Single-trial Neuroimaging
...Identifying Neural Correlates of Trial-to-trial Behavioral Variability...

Paul Sajda
Laboratory for Intelligent Imaging and Neural Computing
Department of Biomedical Engineering
Columbia University

Perceptual Decision Making

Direction of motion discrimination
Perceptual Decision Making

Object discrimination

Behavioral Response

What are the neural correlates (origins) of these behavioral responses?
**Identifying Cortical Networks Involved in Perceptual Decision Making in the Human Brain**

**Localization of decision making (fMRI)**

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 Discrimination

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

\[
y(t) = w_{i,0}^T x_i(t)
\]

**Localization of Discriminating Component**

Possible because we have a linear model

\[
a = \frac{X y}{y^T y}
\]

Strong coupling indicates low attenuation. Intensity on these "sensor projections" \( a \) indicates closeness of the component to the sensors.

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**Single-trial Discrimination**

**Discrimination performance**
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

![Psychometric Function](image)

Neurometric functions predictive of psychophysical performance

Face vs. Car Discrimination

![Psychometric Function](image)

Philiastides & Sajda, Cerebral Cortex 2006
Early and Late Discriminative Components
…both components stimulus locked…

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.

Single-trial EEG-derived neurometric functions predict psychophysical performance
Neurometric and Psychometric Functions across 6 subjects

Testing Importance of Spatial Integration and Possible RT Confounds

EEG sensor arrangement

- Use only PO8 for classification

Proportion Correct vs. % Phase Coherence

- PO8
- All Electrodes
- PMF
- During RT
Temporal Latencies of Components as a Function of Stimulus Evidence

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

Identifying a Component Discriminative of Task Difficulty

Manipulating task/decision difficulty while keeping stimulus evidence unchanged.
Component Discriminative of Task Difficulty

Subject Cued: Face vs Car (Hard Decision)

Subject Cued: Face vs Car (Easy Decision)

Manipulating task/decision difficulty by changing the stimulus evidence

Subject Cued: Red vs Green (Easy Decision)

Manipulating task/decision difficulty while keeping stimulus evidence unchanged
Component Discriminative of Task Difficulty

Subject Cued: Face vs Car (Hard Decision) vs 220 ms vs Subject Cued: Face vs Car (Hard Decision)

Subject Cued: Face vs Car (Easy Decision) vs 45%

Subject Cued: Red vs Green (Easy Decision)

Characterizing the “220” Component

220 amplitude correlates with onset of ‘late’ component

220 ms component predicts onset of ‘late’ component
How Are the Two Other Components Affected?

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

Early Component
Late Component

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

‘Late’ component (face-vs-car) goes away when subjects discriminate color

Beginnings of a Timing Diagram

- Early Visual Perception: ‘Early’ Component - N170
- Postsensory/Decision Process: “220” Component, ‘Late’ Component
What are the Cortical Origins of Response Time Variability in a Visual Discrimination Task?

Stimulus

Behavioral Response

- percent correct
- (presentation rate)\(^1\)
- number of trials
- response time

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

Perception → Recognition → Decision Planning → Motor Response → Somatosensory Feedback

Trials

stimulus → response → time
Approach: Analysis of Response Locking for Discriminating Components

![Graph showing response locking analysis](image)

Single-trial Results

![Single-trial results graph](image)

Neural activity becomes strongly response locked during transition from far-frontal to parietal activity.
Evidence for Variability Introduced via Late Cortical Processing

Perception → Recognition → Decision Planning → Motor Response → Somatosensory Feedback

Cortical areas engaged in visual object recognition during the RVP task:

<table>
<thead>
<tr>
<th>Function</th>
<th>Occipital</th>
<th>Frontal</th>
<th>Parietal</th>
<th>Motor and somatosensory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feature extraction</td>
<td>100</td>
<td>150</td>
<td>300</td>
<td>300</td>
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<td>Object encoding</td>
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<tr>
<td>Attention and decision making</td>
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<tr>
<td>Memory and decision making</td>
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<td>75</td>
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<td>100</td>
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<tr>
<td>Response preparation</td>
<td></td>
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</tbody>
</table>

Processing times indicate the latency of each neural 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 task percentages from nine subjects. "Functions" describes the component-related functionality of each area.

Gerson, Parra & Sajda, Neuroimage 2005

Localization of Discriminating Activities Using fMRI

P<0.001
Magnet-Compatible
64 Channel Amplifier

Twisted Pair Multi-Lead
Electrodes with
10kΩ Series Resistors

EEG Recorded During fMRI
EEG Recorded During fMRI

Two representative sensors
N=12

Targets (Oddballs)

Distractors

Full montage

Average ERP’s consistent with P300 oddball literature
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

Relating Single-trial EEG and fMRI

Discriminating components

Regressor fits for a target trial

EEG-derived explanatory variables
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.

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