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Single-trial Neuroimaging

…Identifying Neural Correlates of Trial-to-trial Behavioral Variability…

Paul Sajda

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Department of Biomedical Engineering
Columbia University

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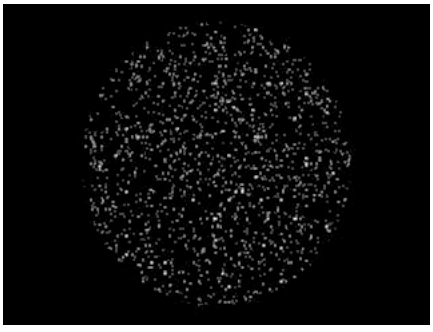
Perceptual Decision Making



Direction of motion discrimination

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Perceptual Decision Making

Object discrimination

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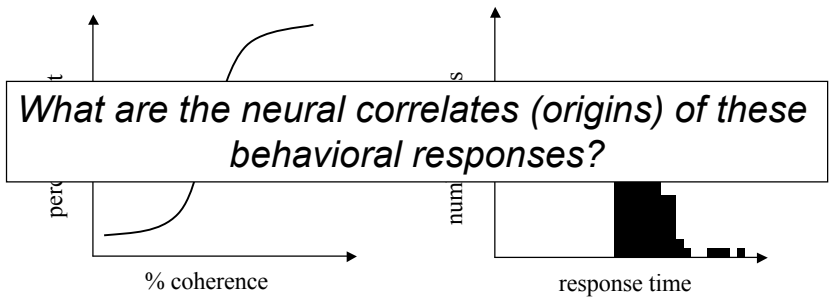
Perceptual Decision Making

Behavioral Response



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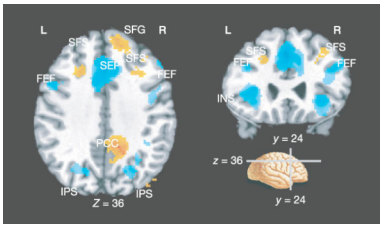
Identifying Cortical Networks Involved in Perceptual Decision Making in the Human Brain

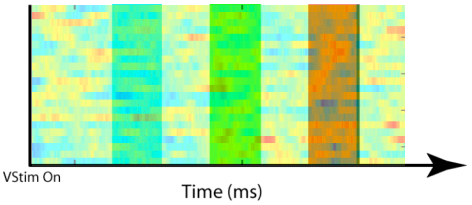
Localization of decision making (fMRI)



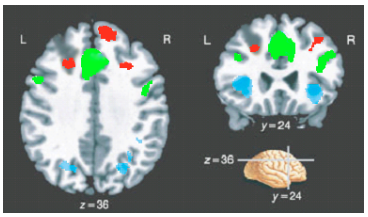
Easy > Hard Decisions
Hard > Easy Decisions

Heekeren et al.
Nature 2004

Timing of decision making (EEG)



Cortical networks (fMRI/EEG)



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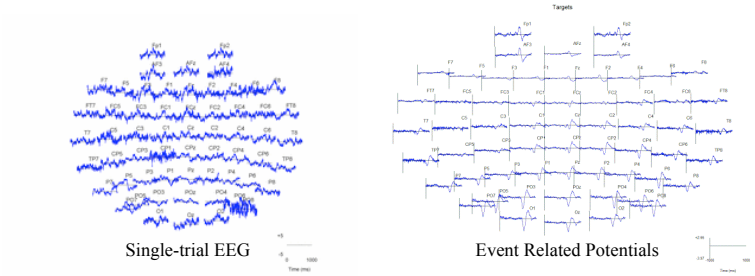
Single-trial EEG Analysis

- Identifying neural correlates requires assessment of trial-by-trial variability--i.e. single trial analysis.
- High-density EEG systems were designed without a principled approach to handling the volume of information provided by simultaneously sampling from large electrode arrays.
- Typically EEG is averaged over trials to increase the amplitude of the signal correlated with cortical processes relative to artifacts.
- In fact, many studies average not only across trials, but subjects,electrodes, or even temporal windows to extract useful information from the data.
- Averaging masks information contained in individual trials and electrodes at specific moments in time.



Single-trial EEG

Event Related Potentials

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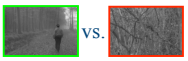
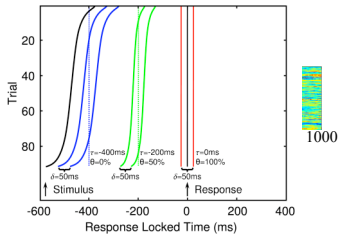
Single-trial Discrimination

Linear discriminants: Compute spatial weighting $\mathbf{w}$ which maximally discriminates sensor array signals $\mathbf{x}(t)$ for two different conditions.



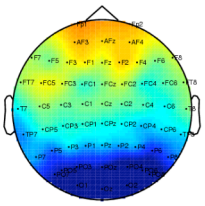
$$\mathbf{y}(t) = \mathbf{w}_{\tau,\delta,\theta}^{T}\mathbf{x}(t) \qquad \tau = \left\{ t_k - \frac{\delta}{2} \rightarrow t_k + \frac{\delta}{2} \right\}$$



Localization of Discriminating Component
possible because we have a linear model

$$\mathbf{a} = \frac{\mathbf{X}\mathbf{y}}{\mathbf{y}^{\mathrm{T}}\mathbf{y}}$$

Strong coupling indicates low attenuation. Intensity on these "sensor projections" $\mathbf{a}$ indicates closeness of the component to the sensors.



Parra, Sajda et al. Neuroimage, 2002
Parra, Spence, Gerson & Sajda, Neuroimage, 2005

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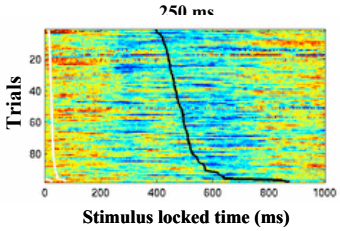
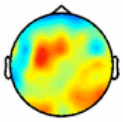
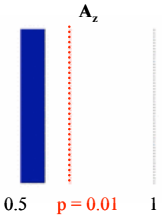
Single-trial Discrimination







$$\mathbf{y}(t) = \mathbf{w}_{\tau,\delta,\theta}^{T}\mathbf{x}(t)$$

$$\mathbf{a} = \frac{\mathbf{X}\mathbf{y}}{\mathbf{y}^{\mathrm{T}}\mathbf{y}}$$

Discrimination performance

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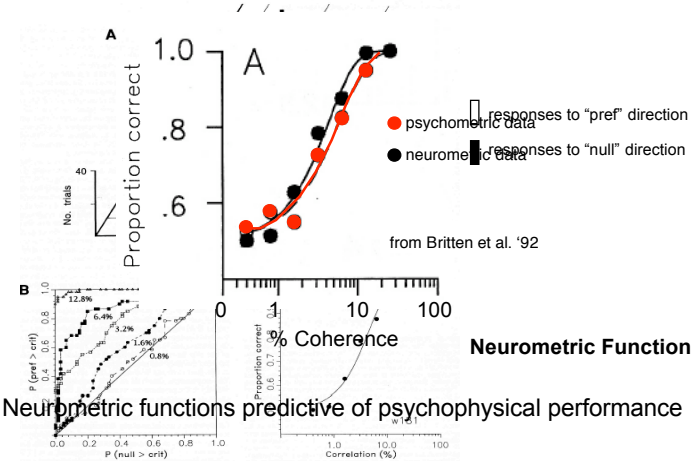
Relating Neural Activity to Behavioral Performance

…previous work: single and multi-unit recordings in primates…

• Signal detection theory used to correlate psychophysical and neuronal responses
Britten et al. '92, '96



Neurometric functions predictive of psychophysical performance

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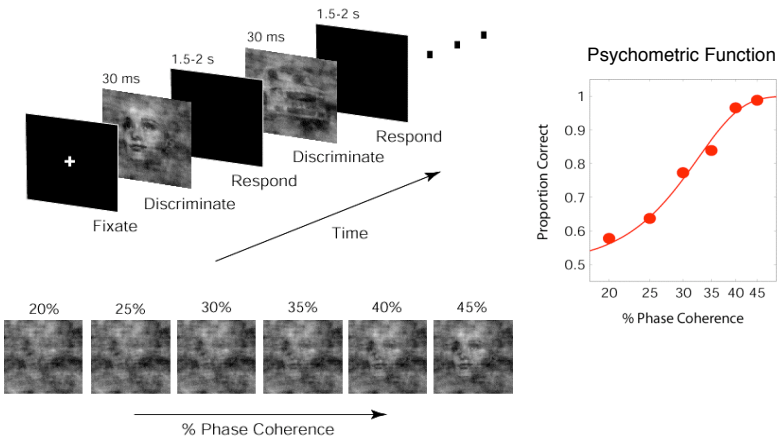
Face vs. Car Discrimination



Philiastides & Sajda, Cerebral Cortex 2006

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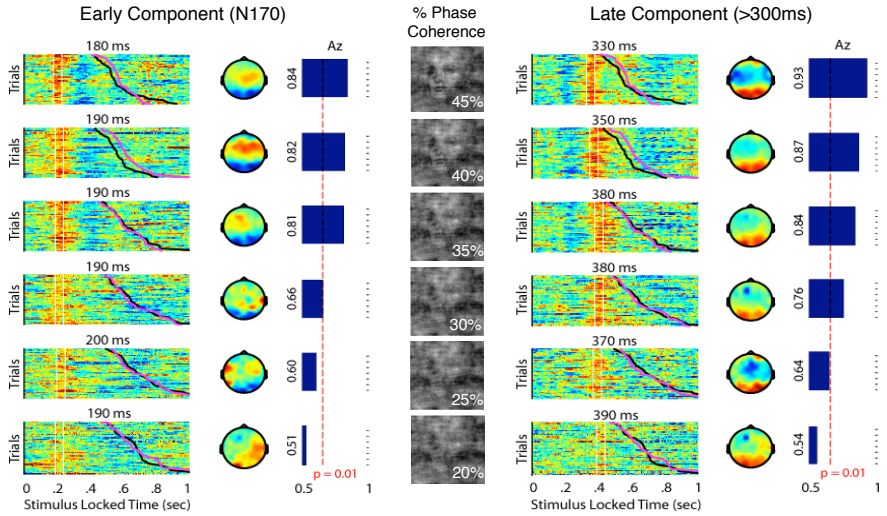
Early and Late Discriminative Components

…both components stimulus locked…



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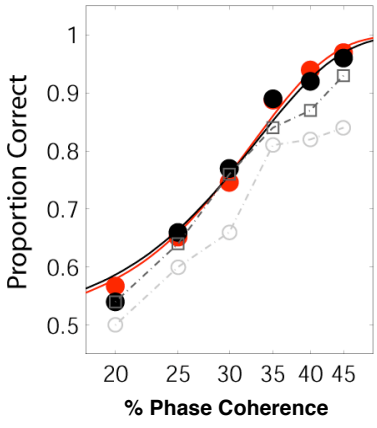
Comparing Neurometric and Psychometric Functions



- Integrate data from ***early and late*** discriminating components to train the classifier.

- Repeat ROC analysis with both sets of data and use Az values to construct a neurometric function.

Psychometric Function
Neurometric Function
Az's (Early Comp.)
Az's (Late Comp.)

Single-trial EEG-derived neurometric functions predict psychophysical performance

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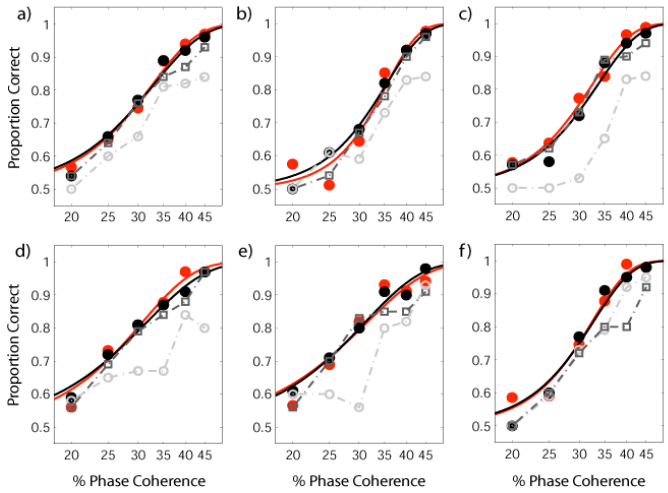
Neurometric and Psychometric Functions

across 6 subjects



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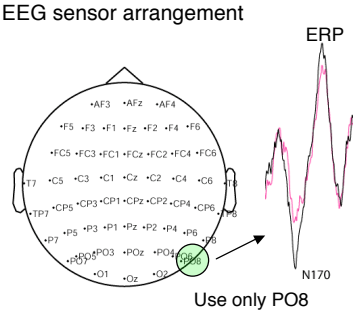
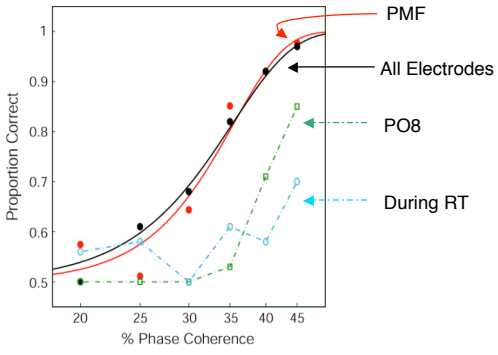
Testing Importance of Spatial Integration and Possible RT Confounds

EEG sensor arrangement





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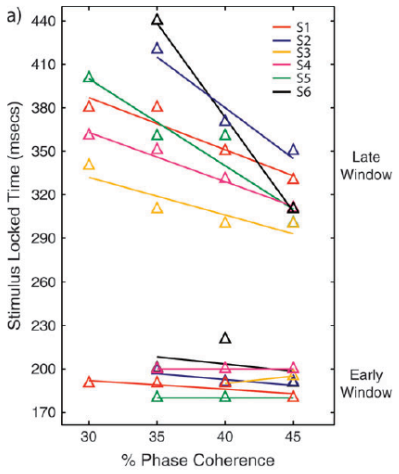
Temporal Latencies of Components as a Function of Stimulus Evidence



Late component systematically shifts forward in time as a function of stimulus evidence

Philiastides and Sajda, SfN 2004 and Cerebral Cortex 2006

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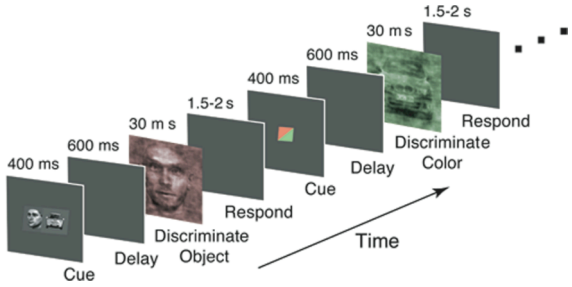
Identifying a Component Discriminative of Task Difficulty



Manipulating task/decision difficulty while keeping stimulus evidence unchanged

Philiastides, Ratcliff & Sajda, J. Neuosci 2006

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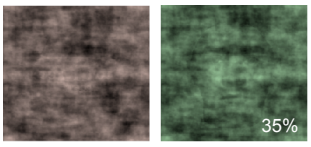
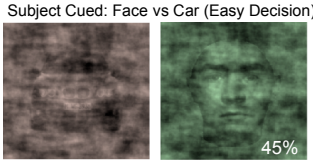
Component Discriminative of Task Difficulty

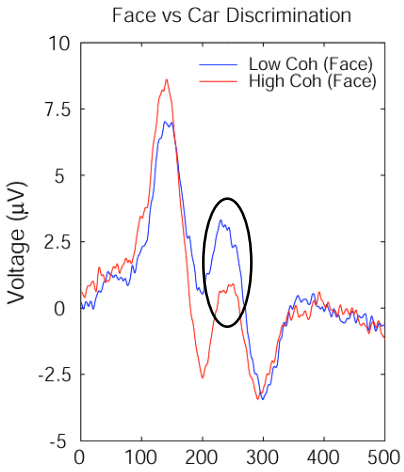
Subject Cued: Face vs Car (Hard Decision)



VS

Subject Cued: Face vs Car (Easy Decision)





Manipulating task/decision difficulty by changing the stimulus evidence

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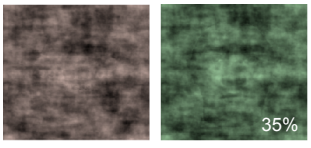
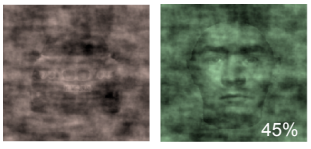
Component Discriminative of Task Difficulty

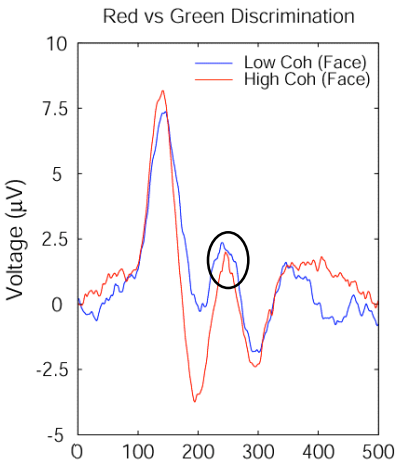
Subject Cued: Red vs Green (Easy Decision)



VS

Subject Cued: Red vs Green (Easy Decision)





Manipulating task/decision difficulty while keeping stimulus evidence unchanged

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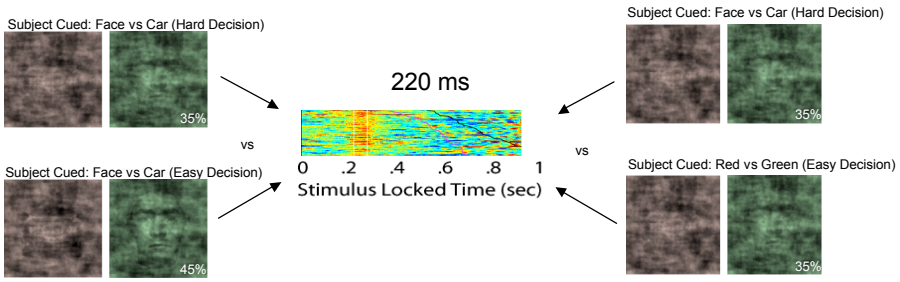
Component Discriminative of Task Difficulty



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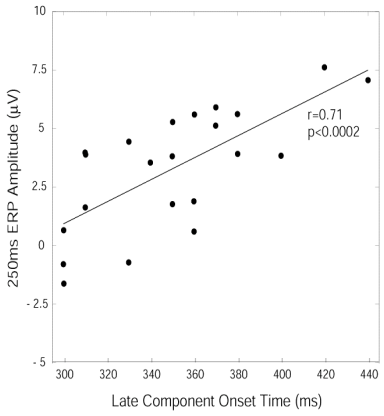
Characterizing the "220" Component

220 amplitude correlates with onset of '**late**' component



220 ms component predicts onset of '**late**' component

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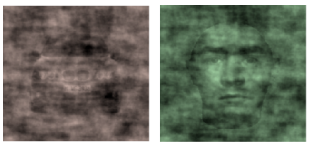
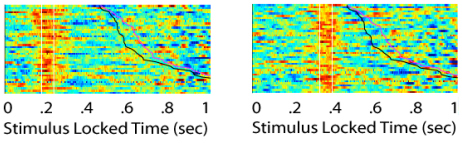
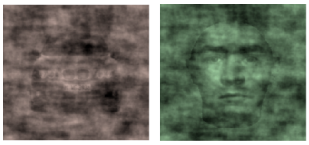
How Are the Two Other Components Affected?

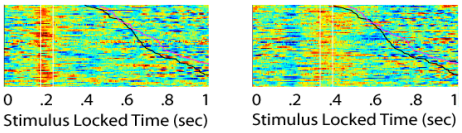
Subject: Face vs Car
Linear discrimination of EEG: Face vs Car





Subject: Red vs Green
Linear discrimination of EEG : Face vs Car





'**Late**' component (face-vs-car) goes away when subjects discriminate color

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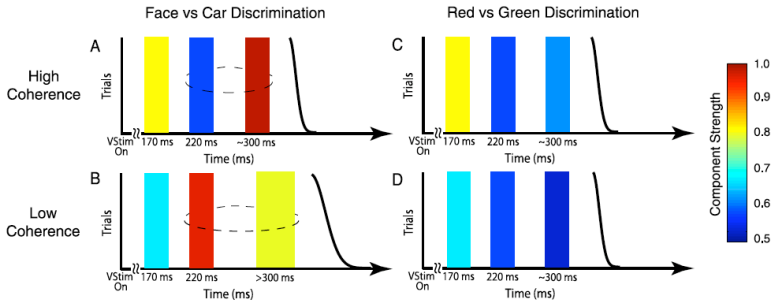
Beginnings of a Timing Diagram



- Early Visual Perception: '**Early**' Component - N170
- Postsensory/Decision Process: "**220**" Component, '**Late**' Component

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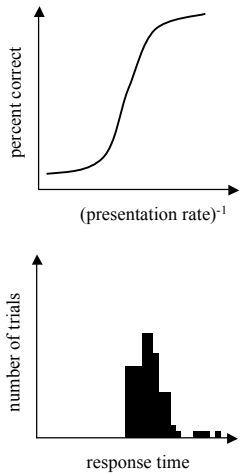
What are the Cortical Origins of Response Time Variability in a Visual Discrimination Task?

Stimulus

Behavioral Response



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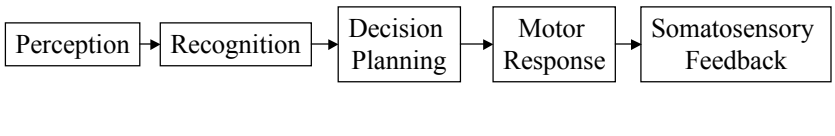
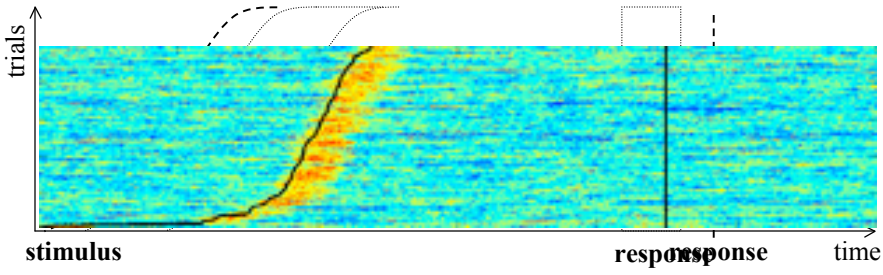
What are the Cortical Origins of Response Time Variability in a Visual Discrimination Task?





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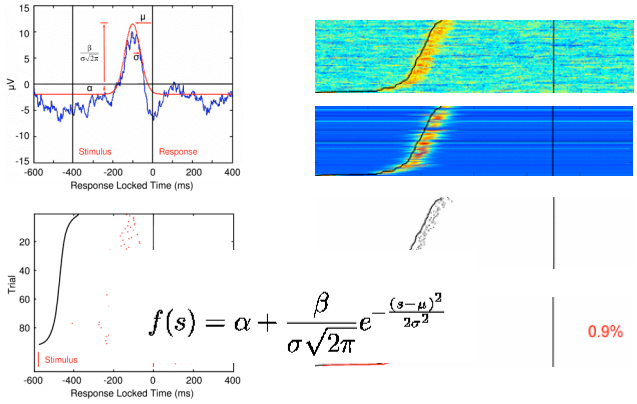
Approach: Analysis of Response Locking for Discriminating Components



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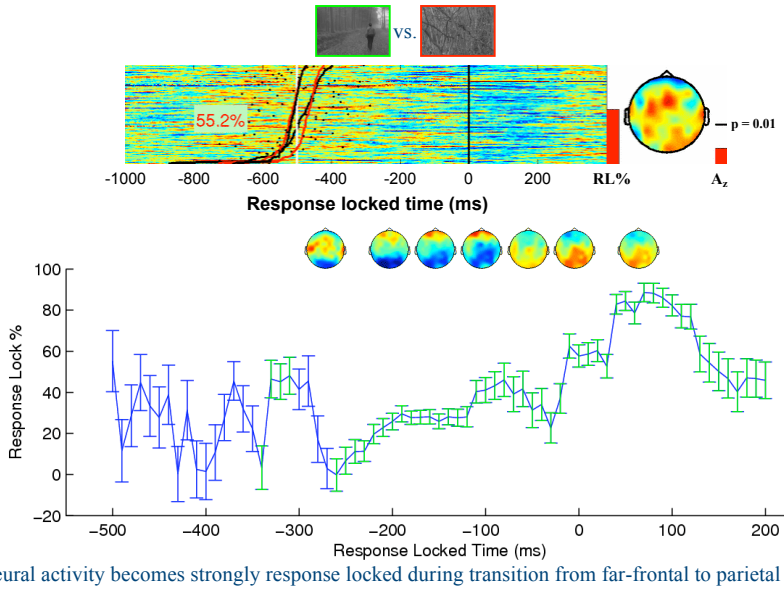
Single-trial Results



Neural activity becomes strongly response locked during transition from far-frontal to parietal activity

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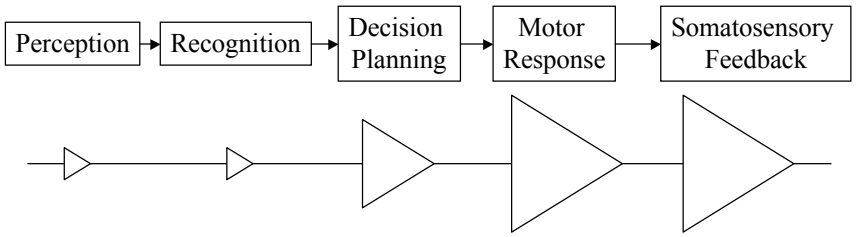
Evidence for Variability Introduced via Late Cortical Processing



Cortical areas engaged in visual object recognition during the RSVP task

Cortical region	Occipital	Frontal	Parietal	Motor and somatosensory
Function	Feature extraction and object encoding	Attention and decision making	Memory and decision making	Response preparation and execution
Earliest processing time (ms)	80	150	300	350
Typical processing time (ms)	150	300	450	500
Minimum delay introduced (%)	5	25	40	100
Typical delay introduced (%)	20	70	85	100

Processing times indicate the latency of earliest neuronal response to target image presentation and a typical average latency. Percentages approximate the cumulative amount of delay introduced by successive processing stages. Values were determined from discriminating component activity and the associated response lock percentages from nine subjects. "Function" describes the commonly ascribed functionality of each area.

Gerson, Parra & Sajda, Neuroimage 2005

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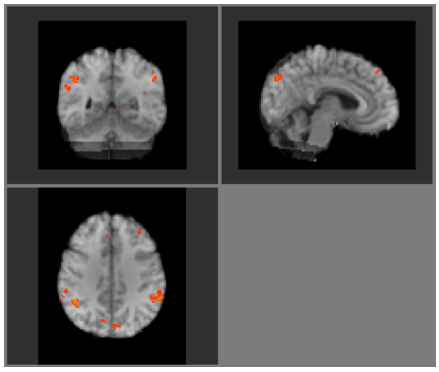
Localization of Discriminating Activities Using fMRI



P<0.001

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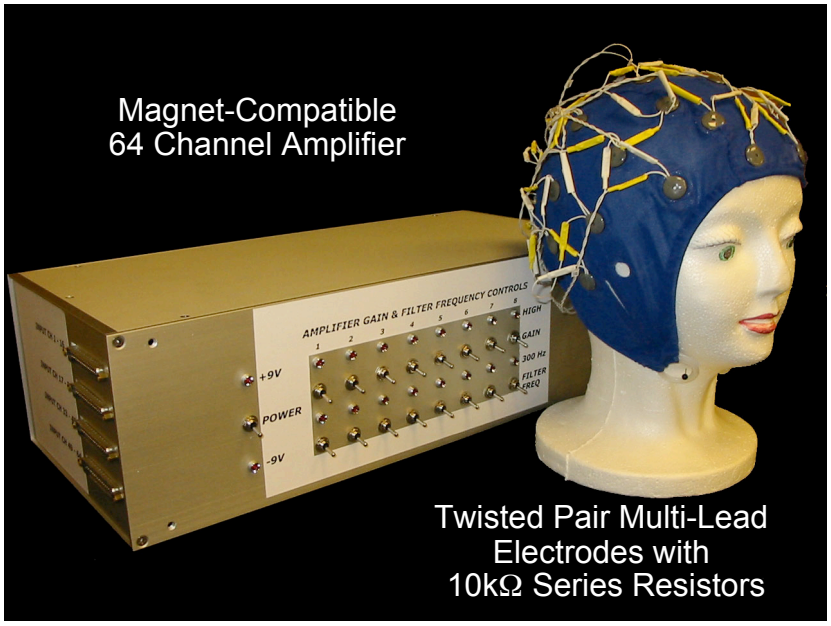

APCTP 8/2007

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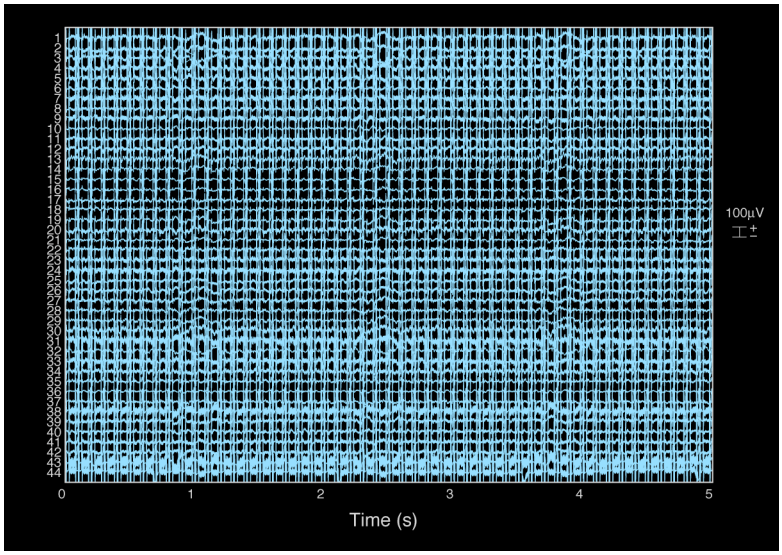
EEG Recorded During fMRI



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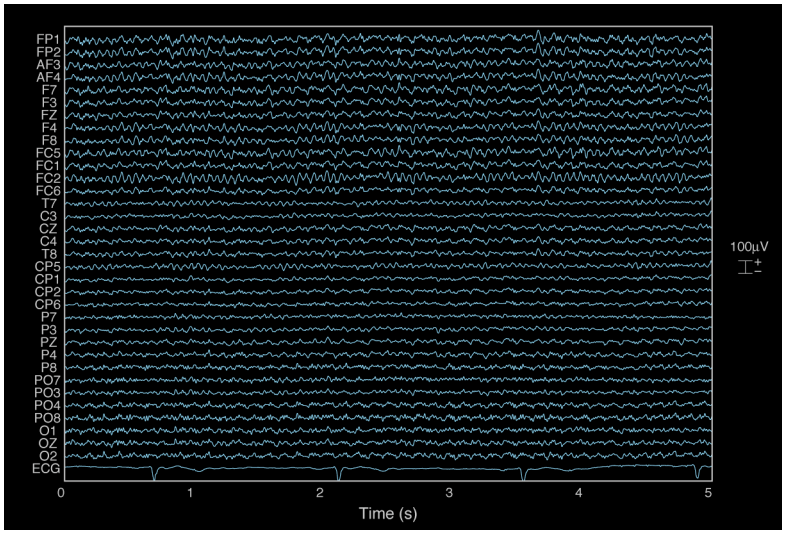
EEG Recorded During fMRI



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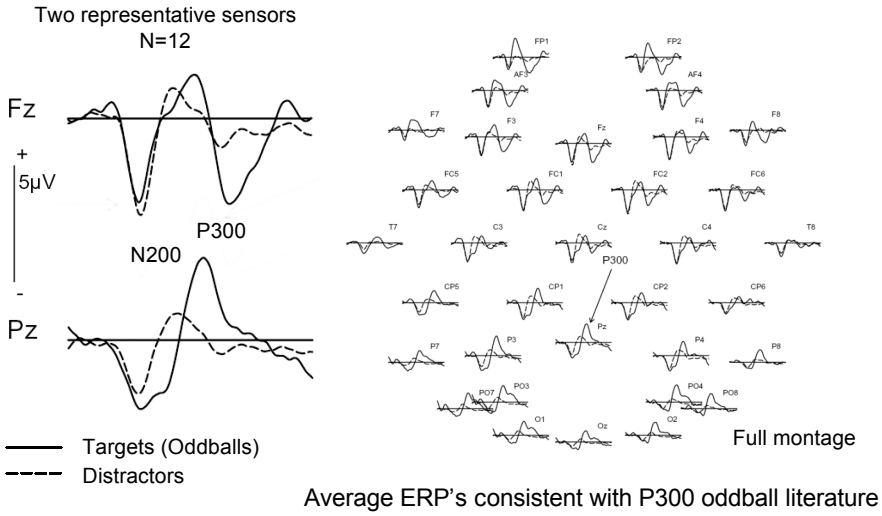
EEG Recorded During fMRI

…ERPs for auditory oddball paradigm…



Average ERP's consistent with P300 oddball literature

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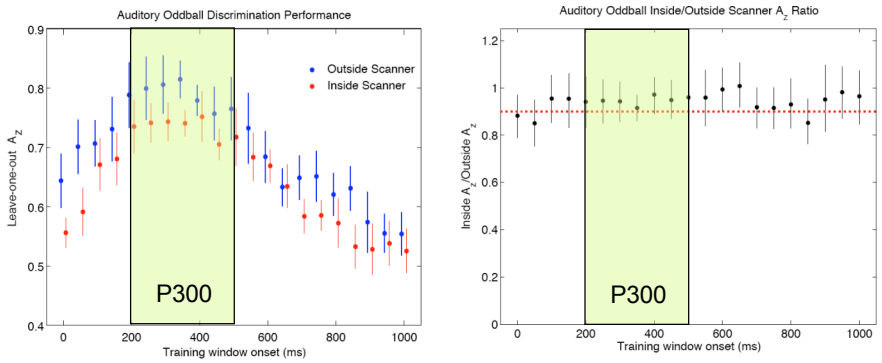
Single-trial Discrimination of EEG Recorded During fMRI

Comparing inside-vs-outside scanner performance



Az inside/outside ratio in the P300 range (200-500 ms) > 94%

Sajda et al. Neural Eng. 2007

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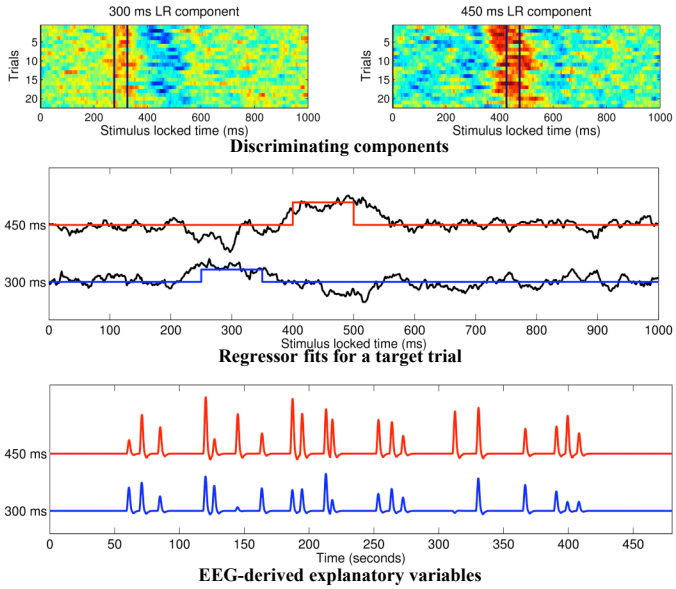
Relating Single-trial EEG and fMRI



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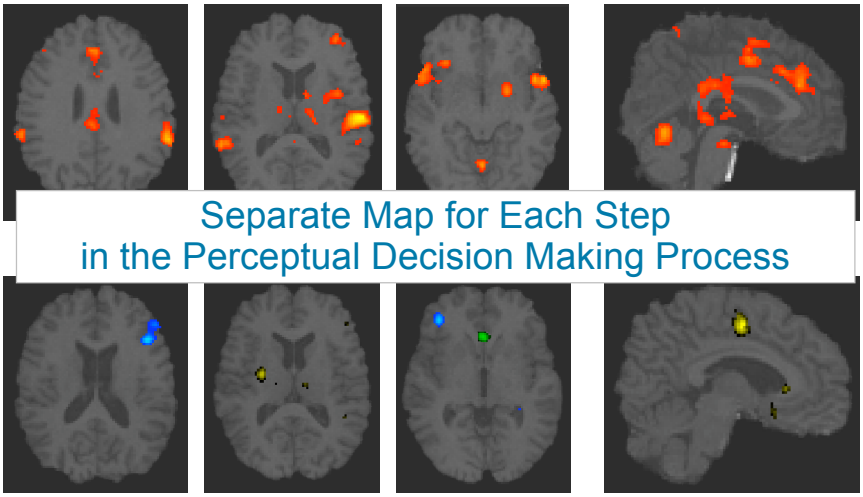
Cortical Networks Localized Using Trial-to-trial Electrophysiological Variability



Separate Map for Each Step
in the Perceptual Decision Making Process

Sajda et al, in prep.

LR 200ms, p<0.01
LR 350ms, p<0.01
LR 450ms, p<0.01

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