

Hierarchical Auditory Prediction: Theory and Application

I predict, therefore I am

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Outline

- The hierarchical prediction hypothesis
 - *The brain is a hierarchically organised predictor*
 - *Event-related Potentials reflect prediction error*
- Applications in brain injury
 - *Prognosis*
 - *Diagnosis*

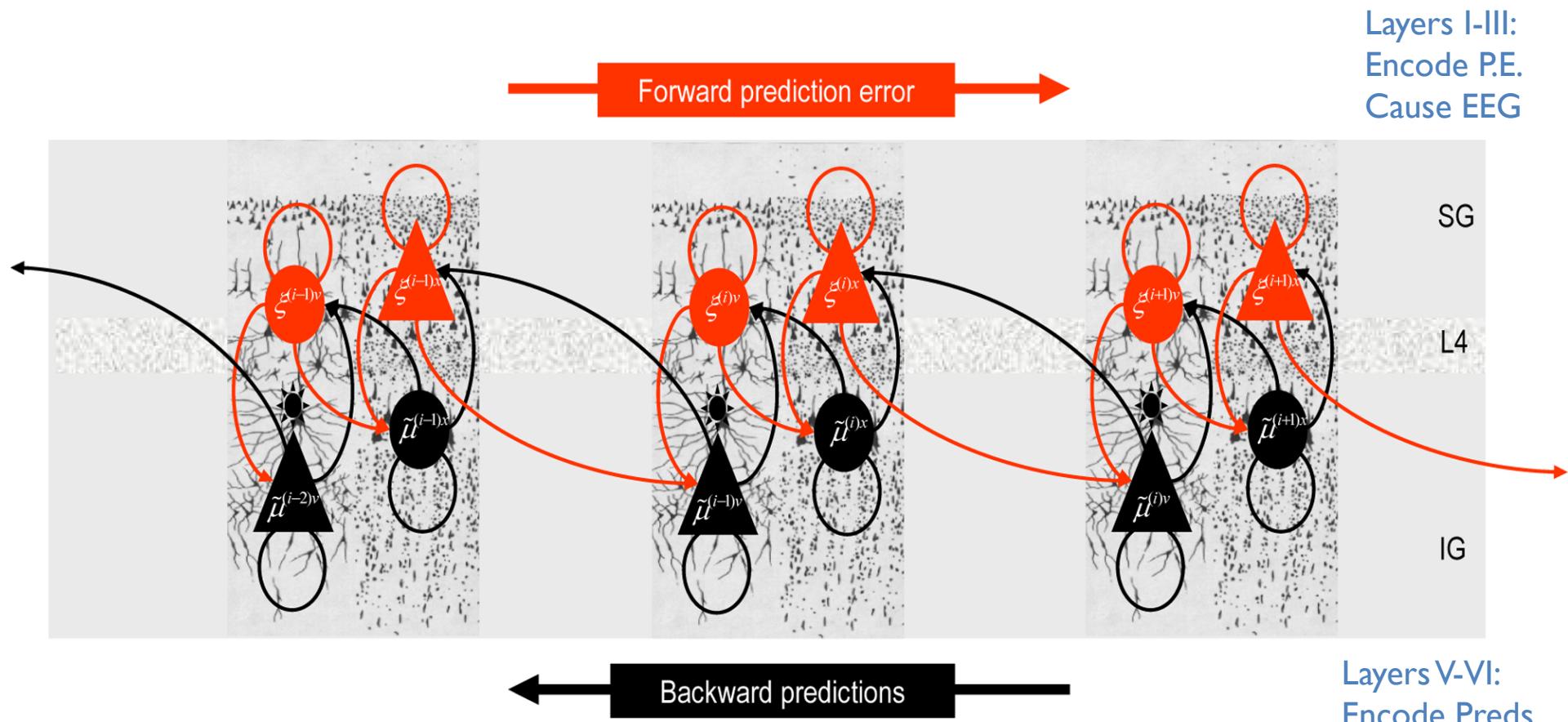
Background

- The Bayesian brain
 - generates predictions about the sensorium
 - Is evolutionarily driven to make better and cleverer predictions
- Hierarchy of increasing predictive complexity
 - Each perceptual level makes predictions
 - And learns from its mistakes (prediction error)
- Current thinking
 - Maybe the brain is *Bayes-optimal*



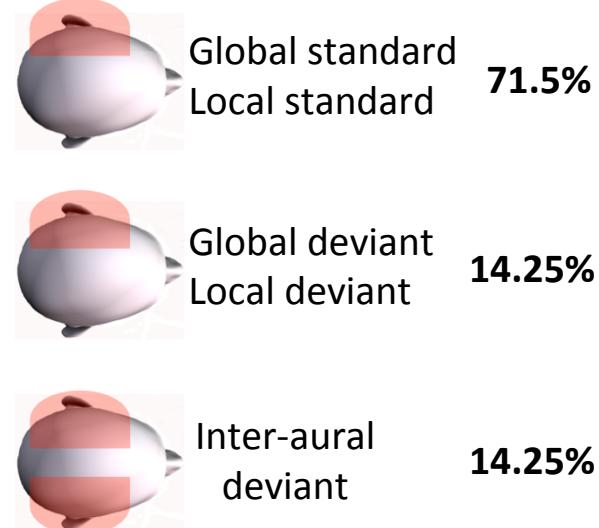
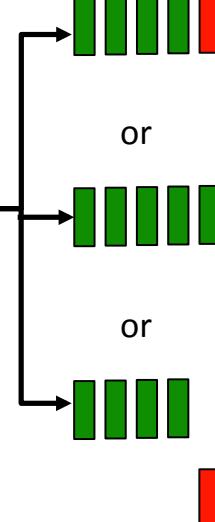
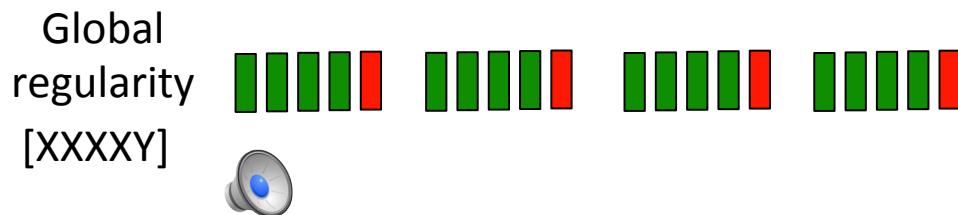
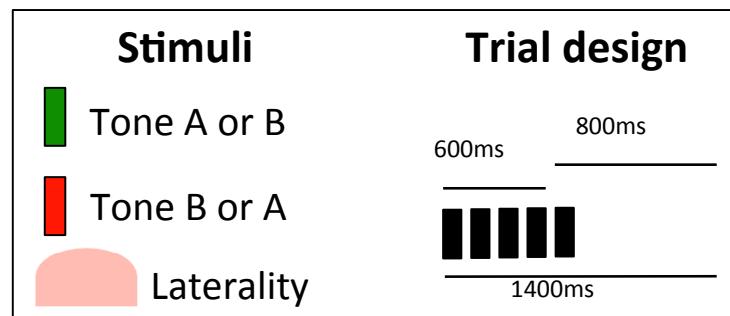
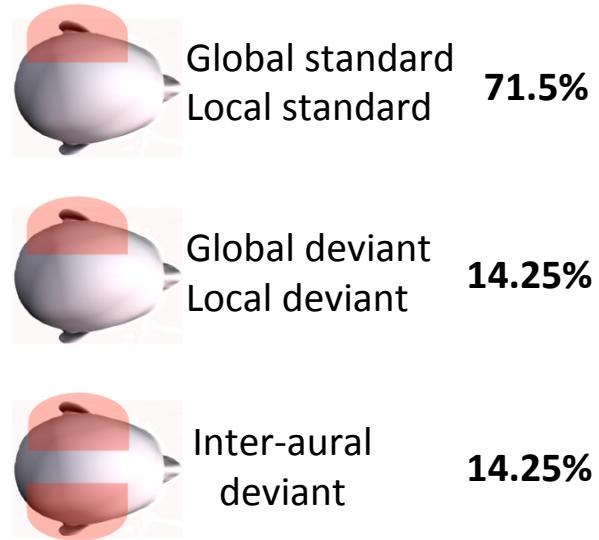
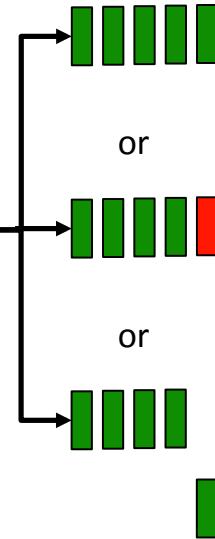
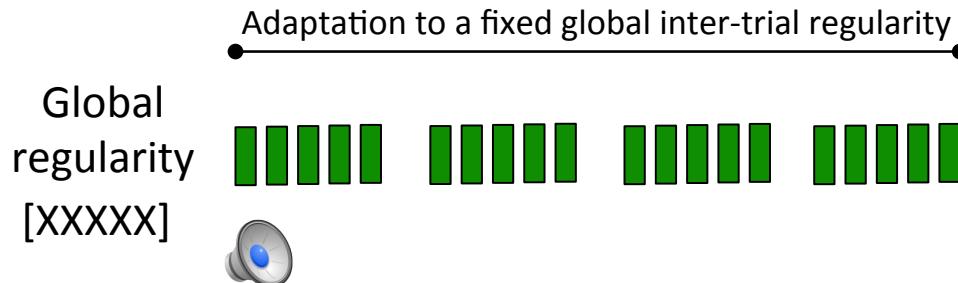
$$p(\text{beliefs}_{\text{new}}) = p(\text{data}_{\text{new}}) \times p(\text{beliefs}_{\text{old}})$$

Hierarchical Auditory Prediction

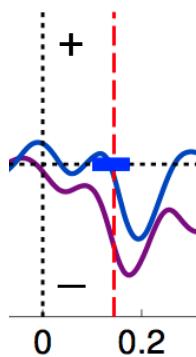
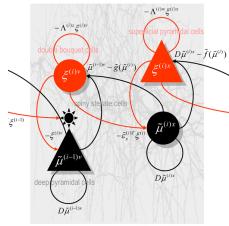


Friston, 2008

Stimulus Design

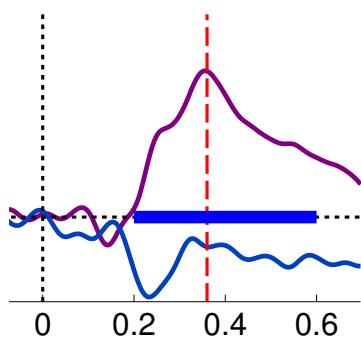
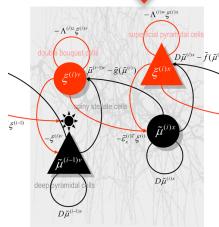


Hierarchical Event-related Potentials



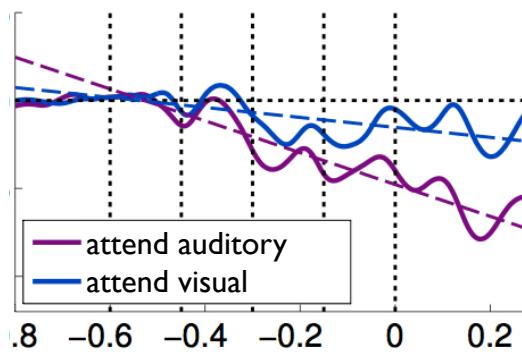
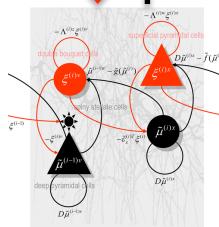
MMN (100-300ms)

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



P300 (300-600ms)

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

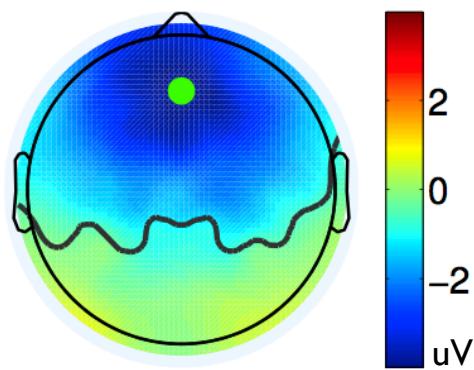


CNV (-600-0ms)

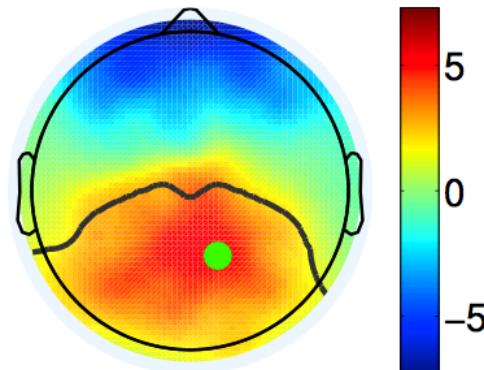
- Slow drift that indexes **expectation**
- Modulates attentional focus to facilitate perception

Cortical Sources

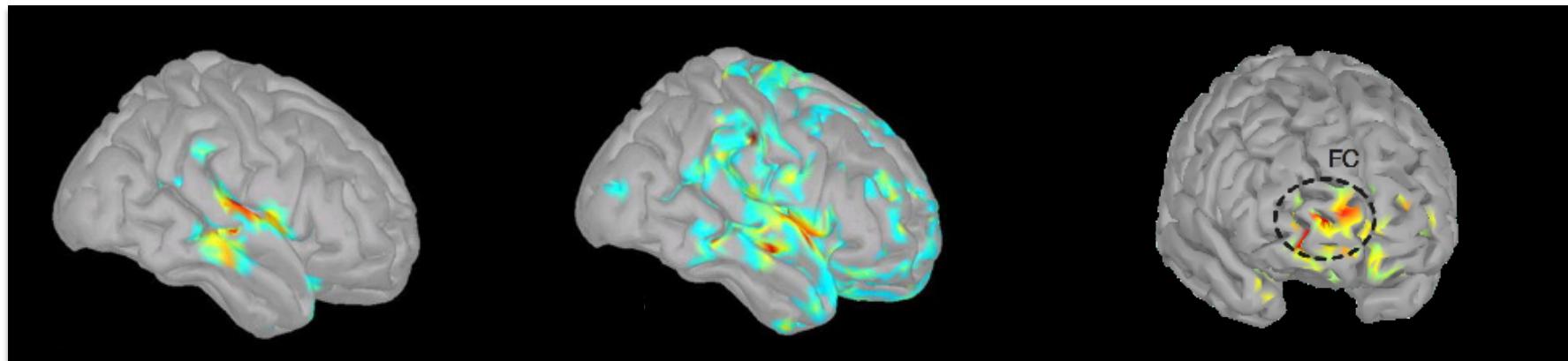
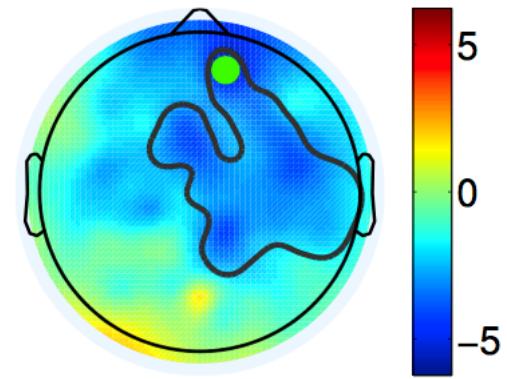
Local* MMN



Global* P300



Expectation CNV

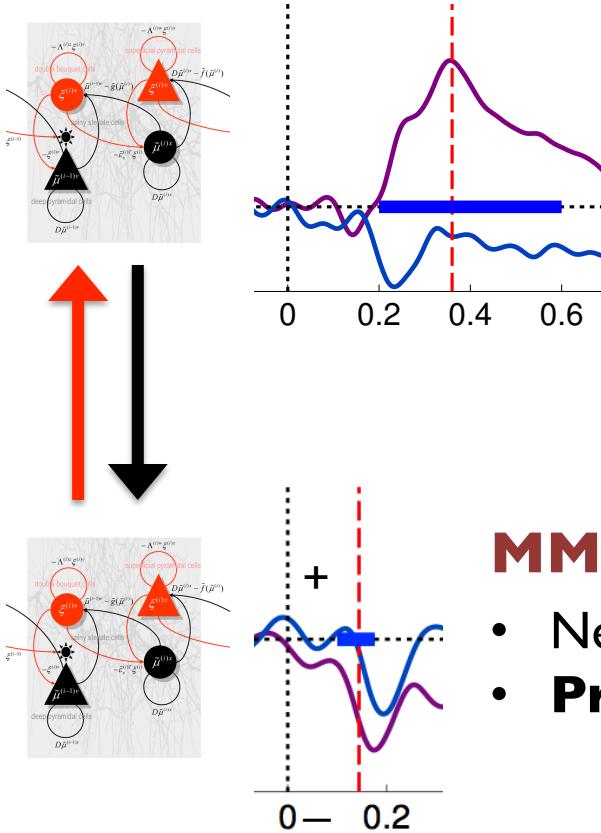


Sup. Temp. Gyrus
Inf. Front. Gyrus
Temporo-parietal Junction

Prefrontal cortex
Posterior parietal cortex

Frontal Pole

Hierarchical Event-related Potentials



P300 (300-600ms)

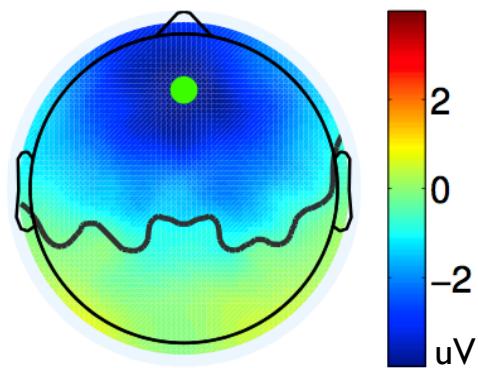
- Positivity indexing late prediction error
- **Contingent on attention**
- Accompanies conscious perception

MMN (100-300ms)

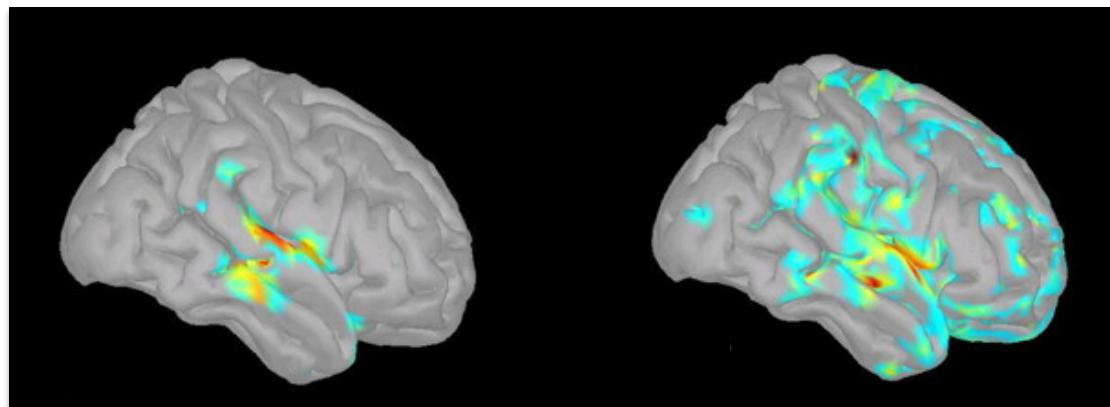
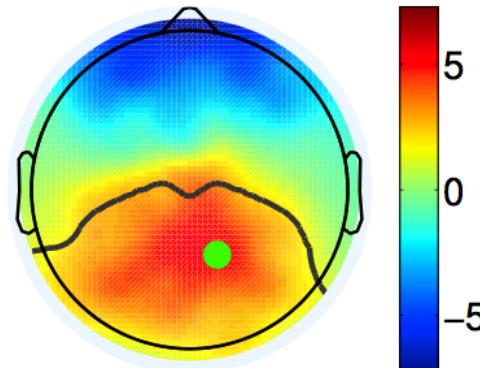
- Negativity indexing early prediction error
- **Pre-attentional**

Cortical Sources

*Local** MMN



*Global** P300



Sup. Temp. Gyrus

Inf. Front. Gyrus

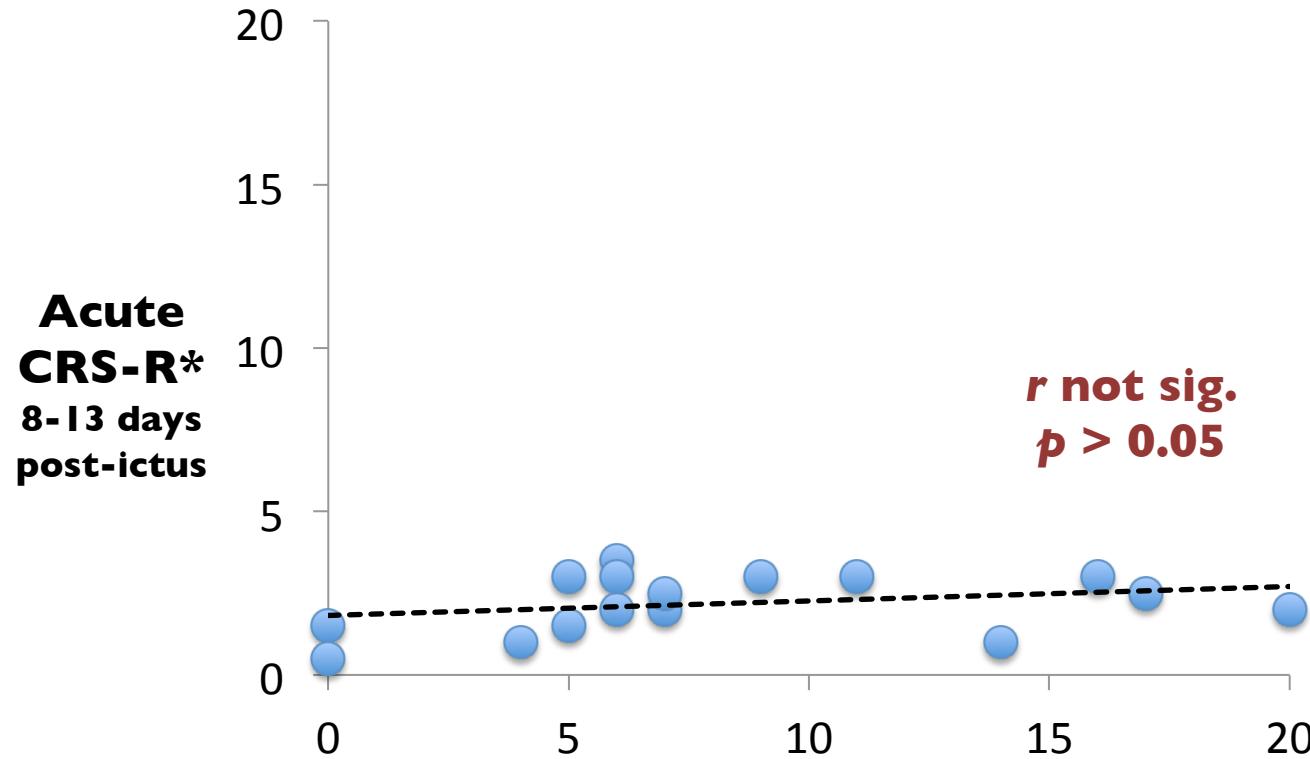
Temporo-parietal Junction

Prefrontal cortex
Posterior parietal cortex

Outline

- The hierarchical prediction hypothesis
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 - *Diagnosis*

The Challenge



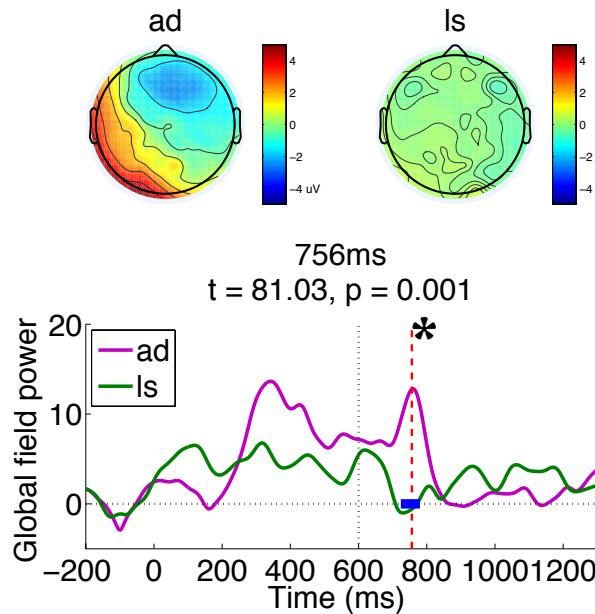
* CRS-R = Coma Recovery Scale - Revised

Outcome CRS-R
60 days post-ictus

Silva and Chennu et al., Submitted

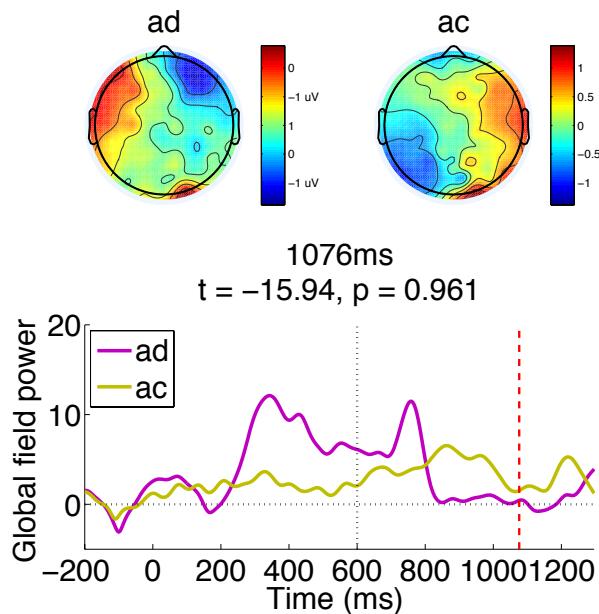
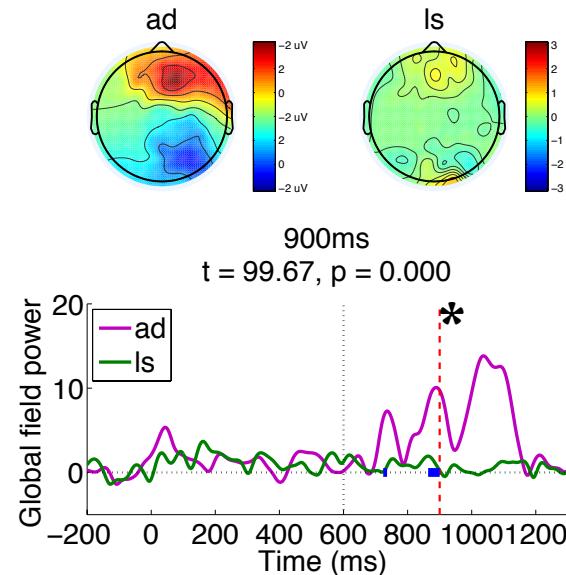
Plum and Posner, 1982; Braakman et al., 1988; Choi et al., 1988; Yingling et al., 1990

**Coma
Patient
Session 1**
(CRS-R = 2)

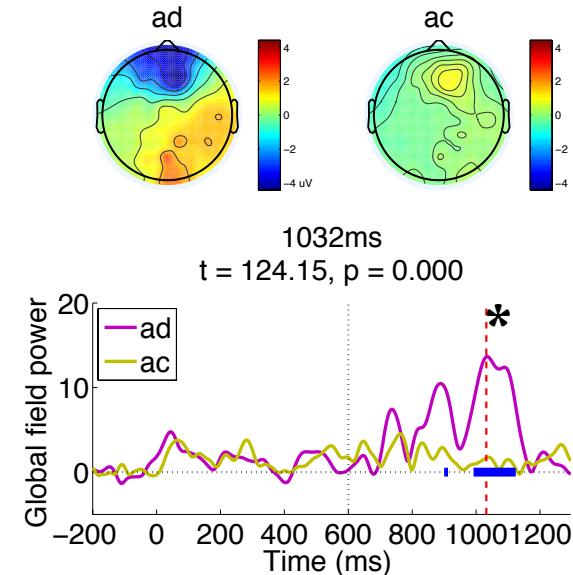


**Interaural Local Effect
(100-300ms)**

**Coma
Patient
Session 2**
(CRS-R = 2)



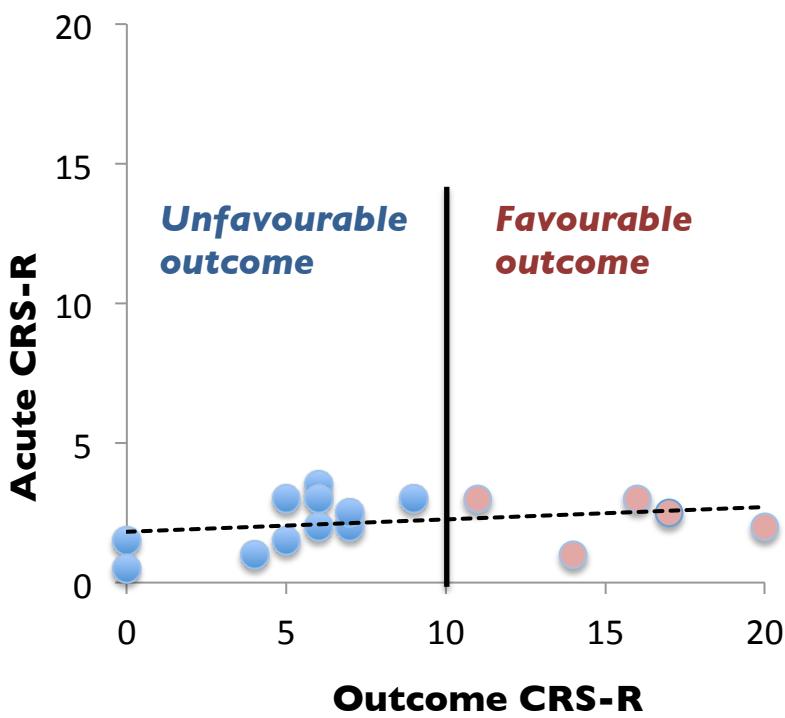
**Interaural Global Effect
(300-600ms)**



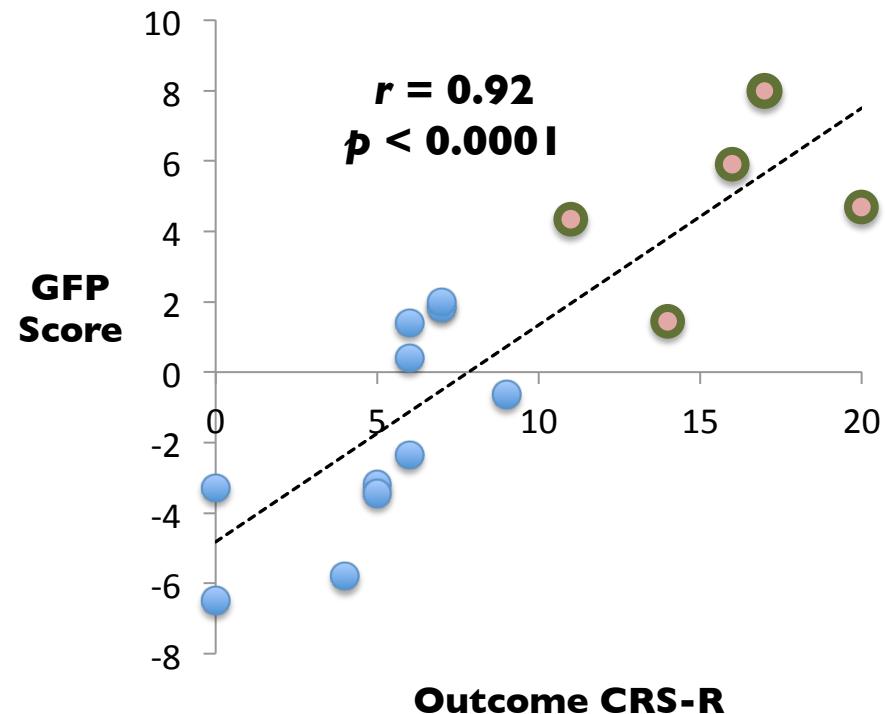
* Statistically significant with single-subject non-parametric **global field power (GFP)** analysis

Prognosis

Behaviour



Interaural Local Effect (100-300ms)

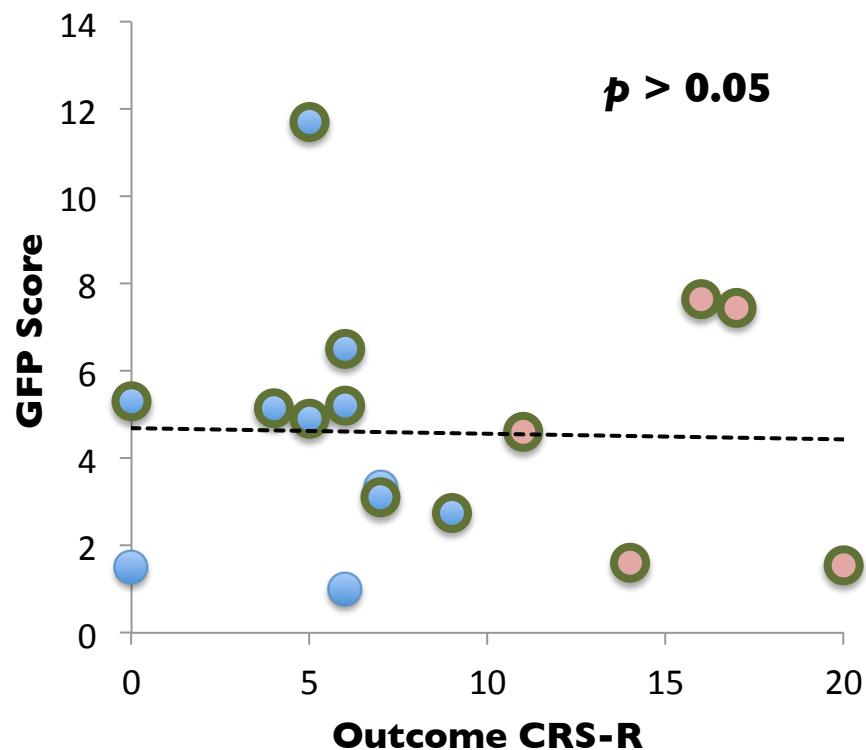


*Sensitivity = 1
Specificity = 1*

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

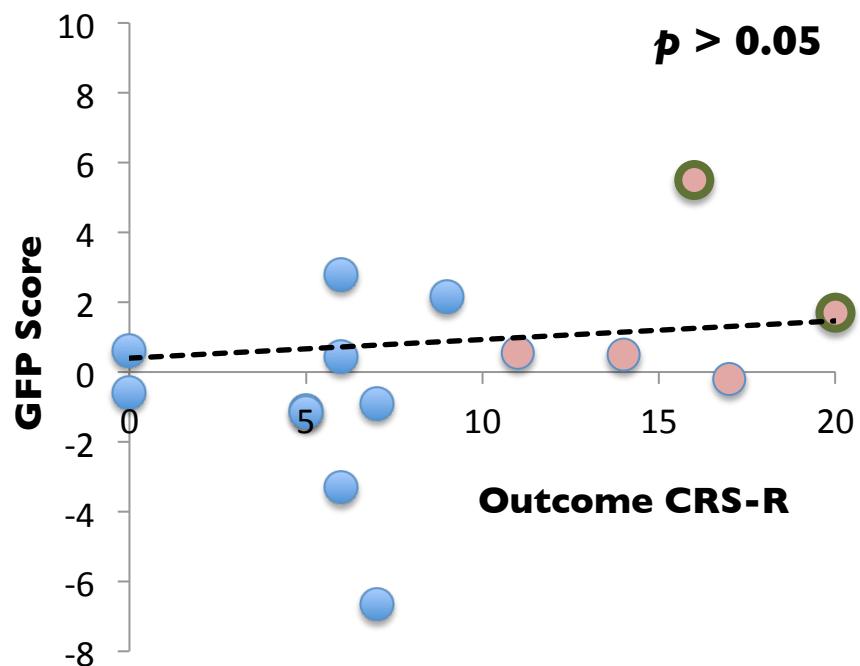
Prognosis

**Primary Auditory Effect
(50-150ms)**



*Sensitivity = 1
Specificity = 0.27*

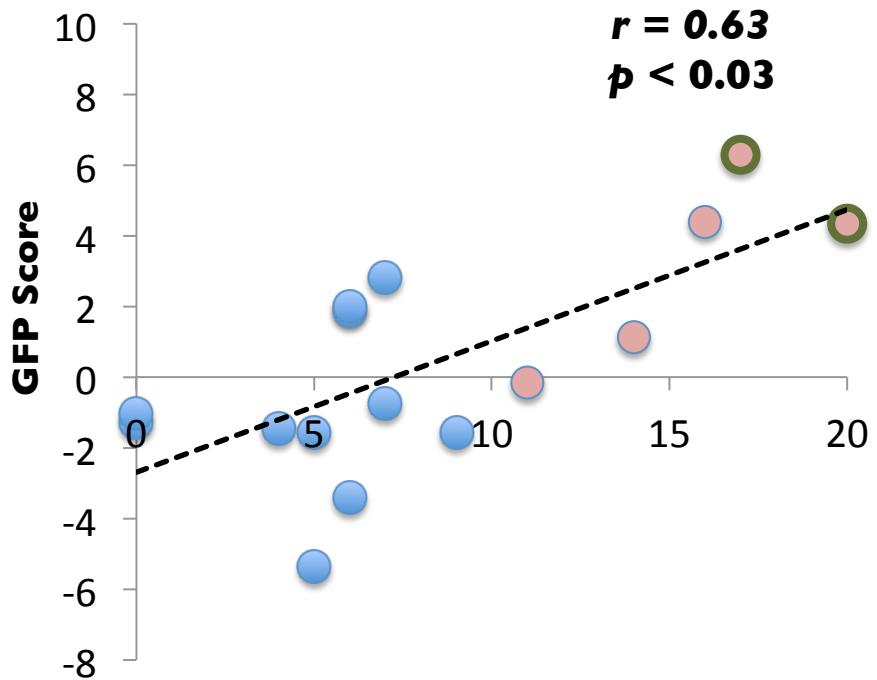
**Interaural Global Effect
(300-600ms)**



*Sensitivity = 0.4
Specificity = 1*

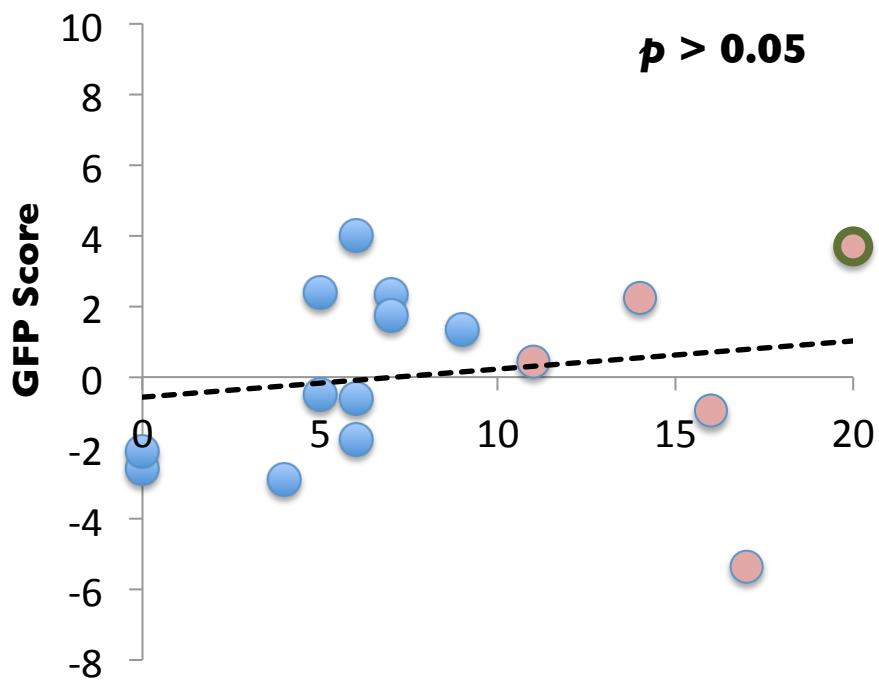
Prognosis

**Monaural Local Effect
(100-300ms)**



Sensitivity = 0.4
Specificity = 1

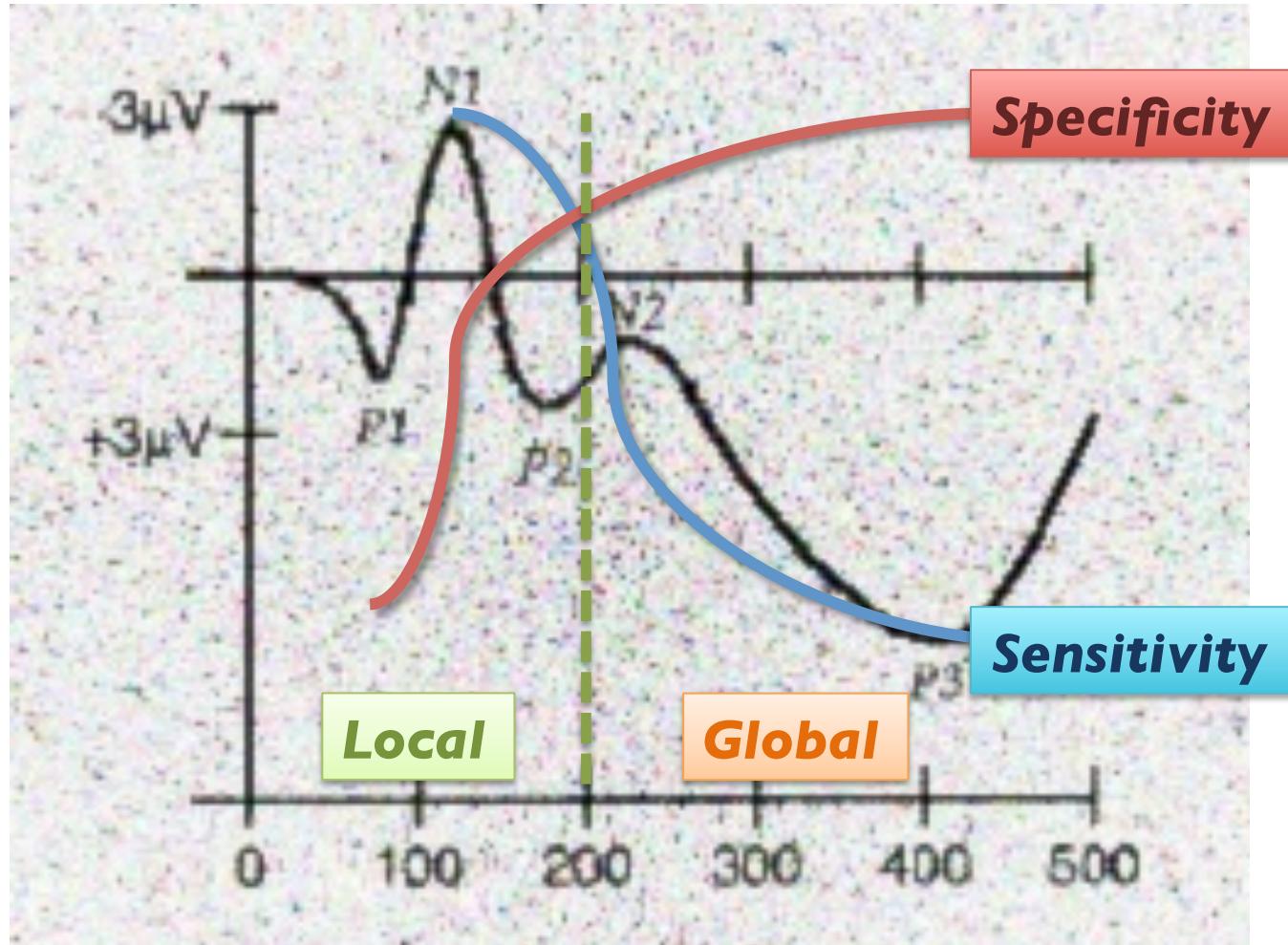
**Monaural Global Effect
(300-600ms)**



Sensitivity = 0.2
Specificity = 1

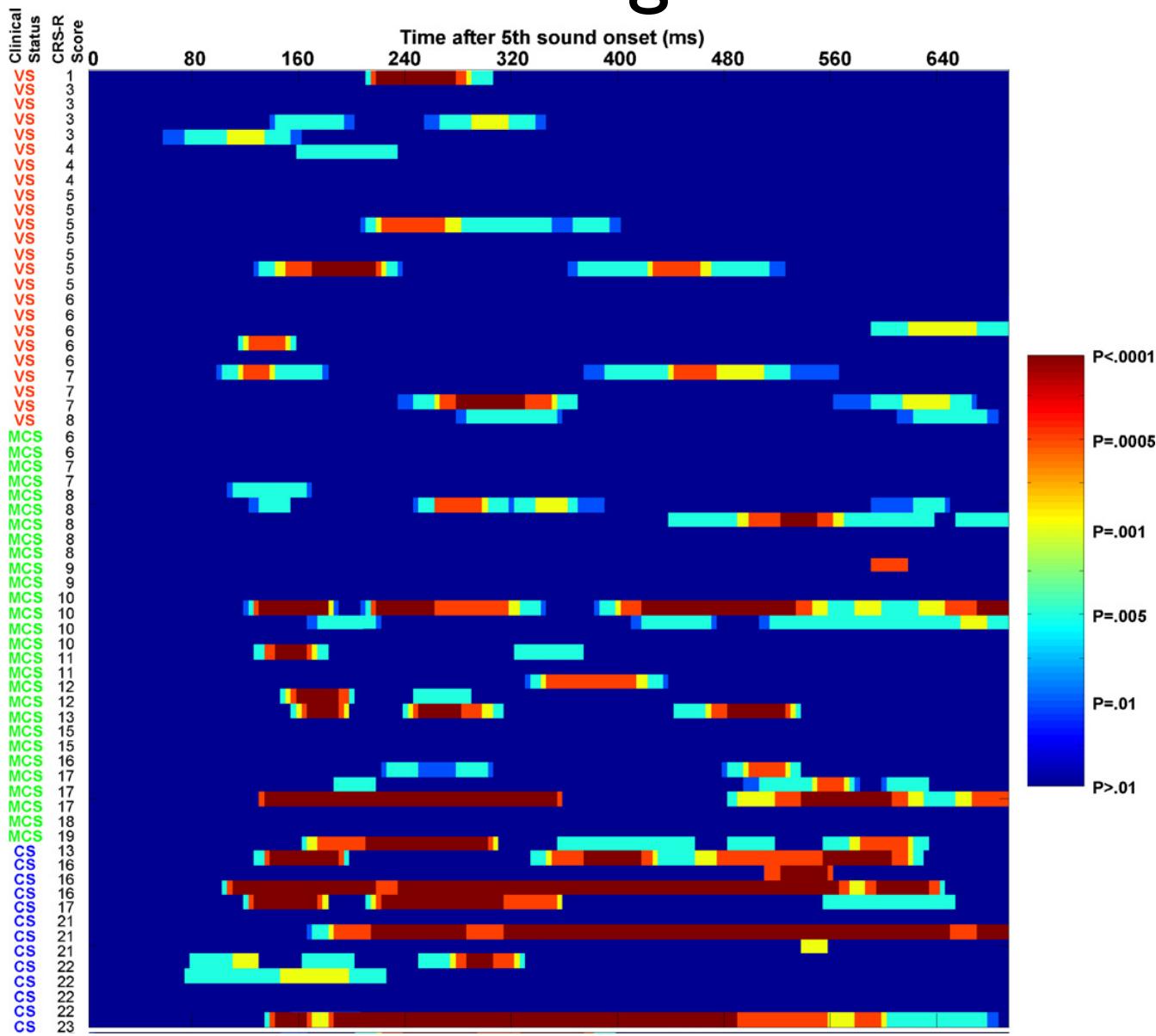
Prognosis

The Big Picture



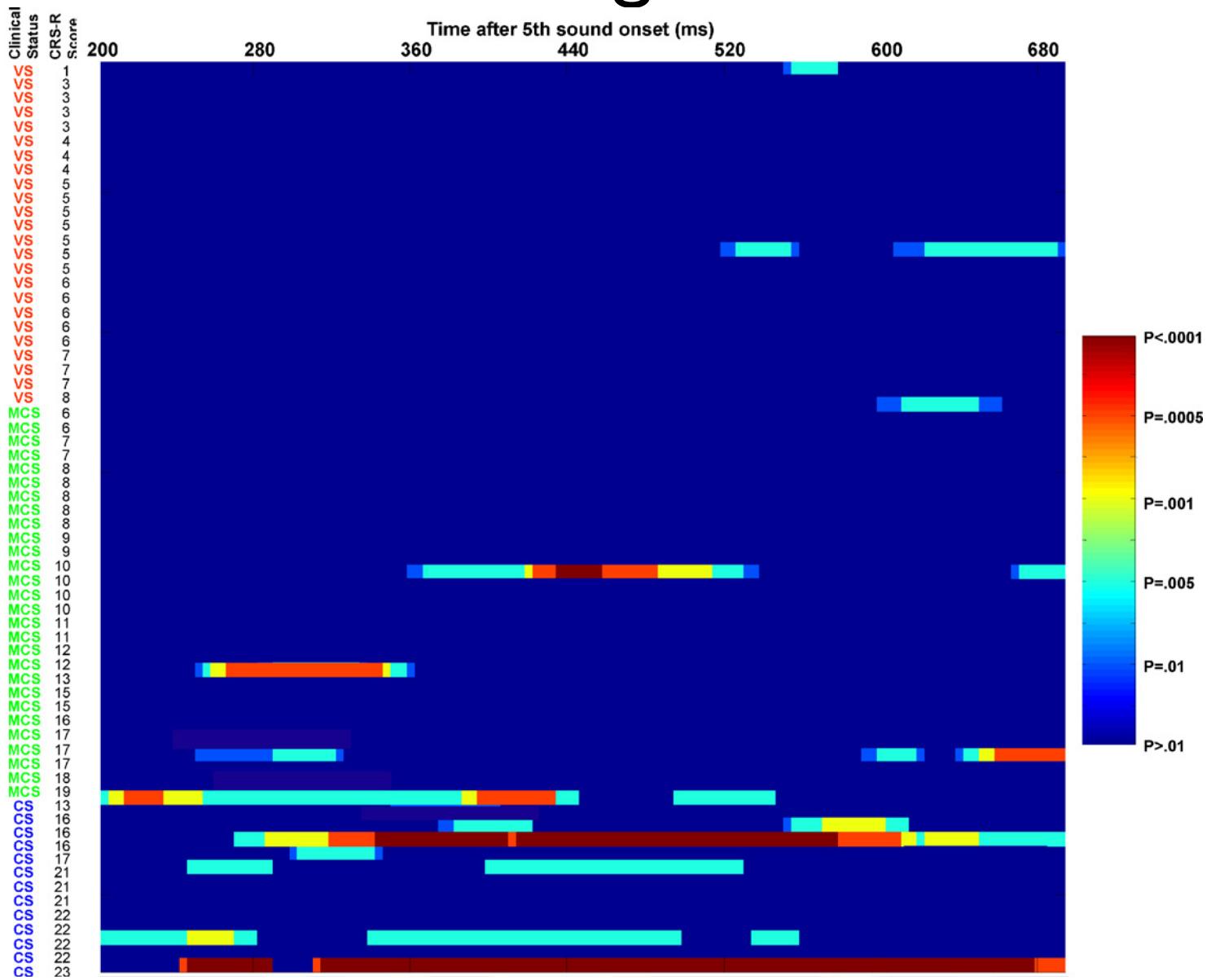
Kane et al., 1993, 1996; Fischer et al, 2004; Daltrozzo et al., 2007

MMN Diagnosis



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

P300 Diagnosis

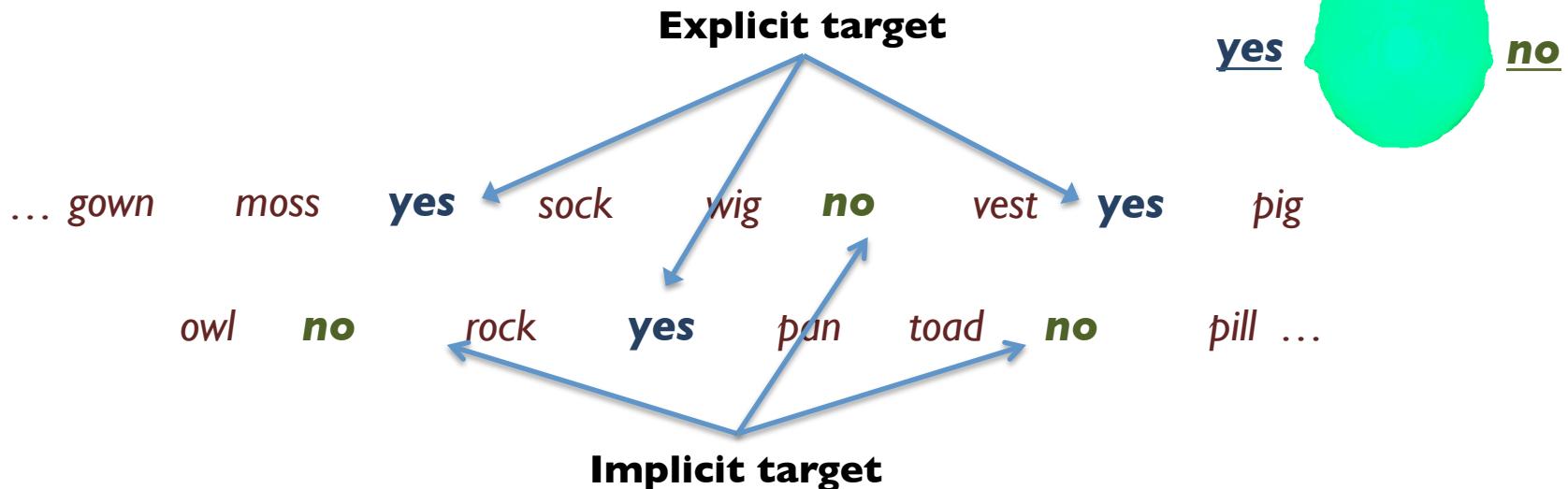


Bekinschtein et al., 2009; Faugeras et al., 2012

Diagnosis

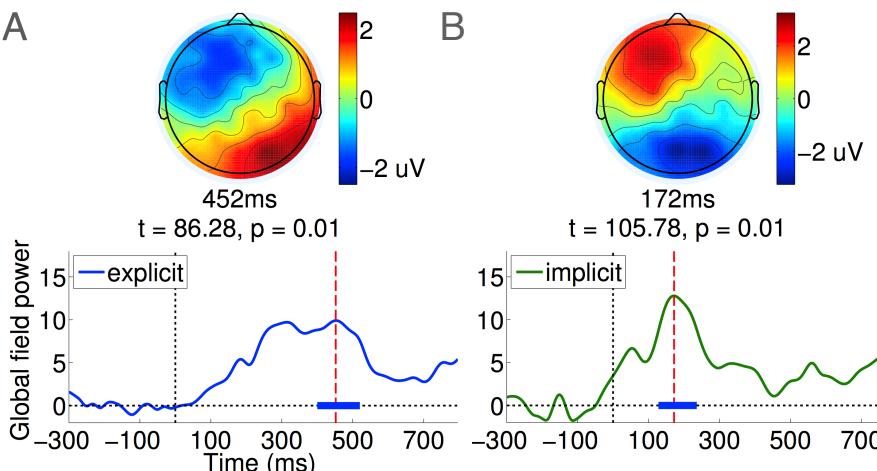
- ‘active’ task to measure language comprehension, attention and awareness
- Streams of words presented auditorily @ ~1 sec/word; blocks of ~1.5 min.
- Subjects asked to attend to **explicit** targets
 - **equally frequent implicit** targets
 - individually **infrequent** distractors
- Letter identity (YES/NO) and laterality (LEFT/RIGHT) randomly switched

“Count the number of times you hear the word yes”

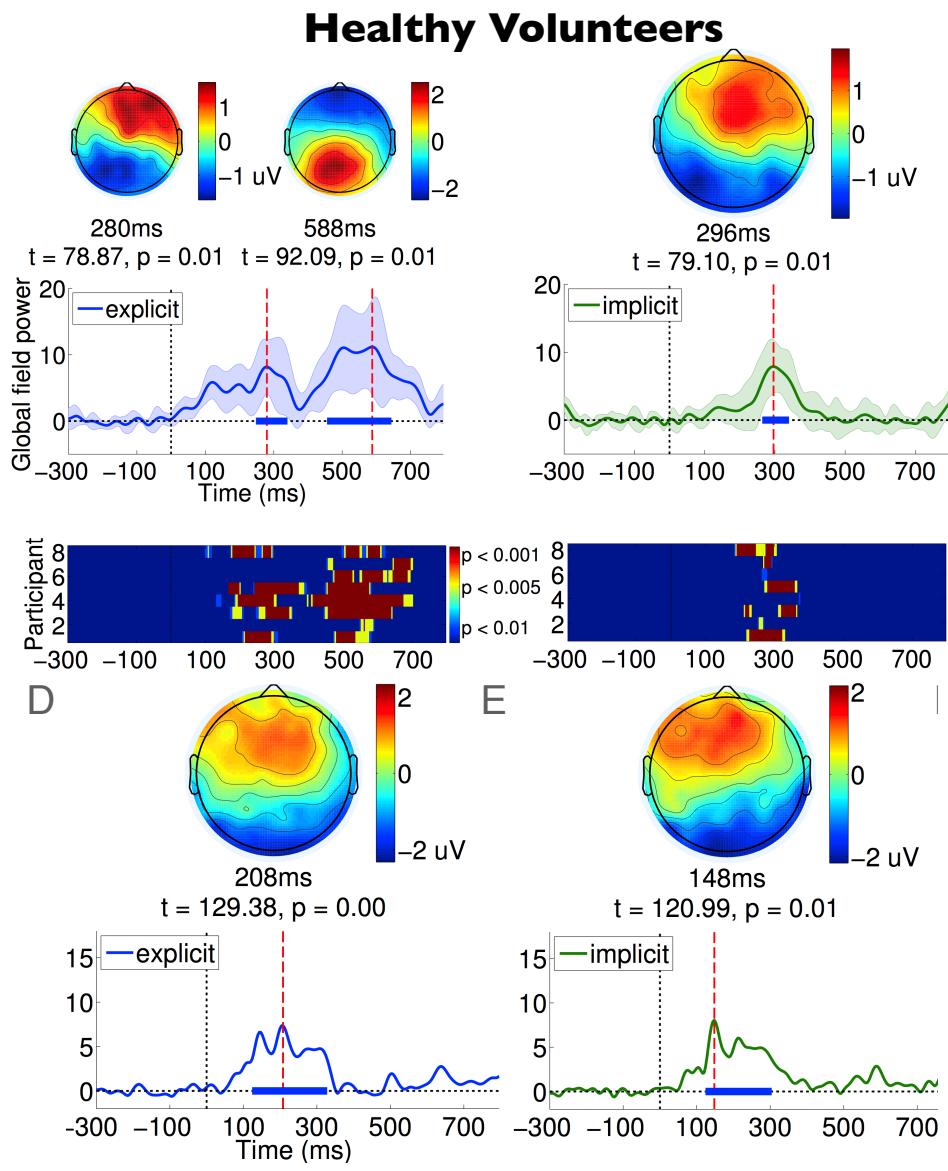


P3a vs. P3b for Diagnosis

- Top-down/bottom-up attentional awareness can be dissociated in the vegetative state
- Late ERPs could contribute to updation of diagnosis



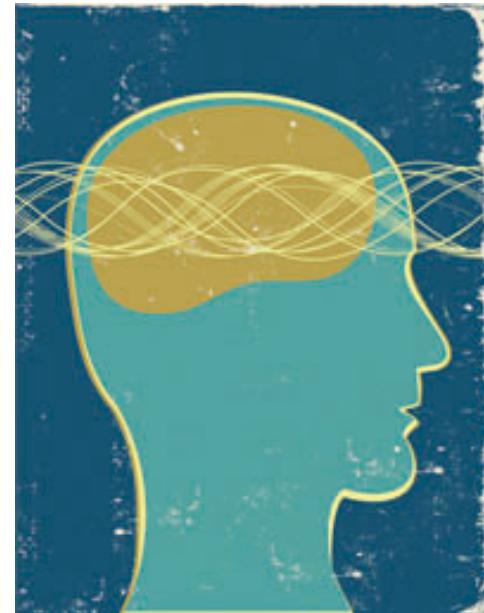
VS patient (TBI)



MCS patient (TBI)

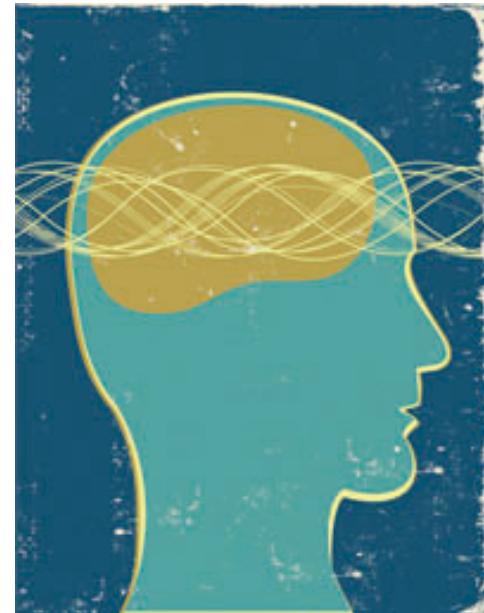
Acute Prognosis: Summary

- (Some) patients' brains recover the ability to engage in ***early, pre-attentional, MMN-based*** prediction
 - Very soon after sedation is stopped
 - Despite the lack of any early behavioural signs
- Only those showing ERP evidence of prediction go on to recover
- Early prediction error ERPs can contribute to improved prognosis



Chronic Diagnosis: Summary

- Some behaviourally unresponsive DoC patients show signs of ***late, attention-dependent, P300-based*** prediction
- P300 ERP is concomitant with reportable conscious perception in healthy volunteers
- Late prediction error ERPs can be used to detect covert attentional engagement and awareness and update diagnosis



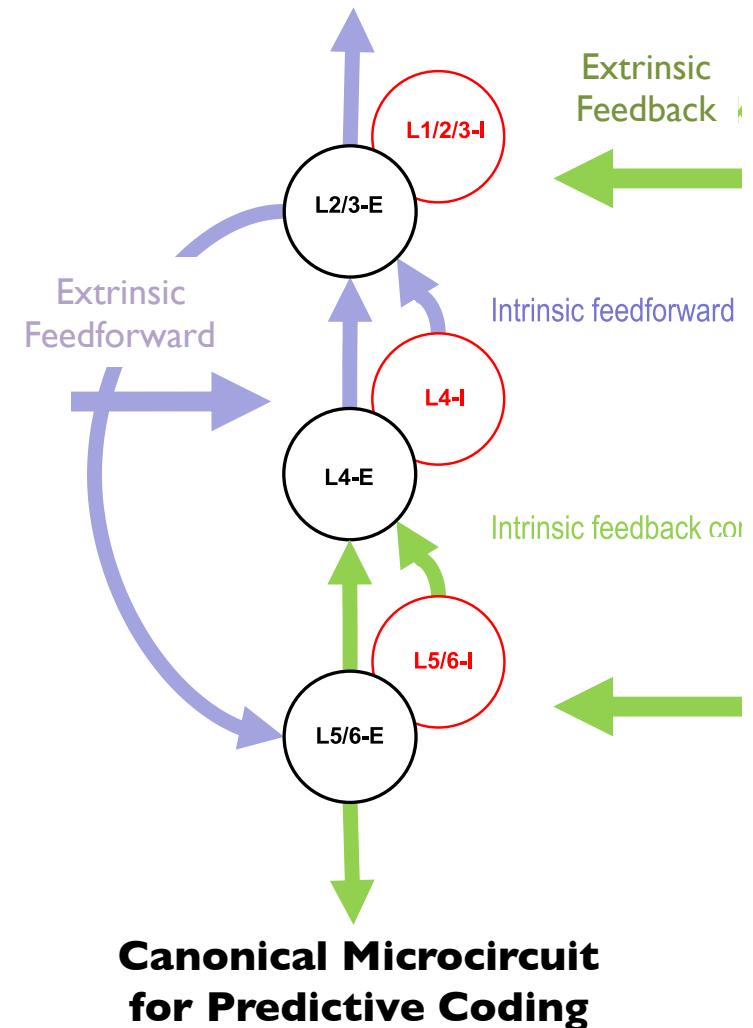
Why Does Hierarchical Prediction Matter?

- **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**



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!



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**MRC Cognition and Brain Sciences Unit
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Dr. Adrian M. Owen

**The Brain and Mind Institute
University of Western Ontario**



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