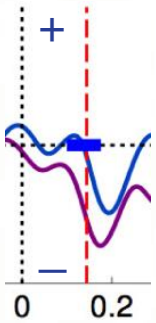
Friston, 2008

EEG Experiment I: Laterality



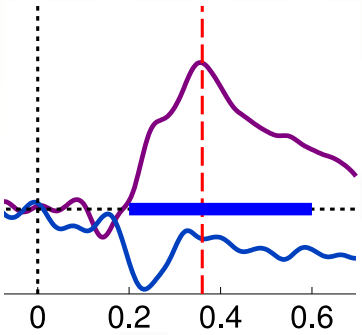
Chennu et al., Journal of Neuroscience, 2013





MMN (100-300ms)

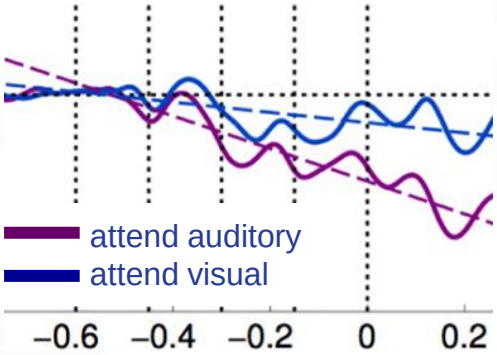
- Negativity indexing early prediction error
- Pre-attentional
- ***Diminished*** by top-down attention



attend auditory
attend visual

P300 (300-600ms)

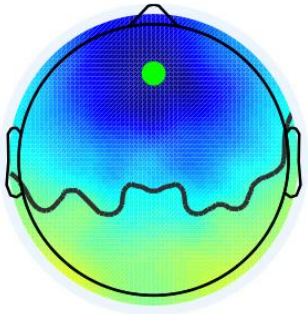
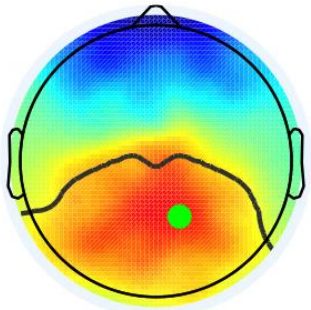
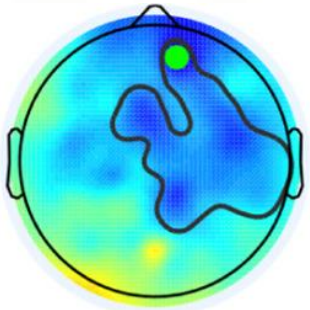
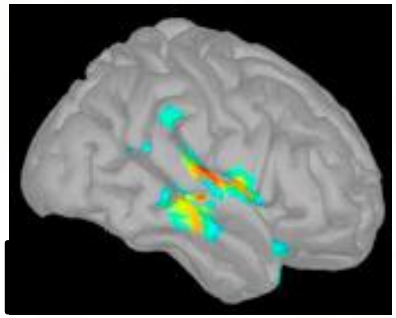
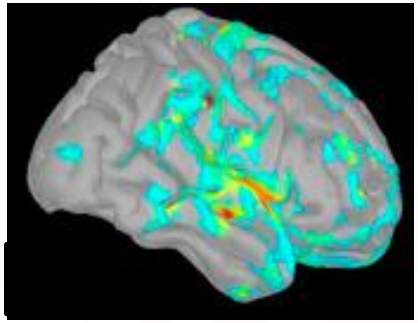
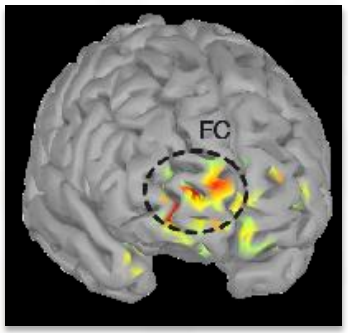
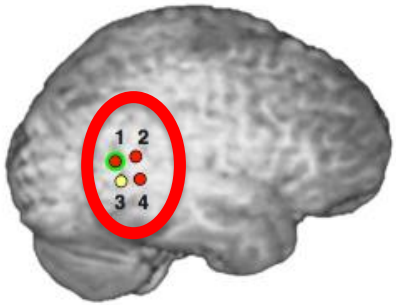
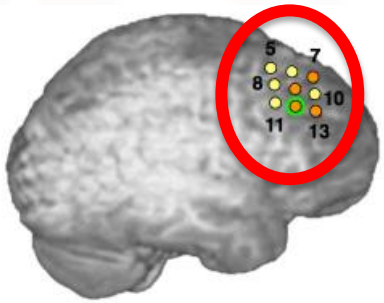
- Positivity indexing late prediction error
- Accompanies conscious perception
- ***Sharpened*** by top-down attention



CNV (-600-0ms)

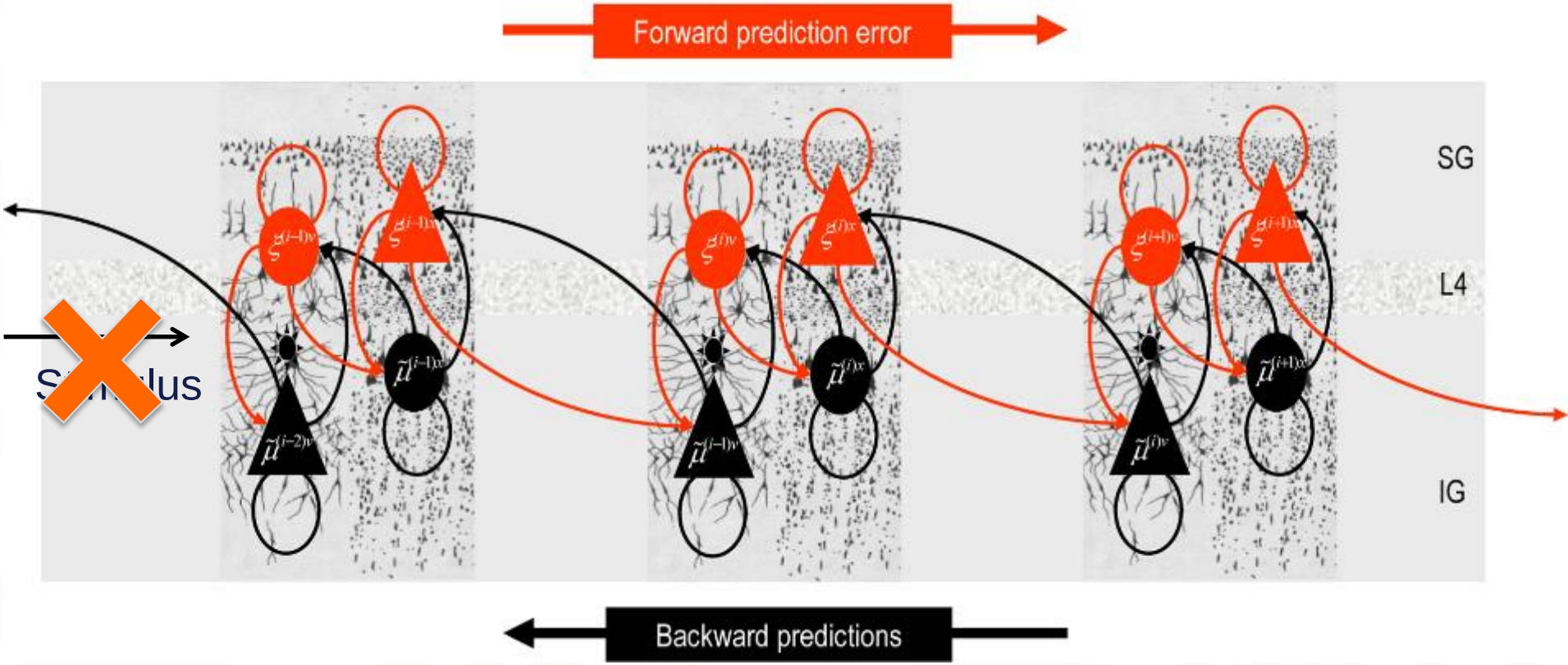
- Slow drift that indexes ***expectation***
- Modulates attentional focus to facilitate perception

Chennu et al., 2013

	Local MMN	*Global* P300	*Expectation* CNV
Topography			
Sources			
	STG, TPJ, IFG	**PFC, PPC**	**Frontal Pole**
Intracranial			

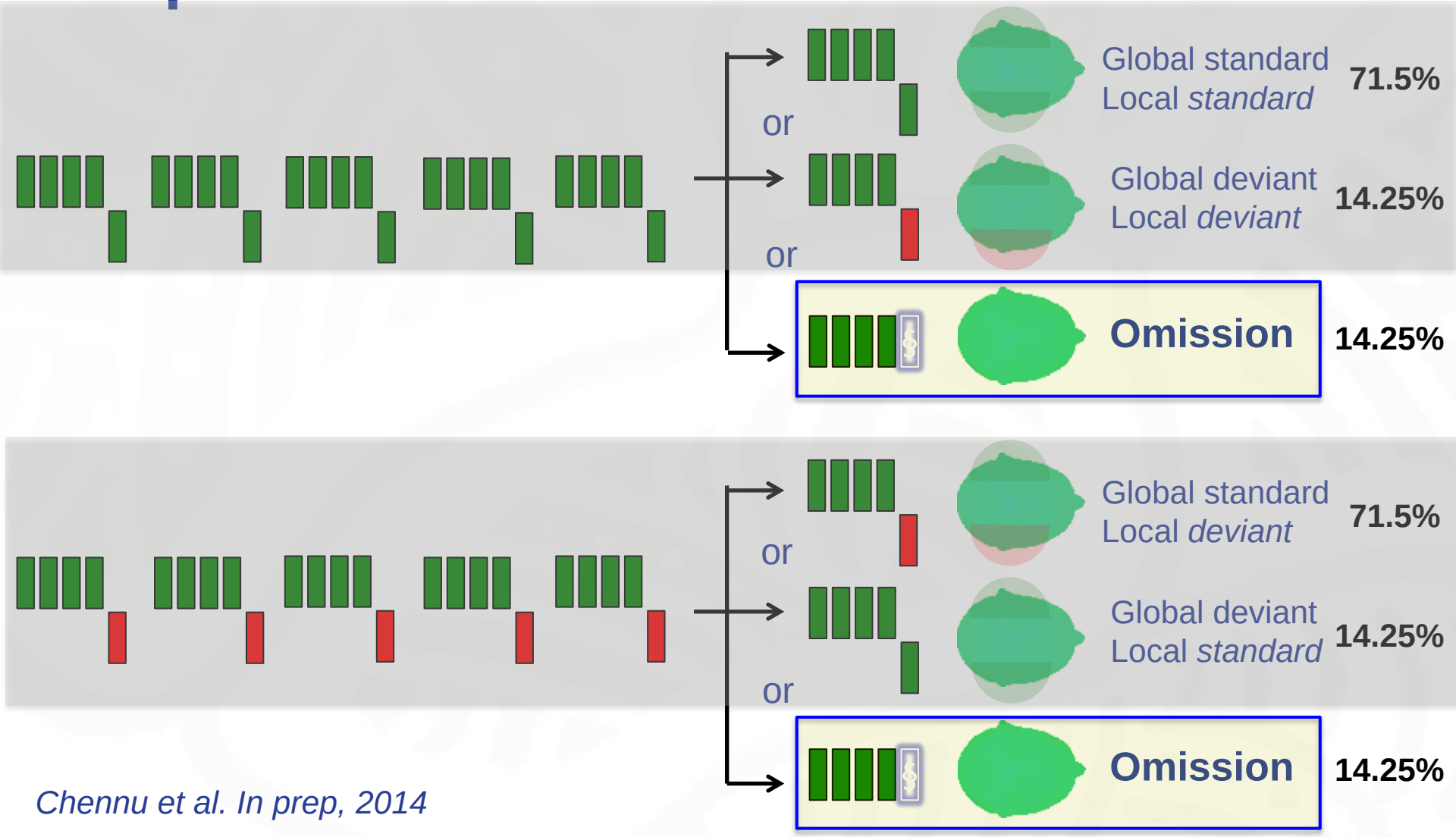
** Dehaene et al., 1998; Wacongne et al., 2011; Chennu et al., 2013*

Hierarchical Auditory Prediction



Friston, 2008

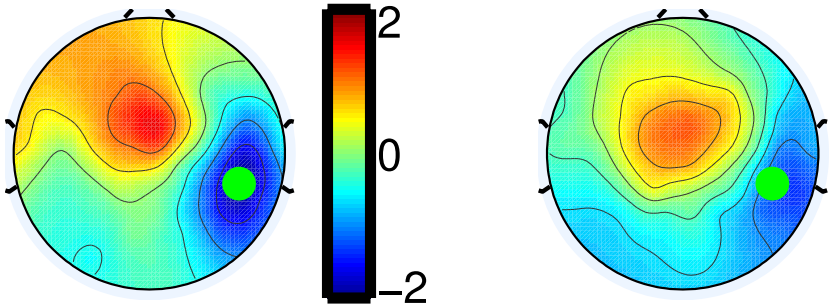
Experiment II: Omissions

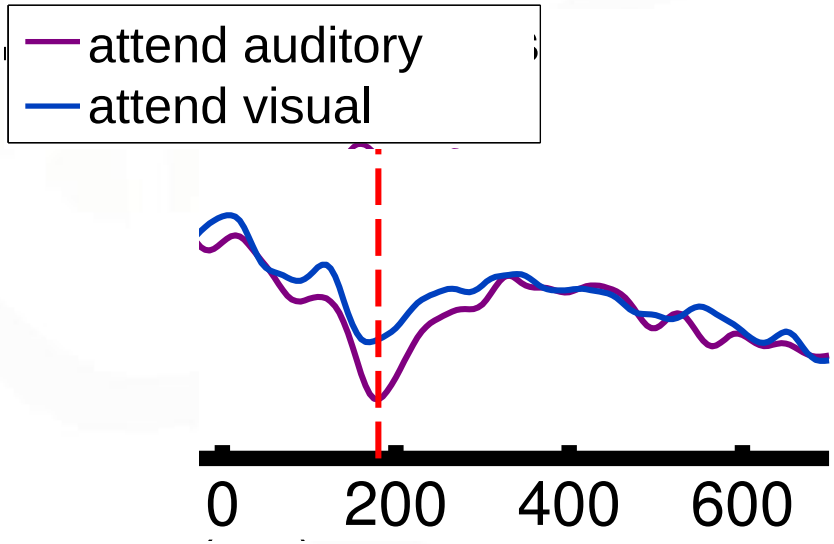


Chennu et al. In prep, 2014

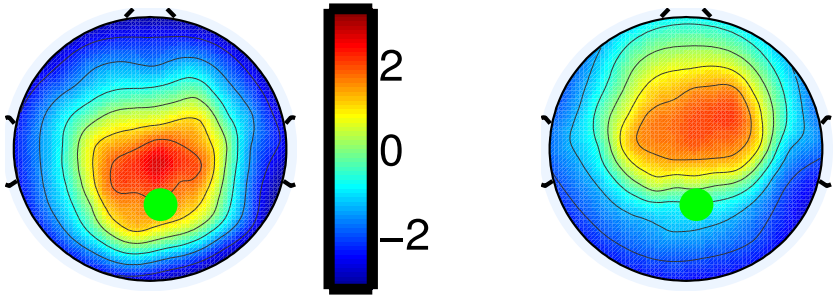
Omission-evoked Responses

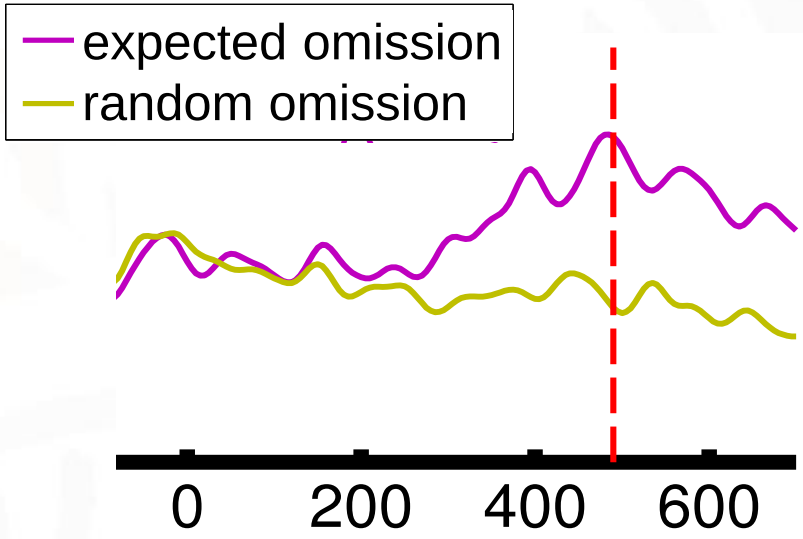
Modulating Attention



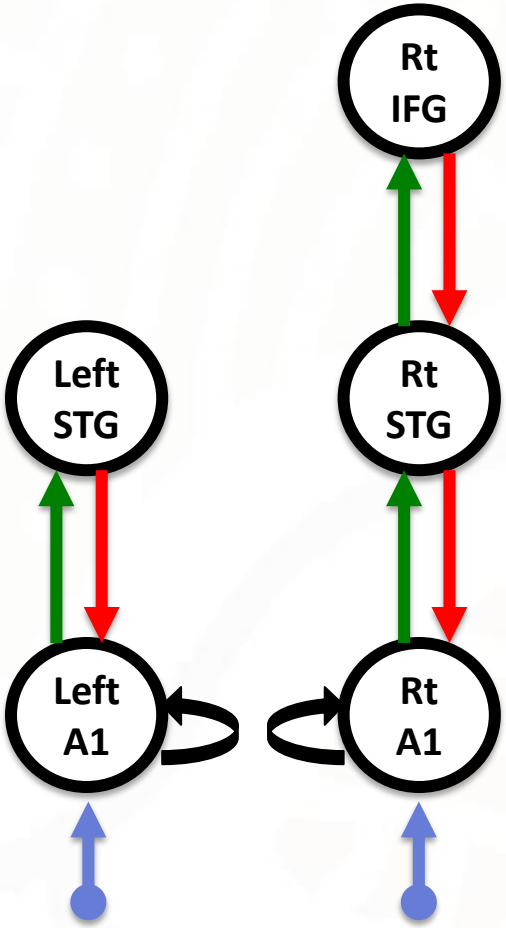


Modulating Expectation



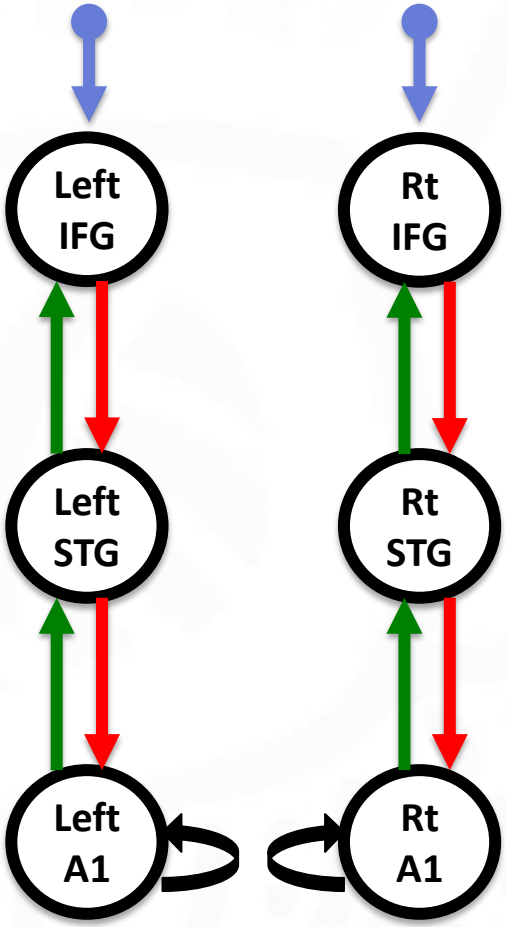


Dynamic Causal Modelling



Mismatch Negativity

Omission



Interim Summary

Hierarchical predictive coding theory

- **Prediction errors** flow upward
- **Predictions** (shaped by expectations) flow downward
- **Attention** as the precision of prediction

Integrating common ERP components

- The **MMN** is pre-attentional and ***diminished*** by expectation
- The **P300** is attention-dependant and ***enhanced*** by expectation
- The **CNV** is a fine-grained marker of this top-down expectation

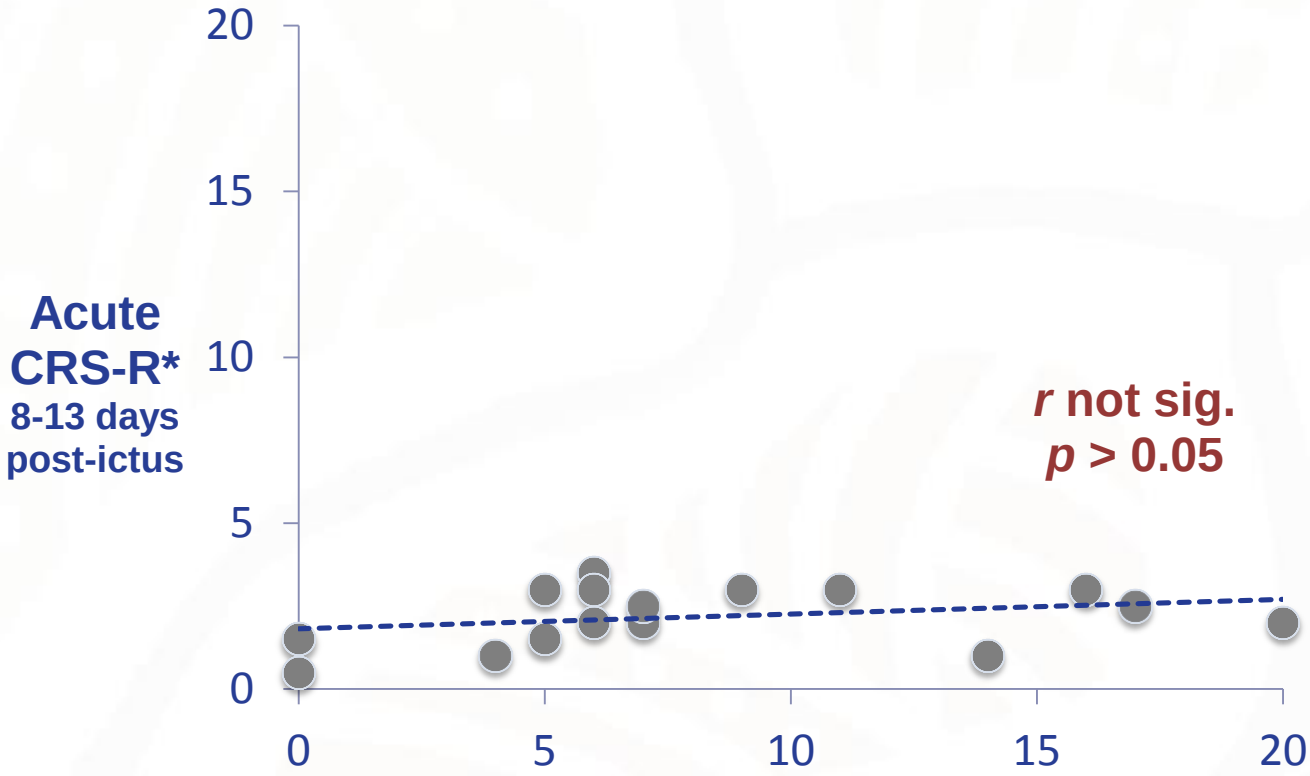
Within this framework

- The omission is a response to the ***absence*** of an expected stimulus
- Hence a pure index of the expectation-driven prediction signal
- Which projects ***downward*** and interacts with attention

Applications in brain injury

- Prognosis
- Diagnosis

The Challenge

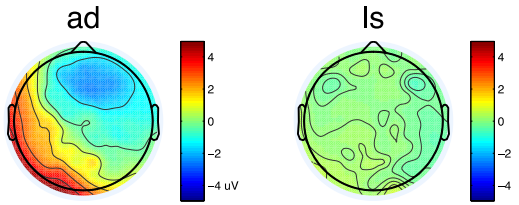


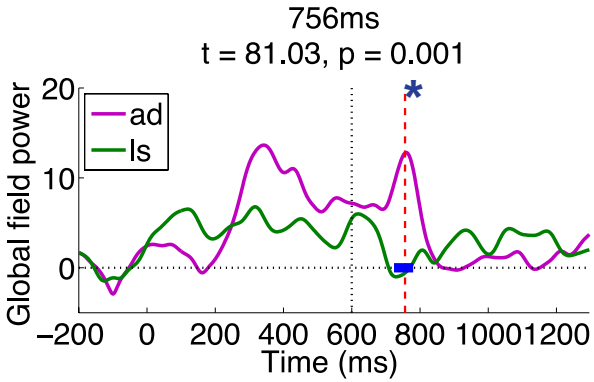
** CRS-R = Coma Recovery Scale - Revised*

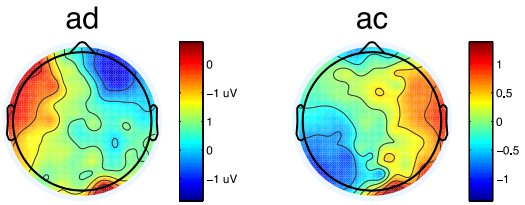
Silva and Chennu et al., in prep

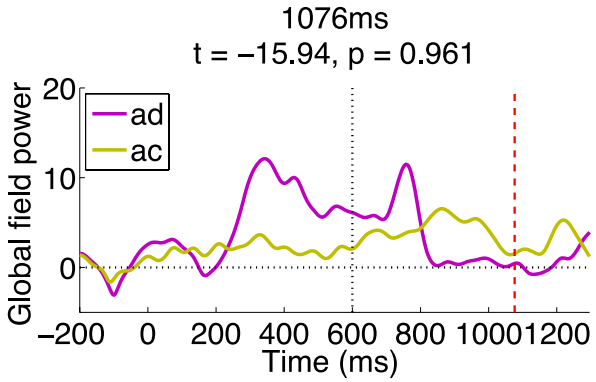
Plum and Posner, 1982; Braakman et al., 1988; Choi et al., 1988; Yingling et al., 1990

Coma Patient Session 1 (CRS-R = 2)





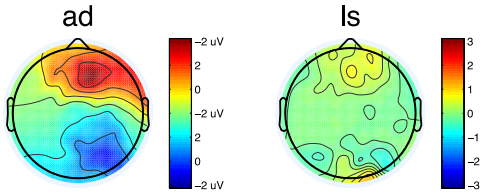


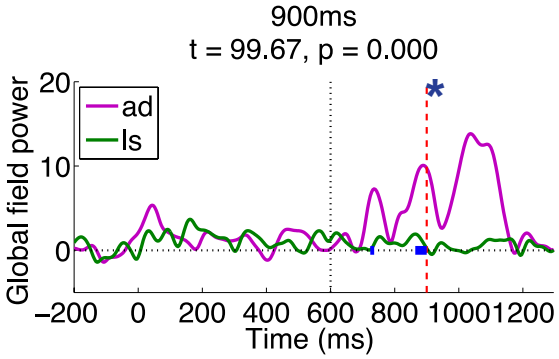


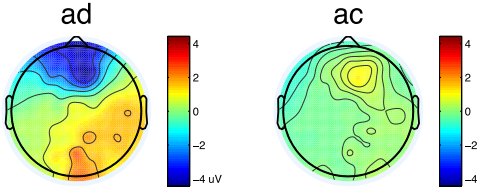
Local Effect (100-300ms)

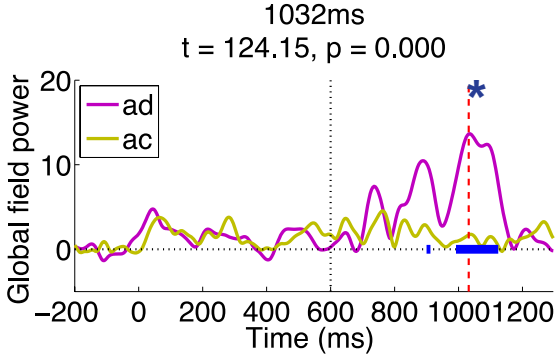
Global Effect (300-600ms)

Coma Patient Session 2 (CRS-R = 2)





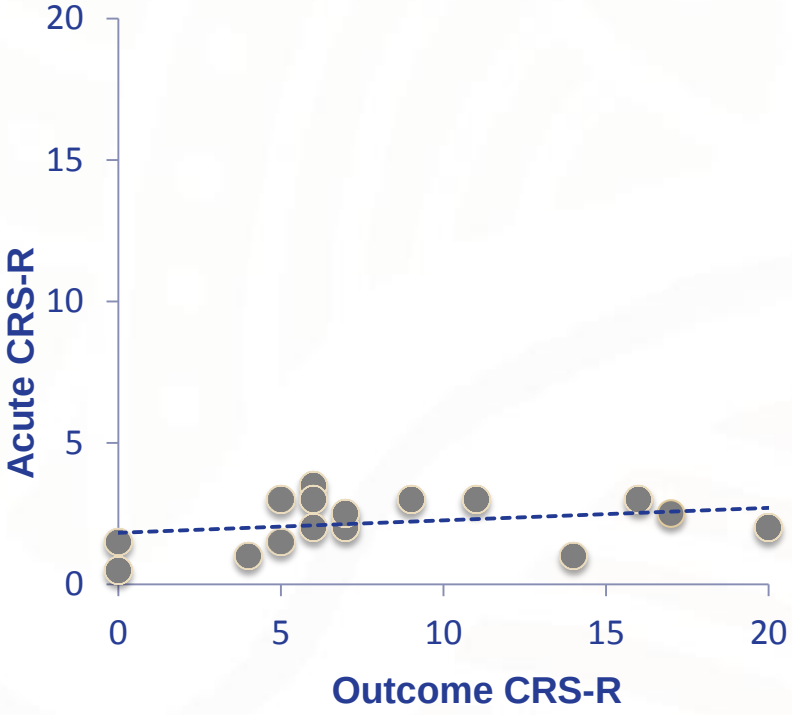




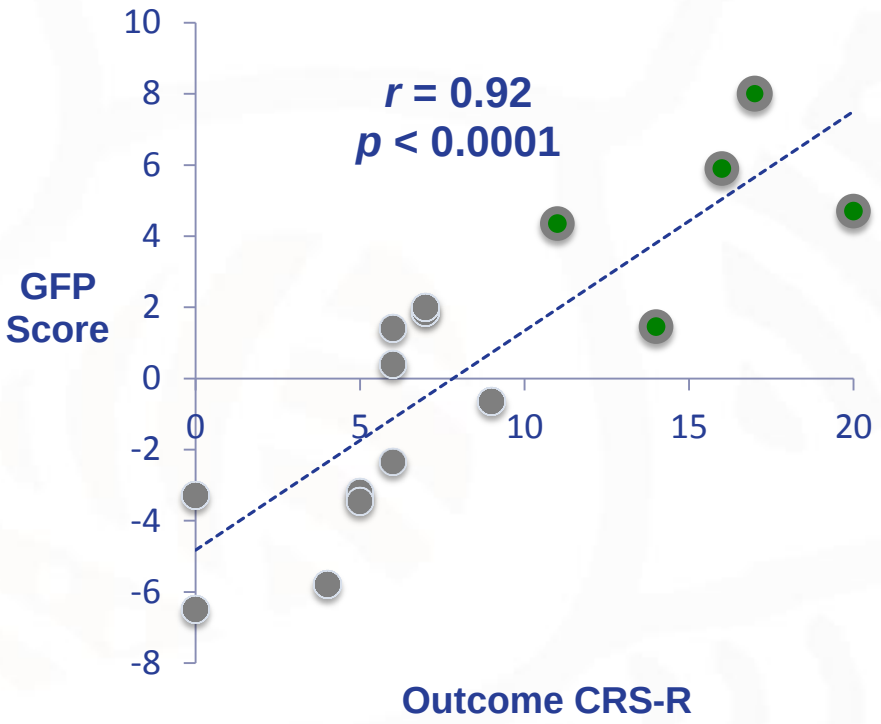
* Statistically significant with single-subject non-parametric **global field power (GFP)** analysis

Acute Prognosis

Behaviour

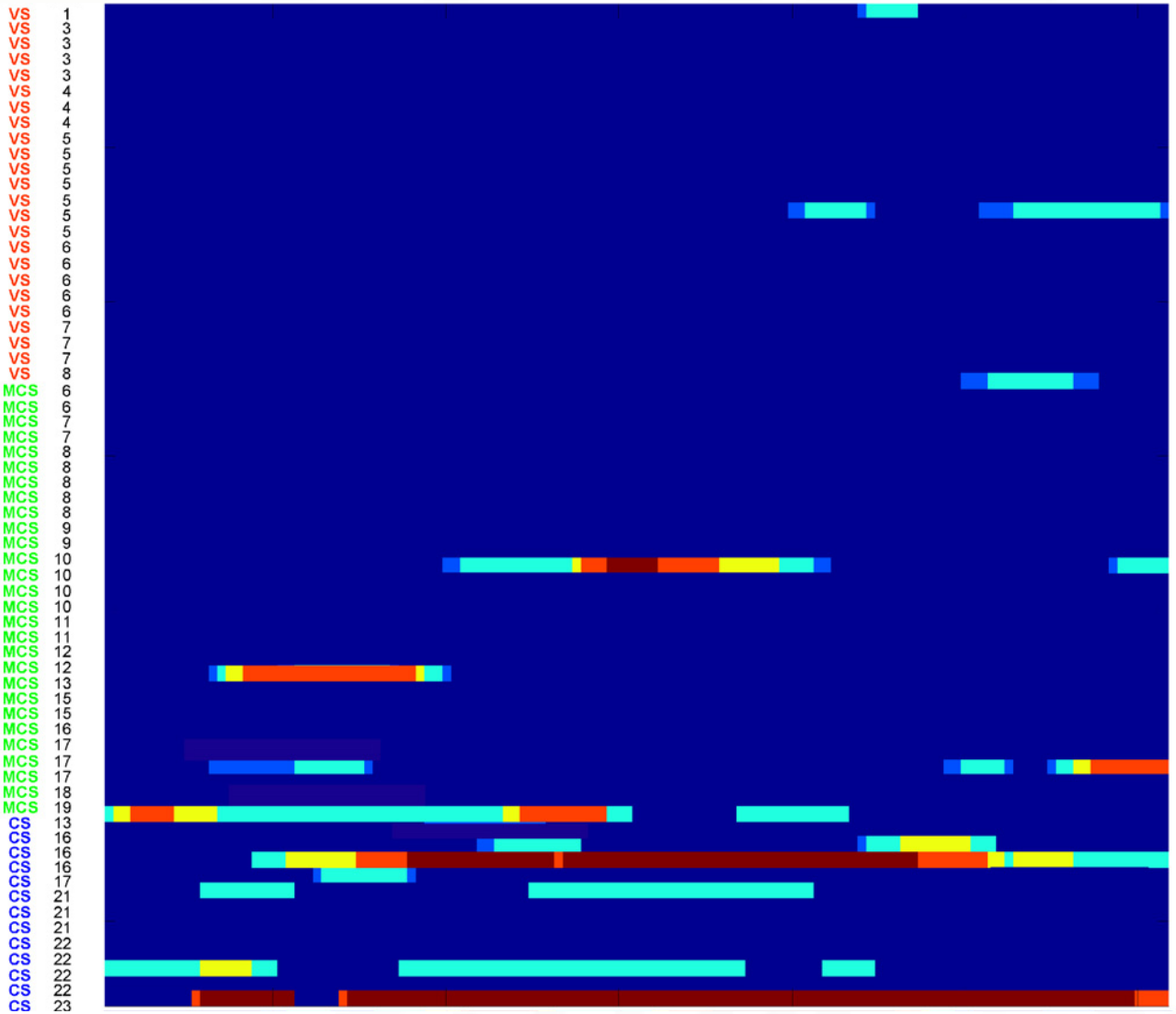


Local Effect



- Statistically significant with single-subject non-parametric **global field power (GFP)** analysis

Chronic Diagnosis



Bekinschtein et al., 2009; Faugeras et al., 2012

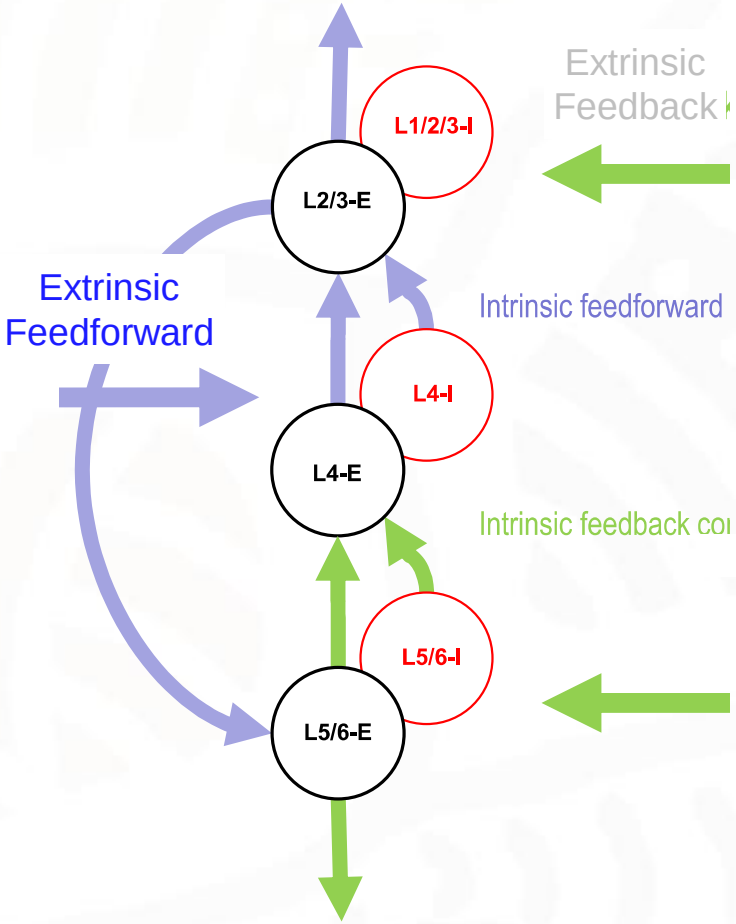
Why Does Prediction Matter?

For prognosis

Early prediction is temporally and spatially localised
Requires few cortical microcircuits
Presages the reestablishment of many more…

For diagnosis

Late prediction is temporally and spatially distributed
Engages many disparate microcircuits
Results in *interoceptive* state externally akin to consciousness



Canonical Microcircuit for Predictive Coding

Bastos et al., 2012

Future Directions

Theoretical

Modeling failures of hierarchical prediction

Detailed understanding of the link between prediction and consciousness

Clinical

Quantitative control of EEG quality

Closed-loop calibration of derived ERP scores

Single-trial decoding, complexity analysis

Thanks!

Dr. Stein Silva

Prof. David Menon

Division of Anaesthesia
University of Cambridge

Dr. Tristan A. Bekinschtein

MRC Cognition and Brain Sciences Unit
Cambridge

Prof. John Pickard

Division of Neurosurgery
University of Cambridge

Dr. Adrian M. Owen

The Brain and Mind Institute
University of Western Ontario

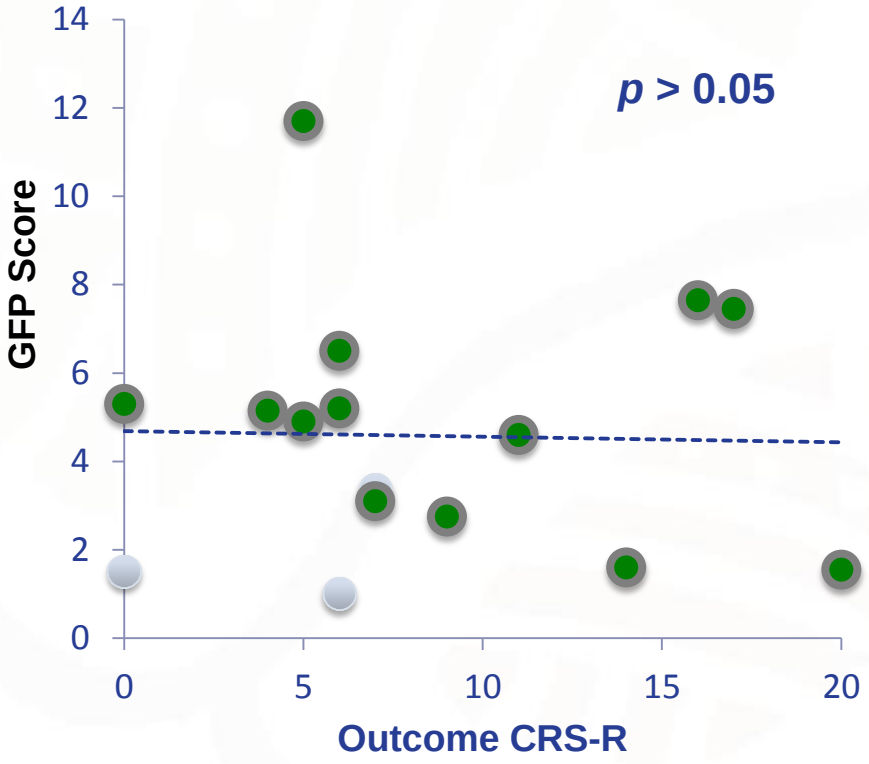
MRC Cognition and Brain Sciences Unit

UNIVERSITY OF CAMBRIDGE

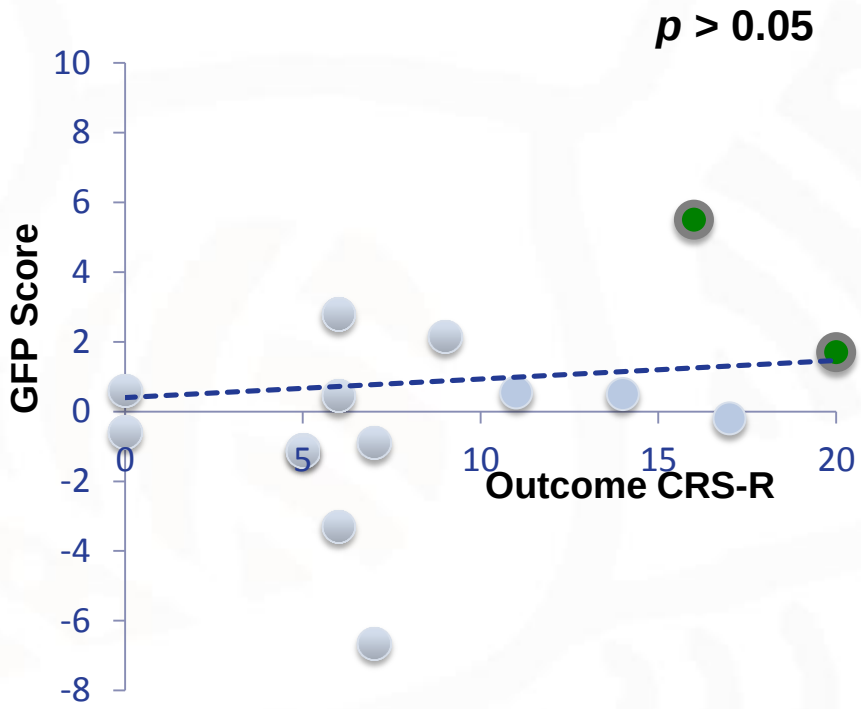
Cambridge University Hospitals NHS Foundation Trust

Prognosis

Primary Auditory Effect

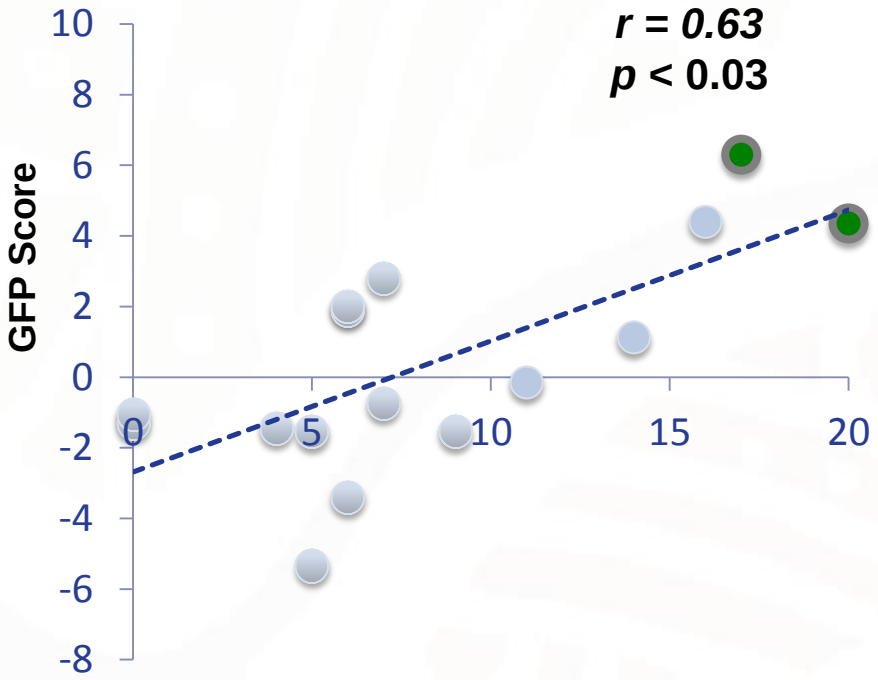


Interaural Global Effect



Prognosis

Monaural Local Effect



Monaural Global Effect