The Event-Related Potential
(aka the ERP)
Announcements

- Lab Section Meets Tuesday, room 317B
- Research Proposal...
  - If you sent me a precis, I sent you feedback
  - A few themes
    - Approach Section: Methodological details
      - See Guidelines papers
    - Aims and Hypotheses
    - Mediation and Moderation
- 3x5 time
Construct Validity of P300 (P3, P3b)

- First observed by Sutton, Braren, Zubin, & John (1965)
- P300 Amplitude; Johnson's model is
  \[ P300 \text{ Amplitude} = f[T \times (1/P + M)] \]
  where
  - \( P \) = probability of occurrence,
  - \( M \) = Stimulus meaning, &
  - \( T \) = amount of information transmitted
Figure 12-1. The ERPs in each column were elicited by the
same physical tone; high-pitched tones were used for the left
column and low-pitched tones for the right column. Both
were presented in a Bernoulli series in which the probability
of the two stimuli were equal. In the middle of each column
(labeled “A”) is the ERP elicited by all the presentations of
the stimulus. The curve labeled “AA” was obtained by
averaging together all the tones of one frequency that were
preceded on the previous trial by tones of the same fre-
quency. On the other hand, the curves labeled “BA” were
elicited by stimuli preceded on the previous trial by the
tones of different frequency. Similar sorting operations
were applied to all other curves in this figure. It can be seen
that the same physical tone elicited quite different ERPs,
depending on the events that occurred on the preceding
trials. Whenever a tone terminated a series of tones from
the other category, a large P300 was elicited, and its magni-
tude was a function of the length of the stimulus series.
(From “Effect of Stimulus Sequence on the Waveform of
the Cortical Event-Related Potential,” by K. C. Squires,
C. D. Wickens, N. K. Squires, and E. Donchin. Science,
1976, 193, 1142–1146. Copyright 1976 by the AAAS.)
Figure 2. Grand-mean waveforms (N = 7) from Fz, Cz, and Pz from three different tasks. The ERPs elicited in an oddball paradigm run under two different task conditions, Counting (solid line) and Reaction Time (dashed line), are superimposed on the ERP elicited when the same stimulus signified correct performance in a feedback paradigm (dotted line). The waveforms were all elicited by a 1000 Hz, 50dB SL tone (p = .50).
P3 Latency

- An index of processing time, independent of response requirements
- RT measures confounds the two
- McCarthy & Donchin (1981) experiment:
  - The words "RIGHT" or "LEFT" embedded in a matrix of letters of X's
  - Compatible condition: respond with hand indicated in matrix; Incompatible condition: respond with opposite hand (e.g., LEFT signals right hand response);
- **Results:**
  - P300 latency delayed when discriminability more difficult
  - Response compatibility had no effect on P300 latency
  - Note amplitude reduction as function of noise--information transmission)
a

b

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image.png}
\caption{Diagram showing the effect of noise on word recognition.}
\end{figure}

\begin{itemize}
\item No noise:
  \begin{itemize}
  \item A
  \item \#\#\#\#\#\# \#\#\#\#\#\# \#R\!G\!HT\ #\#\#\#\#\# \#\#\#\#\#\# \#L\!E\!F\!T\!\ a \ #\#\#\#\#\# \#\#\#\#\#\# \#b
  \end{itemize}
\item Noise:
  \begin{itemize}
  \item NR\!G\!HT \ K\!W\!S\!M\!N\!T
  \item BM\! J\! U\! K\! M \ U\! Y\! R\! M\! U\! D
  \item EQ\!\!\! I\! K\! M \ V\!T\! F\! M\! Z\! S
  \item KE\!H\!E\!H\! G \ I\!L\!E\!F\!T\!A
  \end{itemize}
\end{itemize}
Not only difficulty in physical discrimination, but difficulty in cognitive categorization.

Figure 4.10. ERP waveforms at Pz averaged across subjects for three different semantic categorization tasks. The solid line indicates ERPs obtained during a task in which the subjects had to distinguish between the word DAVID and the word NANCY (the FN condition). The dotted line indicates ERPs obtained during a task in which the subjects had to decide whether a word presented was a male or a female name (the VN condition). The dashed line indicates ERPs obtained during a task in which the subjects had to decide whether a word was or was not a synonym of the word PROD (SYN condition). These three tasks were considered to involve progressively more difficult discriminations. Note the latency of P300 peak is progressively longer as the discrimination is made more difficult. (Copyright 1977, AAAS. Adapted with permission of the author and publisher from Kutas, McCarthy, & Donchin, 1977.)
What, then, does the P300 mean in very general terms?

- A stimulus (or class of stimuli) is "important"; denotes information that is necessary or useful to the task
- Stimulus is meaningful, important, noticeable
- Evaluated within context of working memory? (cf. Donchin & Coles, 1988; Verlager 1988; Polich, 2007; Verlager, 2008)

The P3a (Squires, Squires, and Hillyard, 1975): P3-like component with a frontal maximum and occurs to improbable stimuli in the "to-be-ignored" class of stimuli; a novelty response.
How Many P3s?

- The Classic P3/P300
  - Parietal Central Maximum
  - Largest when stimuli rare and task-relevant

- The P3a (Squires et al., 1975) or Novelty P3
  - More anterior scalp distribution
  - Slightly earlier latency
  - Responsive to rare, unexpected, unattended stimuli
Simons et. al, 2001

• Squires Task was tones (two tones)
• Courchesne task was digitized speech (“me” “you” and collection of naturally occurring sounds
• In all cases subjects merely counted Tones

Fig. 1. ERP waveforms (left) and PCA basis waves (right) obtained from infrequent targets during the Squires (top) task and infrequent nontargets/novels during the Courchesne (bottom) task. PCA was conducted during the 220–420 ms epoch following stimulus onset and four factors were extracted from each data set.
P3a – Can you see it?

- Some inconsistencies in finding P3a following the initial Squires, Squires and Hilyard 1975 report
- Comerchero & Polich (1998) may have resolved the enigma
  - P3a highly dependent on foreground discrimination
<table>
<thead>
<tr>
<th>Modality</th>
<th>Nontarget distinctiveness</th>
<th>Auditory</th>
<th></th>
<th>Visual</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Target (0.10)</td>
<td></td>
<td>2000 Hz</td>
<td>2000 Hz</td>
<td>12.57 cm²</td>
<td>12.57 cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75 dB</td>
<td>75 dB</td>
<td>● Blue</td>
<td>● Blue</td>
</tr>
<tr>
<td>Standard (0.80)</td>
<td></td>
<td>1940 Hz</td>
<td>1940 Hz</td>
<td>10.18 cm²</td>
<td>10.18 cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75 dB</td>
<td>75 dB</td>
<td>● Blue</td>
<td>● Blue</td>
</tr>
<tr>
<td>Nontarget (0.10)</td>
<td></td>
<td>500 Hz</td>
<td>4000 Hz</td>
<td>12.57 cm²</td>
<td>12.57 cm²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75 dB</td>
<td>90 dB</td>
<td>● Blue</td>
<td>● Fuchsia</td>
</tr>
</tbody>
</table>
Note: Nontarget peak amplitude was earlier and larger at the frontal electrodes than those from the target stimuli, but especially when foreground discrimination is difficult.
Fig. 1. Schematic illustration of the single-stimulus (top), oddball (middle), and three-stimulus (bottom) paradigms, with the elicited ERPs from the stimuli of each task at the right (Polich and Criado, 2006). The single-stimulus task presents an infrequent target (T) in the absence of any other stimuli. The oddball task presents two different stimuli in a random sequence, with one occurring less frequently than the other (target = T, standard = S). The three-stimulus task is similar to the oddball with a compelling distracter (D) stimulus that occurs infrequently. In each task, the subject is instructed to respond only to the target and otherwise to refrain from responding. The distracter elicits a P3a, and target elicits a P3b (P300). Reprinted with permission of the authors and from Elsevier (Copyright 2006).
“…the manipulation of target-standard stimulus discriminability produced a stimulus environment in which the infrequently occurring nontarget engaged focal attention in a manner similar to that observed previously for ‘novel’ stimuli.”

“However, all stimuli in the present study were employed because of their ‘typical’ characteristics, so that the results imply that an anterior P3a component can be produced without using ‘novel’ stimuli per se.”

“If stimulus context is defined primarily by a difficult target-standard discrimination, attentional redirection to the nontarget would occur because of the frontal lobe activation that generates P3a.”

Comerchero & Polich 1998, p. 47
ERPs and Memory

- Sensitive to both Recognition
- Likely episodic recollection
- Sensitive to Encoding
Repetition Priming Effects

- Robust effect that repeated items produce an enhanced late positivity across a broad latency range
- Magnitude of effect related to strength of memory trace
Replication Priming

- Are there repetition effects that do not depend on the subjective awareness of the subject?
- Can use Masked Priming to examine (Schnyer, Allen, Forster, 1997)
Standard Repetition Effect for Words Seen Unmasked in Previous Blocks
Task is to make OLD-NEW decision

Schnyer, Allen, Forster, 1997
Standard Repetition Effect for Words Seen Unmasked in Previous Blocks
But Task is to make WORD-NONWORD decision

Note consistency with hemispheric encoding/retrieval asymmetry (HERA) model: left encode, right retrieve

Schnyer, Allen, Forster, 1997
<table>
<thead>
<tr>
<th>Trial Duration</th>
<th>Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>100/150</td>
<td><img src="100-150" alt="Image" /></td>
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<tr>
<td>150/200</td>
<td><img src="150-200" alt="Image" /></td>
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<td>200/250</td>
<td><img src="200-250" alt="Image" /></td>
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<tr>
<td>950/1000</td>
<td><img src="950-1000" alt="Image" /></td>
</tr>
</tbody>
</table>

Masked Repetition Priming Effect for Words Presented only a Trial Previously

Schnyer, Allen, Forster, 1997
Memory Encoding

- Words subsequently remembered show enhanced positivity at encoding
- Strategy interacts, however
Note prototypic DM effect on left, but not on right for those that used elaborative strategies. Note enhancement over frontal lead for these latter subjects.

Figure 4.12. ERPs elicited by “isolated” words that were later recalled (solid line) or not-recalled (dashed line). The left column shows ERPs for subjects who used rote mnemonic strategies; the right column shows ERPs for subjects who used elaborative strategies. Note that the amplitude of P300 is related to subsequent recall for the rote memorizers, but not for elaborators. (Copyright 1986, Elsevier Science Publishers. Reprinted with permission of the publisher from Fabiani, Karis, & Donchin, 1986b.)
Fig. 3.  A: Grand mean ERPs elicited by study items that were subsequently associated with remember or know judgments (hits) or were unrecognized (misses) during the subsequent recognition test. B: Grand mean difference waveforms computed by subtracting the ERPs to study items subsequently missed from those that were subsequently associated with either a remember or know judgment (Modified from Friedman and Trott, 2000). C: CSD maps for 2 intervals (500–800; 810–1,100 ms) measured in the Dm waveform associated with a subsequent Remember judgment. Data in A and B recorded at a left inferior prefrontal scalp site.
Indirect Assessments of Recognition

- Can the ERP detect recognition, independent of subjects’ overt responses?
- Two applications
  - Clinical Malingering
  - Forensic Assessment
ERP Memory Assessment Procedures

- Learn a list of words
- Learn a second list of words
- Task: Concealed (1st list) and Nonconcealed (2nd list) words appear infrequently.

<table>
<thead>
<tr>
<th>Item Type</th>
<th>Probability</th>
<th>Response</th>
<th>P3 Amplitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonconcealed</td>
<td>1/7</td>
<td>“Yes”</td>
<td>Large</td>
</tr>
<tr>
<td>Concealed</td>
<td>1/7</td>
<td>“No”</td>
<td>Large if Recognized</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Small if not Recognized</td>
</tr>
<tr>
<td>Unlearned</td>
<td>5/7</td>
<td>“No”</td>
<td>Small</td>
</tr>
</tbody>
</table>

- Similar to procedures by Rosenfeld et al, Farwell & Donchin
# Motivational Variations

<table>
<thead>
<tr>
<th>Conceal</th>
<th>Lie</th>
<th>Lie + $$</th>
</tr>
</thead>
<tbody>
<tr>
<td>➢ &quot;YES&quot; for words <em>JUST</em> learned, &quot;NO&quot; for all others</td>
<td>➢ &quot;YES&quot; for words learned</td>
<td>➢ &quot;YES&quot; for words learned</td>
</tr>
<tr>
<td>➢ <em>Try to hide the fact that you learned the first list of words I taught you</em></td>
<td>➢ <em>Lie about words from the first list I taught you</em></td>
<td>➢ <em>Lie about words from the first list I taught you</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td>➢ $5.00 incentive</td>
</tr>
</tbody>
</table>
After Allen & Iacono, 1997
The Challenge

To provide statistically supported decisions for each and every subject, despite considerable individual variability in ERP morphology.
P3 Amplitude
Sensitivity = .925
Specificity = .920

Raw ERP H^2
Sensitivity = .950
Specificity = .920

1\textsuperscript{st} Derivative H^2
Sensitivity = .875
Specificity = .810

2\textsuperscript{nd} Derivative H^2
Sensitivity = .750
Specificity = .740

Deviation H^2
Sensitivity = .925
Specificity = .920
Bayesian Combination of ERP Indicators: Probability that an ERP was elicited by Learned Items

<table>
<thead>
<tr>
<th>Subject</th>
<th>NonConceal</th>
<th>Conceal</th>
<th>U1</th>
<th>U2</th>
<th>U3</th>
<th>U4</th>
<th>U5</th>
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</thead>
<tbody>
<tr>
<td>#01</td>
<td>1.0</td>
<td>0.999</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td>#02</td>
<td>1.0</td>
<td>1.0</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>#03</td>
<td>1.0</td>
<td>0.999</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.002</td>
<td>0.000</td>
</tr>
<tr>
<td>#04</td>
<td>1.0</td>
<td>1.0</td>
<td>0.000</td>
<td>0.001</td>
<td>0.002</td>
<td>0.000</td>
<td>0.000</td>
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<tr>
<td>#05</td>
<td>1.0</td>
<td>0.971</td>
<td>0.002</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
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<tr>
<td>#06</td>
<td>1.0</td>
<td>0.999</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
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<tr>
<td>#07</td>
<td>0.983</td>
<td>1.0</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>#18</td>
<td>0.996</td>
<td>0.983</td>
<td><strong>0.874</strong></td>
<td>0.001</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>#19</td>
<td><strong>0.009</strong></td>
<td><strong>0.214</strong></td>
<td><strong>0.971</strong></td>
<td>0.000</td>
<td>0.002</td>
<td><strong>0.189</strong></td>
<td><strong>0.983</strong></td>
</tr>
<tr>
<td>#20</td>
<td>1.0</td>
<td>0.999</td>
<td>0.002</td>
<td>0.000</td>
<td>0.009</td>
<td>0.000</td>
<td>0.214</td>
</tr>
</tbody>
</table>

Note: Only trials in which subjects did not acknowledge concealed items included
Classification Accuracy based on ERPs

<table>
<thead>
<tr>
<th></th>
<th>Learned (true pos)</th>
<th>Unlearned (true neg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conceal</td>
<td>0.95</td>
<td>0.96</td>
</tr>
<tr>
<td>Lie</td>
<td>0.93</td>
<td>0.94</td>
</tr>
<tr>
<td>Lie + $$</td>
<td>0.95</td>
<td>0.98</td>
</tr>
<tr>
<td>Combined</td>
<td>0.94</td>
<td>0.96</td>
</tr>
</tbody>
</table>

Executive Summary

Farwell Brain Fingerprinting is a revolutionary new technology for investigating crimes and exonerating innocent suspects, with a record of 100% accuracy in research on FBI agents, research with US government agencies, and field applications.

The technology is proprietary and patented. Brain Fingerprinting fulfills an urgent need for government, law enforcement agencies, corporations, and individuals. Over a trillion dollars are spent annually on crime fighting worldwide.

Brain Fingerprinting solves the central problem by determining scientifically whether a suspect has the details of a crime stored in his brain. It has received extensive media coverage around the world. The technology is fully developed and available for application.

Brain Fingerprinting is a powerful tool for the investigation of suspected terrorists. Measuring the brain wave activity while suspects are shown words or pictures related to specifics of the September 11, 2001 attacks can help determine if they are members of terrorist cells. Brain Fingerprinting can identify trained terrorists before they strike.
Counterterrorism Applications

How do we determine if a person is a terrorist or spy? There is a new technology, that for the first time, allows us to measure scientifically if specific information is stored in a person's brain. Brain Fingerprinting technology can determine the presence or absence of specific information, such as terrorist training and associations. This exciting new technology can help address the following critical elements in the fight against terrorism:

Aid in determining who has participated in terrorist acts, directly or indirectly.

Aid in identifying trained terrorists with the potential to commit future terrorist acts, even if they are in a “sleeper” cell and have not been active for years.

Help to identify people who have knowledge or training in banking, finance or communications and who are associated with terrorist teams and acts.

Help to determine if an individual is in a leadership role within a terrorist organization.
The Claim

- Brain Fingerprinting can determine “scientifically whether a suspect has details of a crime stored in his brain”

- Thus these ERP-procedures should be able to identify memories in laboratory studies

- Two tests of the robustness of this procedure:
  - False recollections
  - Virtual Reality Mock Crime
A Laboratory Paradigm for False Recollections: DRM

- Subjects presented with 15 words highly associated with an omitted critical item
A Laboratory Paradigm for False Recollections: DRM

- Subjects presented with 15 words highly associated with an omitted critical item

Bed, rest, awake, tired, dream, wake, snooze, blanket, doze, slumber, snore, nap, peace, yawn, drowsy

Sleep
Reported Rates of Recognition

Allen and Mertens (2008)
Learned

Unlearned

Lure

Allen and Mertens (2008)
## The Box Score Blues

<table>
<thead>
<tr>
<th>Ground Truth</th>
<th>Test Verdict</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actually Learned</td>
<td>56%</td>
</tr>
<tr>
<td>Critical Lure</td>
<td>72%</td>
</tr>
<tr>
<td>Unlearned</td>
<td>4%</td>
</tr>
</tbody>
</table>

- Highlights the need to have memorable items in the test
- Suggests limited utility in substantiating disputed memories; e.g., claims regarding recovered memories
- Still has low false positive rate when person denies knowledge
Virtual Reality Mock Crime

- Subjects received email detailing their “Mission”
- Sneak into graduate student office to break into virtual apartment
- Apprehended and interrogated using ERP-based procedure
- Some subjects given details about utilizing countermeasures
- Innocent subjects tour the same virtual apartment, but with different objects and details.
Police Beat

By David Halperin
Arizona Daily Wildcat
Friday December 6, 2002

Suspicious e-mail sent

An employee reported that he received an e-mail Wednesday stating he is supposed to commit a crime today, reports stated.

At about 11:35 a.m., the employee told police he had received the suspicious e-mail while in his office at the Arizona Health Sciences Center, 1501 N. Campbell Ave.

The employee told police he did not know the sender of the message or why he received it. He decided to report the incident after his supervisor advised him to do so.

The message read: “This message is simply a reminder of the crime you are to commit on December 6th at 9:00a.m. You should have carefully read over your mission plan and memorized all relevant information in order to carry out your mission. Remember, do not bring materials with you related to the crime and maintain your innocence at all times. Good luck. Dispose of this message once understood,” reports stated.
### Results of Mock Crime Brainwave Procedure

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Guilty Verdict</th>
<th>Innocent Verdict</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guilty</td>
<td>15</td>
<td>47%</td>
<td>53%</td>
</tr>
<tr>
<td>Guilty (countermeasure)</td>
<td>45</td>
<td>17%</td>
<td>83%</td>
</tr>
<tr>
<td>Innocent</td>
<td>15</td>
<td>6%</td>
<td>94%</td>
</tr>
</tbody>
</table>

Note: Using Bootstrapping approach, Guilty detection drops to 27%, but innocent subjects classified correctly in 100% of cases. Allows indeterminate outcomes.
ERPs and Affective Processing

- IAPS = International Affective Picture System
  - Pleasant, Neutral, Unpleasant
  - Vary in Arousal: Pleasant and Unpleasant tend to be more arousing
  - Predict more significant stimuli produce larger P3
Fig. 1. Stimulus synchronized grand average ERP waveforms for Fz, Cz, and Pz electrodes during viewing of affective pictures, separately for each valence category (pleasant, neutral and unpleasant). The left panel illustrates the picture onset potentials on a finer time scale, and the vertical lines at Pz illustrate the time areas subjected to statistical analysis (i.e. 200–300, 300–400, 400–700, 700–1000 ms). The right panel shows the subsequent 5 s of slow potential change.
1.5 sec Presentation Duration

Cuthbert et al (2000), *Biological Psychology*

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*Figure 1. Picture onset synchronized grand-average event-related potential (ERP) waveforms for each valence category (pleasant, neutral, and unpleasant) from midline electrodes Fz, Cz, and Pz.*
ERPS and Implicit Affective Processing

- Ito & Cacioppo (2000) *JESP*
  - Evaluative Processing (positive vs negative)
  - Nonevaluative (people vs no-people)
FIG. 2. Averaged event-related potential waveforms at electrode Pz as a function of target and context valence. The top panel depicts explicit evaluative categorization effects (data from participants in the evaluative task condition). The bottom panel depicts implicit evaluative categorization effects (data from participants in the nonevaluative task condition). The late-positive potential is the positive (downward) deflection peaking at approximately 450–550 ms.
N400 and Language

• Originally reported by Kutas & Hillyard, 1980.
• Semantic Incongruity is separable from other forms of deviations (e.g. large font)
  • N400 Semantic Deviation
  • P300 Physical Deviation
• Also seen in semantic differentiation tasks (Polich, 1985); APPLE, BANANA, ORANGE, MANGO, TRUCK
• Subject-Object mismatch (the Florida group)
• NOTE: N400 will appear before P3 (which will be ~P550 in word tasks)
N400 and Language

Sensitive to degree of semantic incongruity
Political Evaluations!

Morris Squires et al. *Political Psychology* 2003

Figure 2. Attitude-priming paradigm and examples of its use.
Congruent or incongruent defined based on idiographic data from pretest

Figure 4. ERPs to congruent and incongruent prime/target pairs.
- Cloze probability: proportion of respondents supplying the word as continuation given preceding context
- N400 reflects unexpected word given the preceding context
- This is independent of degree of contextual constraint
- Larger N400
  - Low cloze, Contextual constraint high: The bill was due at the end of the hour
  - Low cloze, Contextual constraint low: He was soothed by the gentle wind
- Smaller N400
  - The bill was due at the end of the month

Kutas & Federmeier, 2011
Sentence completion
- Best (expected) ending *small*
- Unexpected but related *larger*
- Unexpected and unrelated *largest*

Categorical relations … sentence final word is:
- an expected category exemplar
- an unexpected, implausible exemplar from the same category as the expected one (related anomalous)
- from a different category (unrelated anomalous)

Note multiple modalities of effect, and graded effect in RVF (LH)

Kutas & Federmeier, 2011
- Word Association, with second word in pair
  - Unrelated to first (eat door)
  - Weakly related to first (eat spoon)
  - Strongly related to first (eat drink)
- Orthographic neighborhood size (among a list of words, pseudowords, and acronyms)
  - Words that share all but one letter in common with particular word
  - Large ‘hood (e.g., slop) – large N400
  - Small ‘hood (e.g. draw) – small N400
Math: (e.g., $5 \times 8 = \Box$)
- Correct (40) small
- Related (32, 24, 16) small if close
- Unrelated (34, 26, 18) large

Movement and Gestures
- Typical actions (cutting bread with knife) = small
- Purposeless, inappropriate, or impossible actions = large
  - Cutting jewelry on plate with fork and knife
  - Cutting bread with saw

N400 modulated by both:
- Appropriateness of object (e.g., screwdriver instead of key into keyhole)
- Features of motor act per se (e.g., orientation of object to keyhole)

Kutas & Federmeier, 2011
- Repetition effects
  - Repetition creates contextual familiarity, reduced processing demands
  - N400 thus useful in studying memory
  - Appears additive with incongruency effects
N400 – The Unexpected Hero!
Contingent Negative Variation

O-wave = Orienting; E-Wave = Expectancy, arguably motor-related
Response-locked potentials

- Lateralized Readiness Potential (LRP), a special case of movement-related potentials
- Error-related Negativity (ERN, aka $N_E$)
Lateralized Readiness Potential

- LRP can be stimulus-locked or response-locked
- For stim-locked, latency is time between stimulus onset and LRP onset
- For rsps-locked latency is time between an LRP deflection and the overt response.

Figure 1. Computation of the lateralized readiness potential (LRP) with the double subtraction method on the basis of event-related brain potential (ERP) waveforms elicited at electrodes C3′ (left hemisphere) and C4′ (right hemisphere). Top panels: Grand-averaged ERP waveforms from 10 subjects elicited at C3′ (solid lines) and C4′ (dashed lines) in response to stimuli requiring a left-hand response (left side) and to stimuli requiring a right-hand response (right side). Middle panel: Difference waveforms resulting from subtracting the ERPs obtained at C4′ from the ERPs obtained at C3′ separately for left-hand responses (solid line) and right-hand responses (dashed line). Bottom panel: LRP waveform resulting from subtracting the C3′ – C4′ difference waveform for right-hand responses from the C3′ – C4′ difference waveform for left-hand responses. A downward-going (positive) deflection indicates an activation of the correct response; an upward-going (negative) deflection indicates an activation
Response conflict in the LRP

Figure 2. Top: Examples of stimulus displays in an experiment on spatial stimulus–response compatibility (Eimer, 1993, Experiment 1a) in which stimulus and response sides could either be compatible (left side) or incompatible (right side). Bottom: Grand-averaged LRP waveforms from 10 subjects, elicited in compatible trials (solid line) and in incompatible trials (dashed line).

Eimer 1998, *Beh Res Methods*
The ERN

Flankers Task:
MMNMM

Also sometimes termed Ne
Fig. 3. Relationship between error-related negativity (ERN) amplitude and three measures of compensatory behavior. Left panel: Average event-related potentials at the Cz electrode as a function of the four levels of the posterior probability measure of ERN amplitude. Right panel, top: Error squeeze force in Kg as a function of the four ERN levels. Right panel, middle: Probability of error correction as a function of the four ERN levels. Right panel, bottom: Correct reaction time on the trial following an error as a function of the four ERN levels.
Modality Specific?

Does not matter what modality stimulus was presented

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Fig. 1. Grand averages (Experiment 4; n = 12) of the RTA for errors (heavy lines) and correct trials (light lines) after visual (vis) and auditory letter stimuli (aud) in a 2-CR task. The error negativity ("Ne") is seen as a sharp negative deflection with central maximum peaking at about 80 ms after the incorrect key press (R). The error positivity ("Pe") is seen as a late parietal positivity with Cz maximum peaking at about 300 ms after the incorrect key press. On correct trials a positive complex with Pz maximum is seen.
Does not matter what modality response was made

Eye
Fig. 2. Source localization of the error-related negativity. Circles represent locations of sources determined for hand and foot responses: (a) coronal view; (b) sagittal view; (c) for comparison, source locations of the ERN determined in previous studies are depicted along with the locations of the ERN obtained in the present study. Squares represent locations of sources found for ERNs elicited by visual, auditory, and somatosensory feedback [10]. Crossed symbols represent locations of sources found for ERNs elicited by errors in two reaction time experiments [2].

Does not matter what modality response was made
- Eye
- Hand
- Foot
Error Detection Vs. Error Compensation

- If Error Compensation, ERN/Ne should not be present in tasks where compensation impossible
- Ergo…
  - the Go-Nogo!
  - Play along… press only for X following X
Fig. 5. Grand averages (Experiment 2; n = 10) of the RTA for false alarms and hits in Go/Nogo tasks (heavy lines), and choice errors and correct choice trials in two-way choice tasks (thin lines). Errors continuous lines, correct responses broken lines. The Ne is delayed relative to the incorrect key press, and the Pe is smaller, for choice errors compared to false alarms. In correct trials a positive complex with Pz maximum is seen, which is larger after visual than after auditory stimuli. However, this complex is not larger for hits than for correct choice trials.
Error Detection Vs. Outcome Impact

- Might the “cost” or “importance” or “salience” of an error be relevant to this process?
- Studies relevant to error salience
  - Speed-accuracy trade off
  - Individual differences
Fig. 4. Grand averages (Experiment 1; n = 9) of the RTA for correct responses (C), errors (E), and difference waveshapes (error minus correct; E - C) in a 2-CR task under moderate (light lines) and severe time pressure (heavy lines). The error rates were 15% (moderate) and 30% (severe); the number of error trials used was equalised for the two conditions. The Ne is smaller for severe time pressure/high error rate.
Individual Differences

- Psychopathy (or analog)
- OCD
Deficits in Error Monitoring in Psychopathy

- Psychopaths appear unable to learn from the consequences of their errors
- Avoidance learning deficits
- In the context of rewards and punishments
- Deficient anticipatory anxiety
Thirty participants selected: 15 high SO 15 low SO

Dikman & Allen, 2000, *Psychophysiology*
Procedure

- Eriksen flanker task: SSHSS
- Two conditions for each subject
  - Reward (REW), errors “No $”
  - Punishment (PUN), errors 95 dB tone
- Consequences of errors could be avoided by self-correcting response within 1700 msec window
- Response mapping switched at start of each of 10 blocks, total trials 600
- Only corrected error trials examined
Results replicate with RT-matched trials.
ERN in OCD

And amplitude of ERN correlates with Symptom severity (correlation magnitude ~.50); Gehring et al. (2000)
Error Detection Vs. Conflict

- Trials on which errors occur will entail greater response conflict than those without errors
- So, is it error detection, or response conflict?
- Stay tuned…
Errors and Feedback

- Endogenous Error Detection
- Exogenous Error Feedback
- Common Mechanism?
The Feedback Medial Frontal Negativity

- Time Estimation Task
- Cue, then press button 1 second later
- Feedback in visual, auditory, or somatosensory modality
- Width of “correct” time window varied dynamically to titrate to 50% accuracy

The Feedback Medial Frontal Negativity

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Miltner, Braun, & Coles, (1997) *Journal of Cognitive Neuroscience*
The Gambling Task

Gehring and Willoughby, 2002 *Science*
Fig. 2. ERP waveforms, scalp topography, and likely neural generator of the MFN. (A) The waveforms are shown at the Fz (frontal) electrode site. The solid red line corresponds to the average ERP waveform for all trials in which the participant lost money. The dashed green line corresponds to those trials in which the participant gained money. The MFN is indicated by the arrow. The error bar represents two standard errors of the mean, based on the mean squared error from the ANOVA (9). (B) The map of scalp activity shows the voltages, derived by subtracting the loss-trial waveform from the gain-trial waveform, computed at 265 ms after the onset of the outcome stimulus. Larger positive values correspond to a greater MFN effect. The MFN is indicated by the focus of activity at the Fz electrode (designated by the arrow). The best-fitting dipole model of the generator of the MFN is shown as a red sphere centered in the ACC on a canonical magnetic resonance imaging template of the human head (9).
Error, or motivation?

Gehring and Willoughby, 2002 Science
Effect may depend on *relevant* dimension of feedback
FRN and Problem Gambling

Why do Gamblers Gamble?
Black Jack Study

- 20 Problem Gamblers, 20 Controls
- Black Jack

Hewig et al. (2010). *Biological Psychiatry*
Black Jack Study

Prob “hit” at 16

Hewig et al. (2010). Biological Psychiatry
FRN may be absence of Reward Positivity

Foti et al. (2011). HBM