The P300 Brain-Computer Interface: Moving from Bench to Bedside
Eric W. Sellers, Ph.D.
Department of Psychology
East Tennessee State University
http://www.etsu.edu/cas/bcilab

Psychiatry Grand Rounds
East Tennessee State University
September 18, 2009

Outline
- Definition of a BCI
- The oddball paradigm and the P300 event-related potential
- Laboratory studies
- Home studies – practical BCI for home use
- Future directions

Definition of a BCI
- Uses brain signals to convey intent
- Does not use peripheral nerves or muscles
- Can provide communication and control to people who are totally paralyzed

Interaction of two adaptive controllers:
- User produces signals that encode a message
- BCI translates signals into device commands
- A new skill that User and BCI acquire and maintain

Wadsworth BCI 3-D Control

McFarland et al, (Submitted)

September 18, 2009 ● Eric W. Sellers

Definition of a BCI

• Who can benefit from a BCI?
  - Amyotrophic lateral sclerosis, brainstem stroke, SCI
  - Possibly: cerebral palsy, muscular dystrophy, multiple sclerosis, TBI

The Oddball Paradigm

• Oddball paradigm elicits a P300
  - Typical requirements
    - Random sequence of at least two distinct events
    - Attention to the sequence of event
    - Classification rule or task
    - One category is presented infrequently

Outline

• Definition of a BCI
• The oddball paradigm and the P300 event-related potential
• Laboratory studies
• Home studies – practical BCI for home use
• Future directions

September 18, 2009 ● Eric W. Sellers
The Oddball Paradigm
- Standard oddball task:

The P300
- Oddball paradigm elicits a P300
  - A positive deflection approximately 300 ms after stimulus presentation
  - Amplitude – 3 to 20 μV
  - Scalp distribution – Fz < Cz < Pz
  - Latency – 200 to 700 ms
  - Realized by averaging
  - Process NOT stimulus dependent

The P300 Speller
- Modified oddball task
  - Random presentation
  - 100 ms flash 75 ms between flashes
  - Stepwise linear discriminant analysis

Squires et al., (1977)
Farwell & Donchin (1988)
The P300 Speller

- Modified oddball task
- Random presentation
- 100 ms flash 75 ms between flashes
- Stepwise linear discriminant analysis

Farwell & Donchin (1988)

Outline

- Definition of a BCI
- The oddball paradigm and the P300 event-related potential
- Laboratory studies
- Home studies – practical BCI for home use
- Future directions
Laboratory Studies – Matrix Size and Flash Rate

- **Rationale:**
  1) adjustable matrix size allows for a more flexible BCI
  2) optimal presentation rate may be user specific
- **Design:**
  - 6x6 and 3x3 matrix
  - 100 ms flash/75 ms between flashes
  - 100 ms flash/250 ms between flashes
  - 5 users – each completed 5 sessions

Laboratory Studies – Intensification Contrast

- **Design:**
  - 4 intensifications contrast values presented in counter-balanced ascending and descending orders
  - 6x6 matrix 100 ms flash 75 ms between flashes
  - 5 users – each completed 5 sessions

Luminance (cd/m²)  
71.9  56.5  36.7  21.3  14.8  
Contrast to rest  
3.86  2.82  1.48  0.44  n.a.  

Ohringer et al. (in prep)
Laboratory Studies – Intensification Contrast

Online accuracy

Laboratory Studies – Optimizing Parameters

Electrode Set
Reference
Common Average
Monopolar Ear
Max SWDA Features
15, 30, 45, 60
Decimation
6, 12, 24

Classification Algorithms – Offline Comparison
• Fisher’s linear discriminant
• Stepwise linear discriminant analysis
• Pearson’s correlation method
• Linear support vector machines
• Gaussian support vector machines

Laboratory Studies – Optimizing Parameters

Electrode Set
Reference
Common Average
Monopolar Ear
Max SWDA Features
15, 30, 45, 60
Decimation
6, 12, 24

Laboratory Studies – Optimizing Parameters

Classification Algorithms – Offline Comparison
• Fisher’s linear discriminant
• Stepwise linear discriminant analysis
• Pearson’s correlation method
• Linear support vector machines
• Gaussian support vector machines

Laboratory Studies – Optimizing Parameters

Electrode Set
Reference
Common Average
Monopolar Ear
Max SWDA Features
15, 30, 45, 60
Decimation
6, 12, 24

Laboratory Studies – Optimizing Parameters

Classification Algorithms – Offline Comparison
• Fisher’s linear discriminant
• Stepwise linear discriminant analysis
• Pearson’s correlation method
• Linear support vector machines
• Gaussian support vector machines
### Laboratory Studies – New Sensor Technology

#### September 18, 2009

- Eric W. Sellers

Sellers et al (2009)

### Laboratory Studies – Row/Col vs. Random

#### September 18, 2009

- Eric W. Sellers

Townsend et al (in prep)

### Results

<table>
<thead>
<tr>
<th>Subject</th>
<th>RC seq</th>
<th>CB seq</th>
<th>RC acc</th>
<th>CB acc</th>
<th>RC sel/min</th>
<th>CB sel/min</th>
<th>RC bit rate</th>
<th>CB bit rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5.00</td>
<td>3.50</td>
<td>160.00</td>
<td>94.74</td>
<td>4.28</td>
<td>3.89</td>
<td>26.38</td>
<td>23.86</td>
</tr>
<tr>
<td>2</td>
<td>5.00</td>
<td>4.00</td>
<td>55.26</td>
<td>89.47</td>
<td>4.28</td>
<td>3.89</td>
<td>10.38</td>
<td>19.62</td>
</tr>
<tr>
<td>3</td>
<td>3.00</td>
<td>2.00</td>
<td>71.05</td>
<td>86.84</td>
<td>4.28</td>
<td>4.28</td>
<td>123.72</td>
<td>123.72</td>
</tr>
<tr>
<td>4</td>
<td>5.00</td>
<td>3.00</td>
<td>94.74</td>
<td>92.11</td>
<td>5.04</td>
<td>6.13</td>
<td>23.66</td>
<td>21.73</td>
</tr>
<tr>
<td>5</td>
<td>4.00</td>
<td>3.50</td>
<td>97.37</td>
<td>100.00</td>
<td>5.04</td>
<td>6.50</td>
<td>26.39</td>
<td>26.62</td>
</tr>
<tr>
<td>6</td>
<td>4.00</td>
<td>4.00</td>
<td>89.47</td>
<td>89.47</td>
<td>5.04</td>
<td>6.50</td>
<td>26.39</td>
<td>26.62</td>
</tr>
<tr>
<td>7</td>
<td>5.00</td>
<td>4.50</td>
<td>89.47</td>
<td>89.47</td>
<td>5.04</td>
<td>6.50</td>
<td>26.39</td>
<td>26.62</td>
</tr>
<tr>
<td>8</td>
<td>4.00</td>
<td>4.50</td>
<td>92.11</td>
<td>94.74</td>
<td>5.04</td>
<td>6.50</td>
<td>26.39</td>
<td>26.62</td>
</tr>
<tr>
<td>9</td>
<td>4.00</td>
<td>5.00</td>
<td>92.11</td>
<td>92.11</td>
<td>5.04</td>
<td>6.50</td>
<td>26.39</td>
<td>26.62</td>
</tr>
<tr>
<td>10</td>
<td>5.00</td>
<td>4.00</td>
<td>94.74</td>
<td>97.37</td>
<td>5.04</td>
<td>6.50</td>
<td>26.39</td>
<td>26.62</td>
</tr>
<tr>
<td>11</td>
<td>4.00</td>
<td>4.00</td>
<td>97.37</td>
<td>97.37</td>
<td>5.04</td>
<td>6.50</td>
<td>26.39</td>
<td>26.62</td>
</tr>
<tr>
<td>12</td>
<td>5.00</td>
<td>2.50</td>
<td>63.16</td>
<td>94.74</td>
<td>5.04</td>
<td>6.50</td>
<td>26.39</td>
<td>26.62</td>
</tr>
<tr>
<td>13</td>
<td>5.00</td>
<td>4.50</td>
<td>47.37</td>
<td>89.47</td>
<td>4.28</td>
<td>3.55</td>
<td>18.01</td>
<td>16.11</td>
</tr>
<tr>
<td>14</td>
<td>4.00</td>
<td>2.00</td>
<td>108.00</td>
<td>100.00</td>
<td>5.04</td>
<td>6.50</td>
<td>26.39</td>
<td>26.62</td>
</tr>
<tr>
<td>15</td>
<td>4.00</td>
<td>3.50</td>
<td>92.11</td>
<td>100.00</td>
<td>5.04</td>
<td>6.50</td>
<td>26.39</td>
<td>26.62</td>
</tr>
<tr>
<td>16</td>
<td>5.00</td>
<td>3.00</td>
<td>86.84</td>
<td>81.58</td>
<td>4.28</td>
<td>3.26</td>
<td>20.52</td>
<td>14.17</td>
</tr>
<tr>
<td>17</td>
<td>4.00</td>
<td>3.00</td>
<td>86.84</td>
<td>92.11</td>
<td>5.04</td>
<td>6.50</td>
<td>26.39</td>
<td>26.62</td>
</tr>
<tr>
<td>18</td>
<td>5.00</td>
<td>4.50</td>
<td>84.21</td>
<td>84.21</td>
<td>4.28</td>
<td>3.55</td>
<td>18.01</td>
<td>16.11</td>
</tr>
<tr>
<td>Mean</td>
<td>4.00</td>
<td>3.61</td>
<td>77.34</td>
<td>91.52</td>
<td>4.68</td>
<td>4.36</td>
<td>19.86</td>
<td>23.13</td>
</tr>
</tbody>
</table>

#### Townsend et al (in prep)

- Eric W. Sellers

Mean 2.69 3.66 16.61 22.59

<table>
<thead>
<tr>
<th>Participant</th>
<th>RC sel/min</th>
<th>CB sel/min</th>
<th>RC bit rate</th>
<th>CB bit rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.28</td>
<td>3.89</td>
<td>26.38</td>
<td>23.86</td>
</tr>
<tr>
<td>3</td>
<td>5.16</td>
<td>5.04</td>
<td>26.39</td>
<td>26.62</td>
</tr>
<tr>
<td>4</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>5</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>6</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>7</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>8</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>9</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>10</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>11</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>12</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>13</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>14</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>15</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>16</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>17</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
<tr>
<td>18</td>
<td>3.76</td>
<td>3.66</td>
<td>16.61</td>
<td>22.59</td>
</tr>
</tbody>
</table>
Laboratory Studies – Row/Col vs. Random

Results

Townsend et al (in prep)

September 18, 2009 ● Eric W. Sellers

Outline

• Definition of a BCI
• The oddball paradigm and the P300 event-related potential
• Laboratory studies
• Home studies – practical BCI for home use
• Future directions

Home Studies – System

September 18, 2009 ● Eric W. Sellers
Wadsworth BCI Home System: P300 Format

Selection Criteria Specifications, Examples
Chronic disorder of voluntary movement ALS, brainstem stroke, cerebral palsy, spinal cord injury
Minimal remaining useful control Single muscle, eye movement
Conventional technologies not adequate Single-switch EMG or eye-movement systems difficult, unreliable
Stable environment Strong medical, physical, social support
Technically capable caregiver(s) Able and willing to master BCI system operation
Realistic understanding of this BCI study Research enterprise, success not assured

User Age Sex ALS type Time since diagnosis Artificial ALS FRS
Nutrition Breathing
A 67 M Bulbar 17 mo Yes No 17
B 47 F Spinal 2 years Yes Yes 6
C 53 M Spinal 4 years No No 20
D 49 F Spinal 1 year No No 13
E 39 M Spinal 3 years Yes No 4
F 36 F Spinal 8 years No No 14

P300 Latency

P300 Amplitude

Nijboer et al. (2008)
### Home Studies – Focus on communication

<table>
<thead>
<tr>
<th>User</th>
<th>Number of Sequences</th>
<th>Selection Time</th>
<th>Chars/min</th>
<th>Mean Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Phase I</td>
<td>Phase II</td>
<td>Phase I</td>
<td>Phase II</td>
</tr>
<tr>
<td>A</td>
<td>20.00</td>
<td>14.00</td>
<td>42.00</td>
<td>29.40</td>
</tr>
<tr>
<td>B</td>
<td>20.00</td>
<td>7.00</td>
<td>42.00</td>
<td>18.40</td>
</tr>
<tr>
<td>C</td>
<td>20.00</td>
<td>13.00</td>
<td>42.00</td>
<td>34.10</td>
</tr>
<tr>
<td>D</td>
<td>20.00</td>
<td>4.00</td>
<td>42.00</td>
<td>10.50</td>
</tr>
<tr>
<td>Mean</td>
<td>20.00</td>
<td>9.50</td>
<td>42.00</td>
<td>23.10</td>
</tr>
</tbody>
</table>

---

### Home Studies – Home system users

<table>
<thead>
<tr>
<th>USER</th>
<th>SEX</th>
<th>AGE</th>
<th>VENT</th>
<th>ALS-FRS</th>
<th>MVMT</th>
<th>BCI USE</th>
<th>OTHER DEVICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>M</td>
<td>45</td>
<td>Yes</td>
<td>0</td>
<td>Horiz</td>
<td>22</td>
<td>E-mail, WP, Env Ctrl</td>
</tr>
<tr>
<td>B*</td>
<td>M</td>
<td>52</td>
<td>Yes</td>
<td>4</td>
<td>Eye</td>
<td>12</td>
<td>WP, 2 to 3, Opt</td>
</tr>
<tr>
<td>C</td>
<td>F</td>
<td>36</td>
<td>Yes</td>
<td>5</td>
<td>Eye</td>
<td>10</td>
<td>MW, Computer, Touchpad</td>
</tr>
</tbody>
</table>

---

Nijboer et al. (2008)  
Sellers et al (submitted)

---

### EC spawns new matrix

- EC spawns new matrix
- Ch shortcuts
- Main menu
- Lights
Sellers et al (submitted)

Home Studies – Results

Asked to describe BCI impact on his life, user A replied:

Subject:  
From:  
Date:  
To: Jonathan R. Wolpaw  
Cc:  

No problem.

I couldn't run my lab without BCI. I do molecular neuroscience research and my grant pays three people.

I'm writing this with my EEG courtesy of the Wadsworth Center Brain-Computer Interface Research Program (www.wadsworth.org)
Home Studies – Results

- Need total concentration
- Tiring
- Accurate but slow
- Complicated to maintain, need for gel

“Some communication is better than none. It works amazingly well. Lack of integration with email, web, etc is important, but that will come with time.”

Outline
- Definition of a BCI
- The oddball paradigm and the P300 event-related potential
- Laboratory studies
- Home studies – practical BCI for home use
- Future directions
**Future Directions**

- Continue to develop an auditory-based system (Klobassa et al, 2009)
- Continue to test acutely disabled people in ICU (Cormier et al, 2008)
- Investigate why some people are unable to use the BCI
- Return communication to a completely locked-in person

**Conclusions**

- The P300-speller produces robust and stable responses sufficient for long-term daily use
- The P300-speller paradigm is a viable communication option for severely disabled persons
- The P300-speller is a clinically practical BCI that can be calibrated and used in minutes

**Acknowledgements**

**University of Lille**
François Cabestain

**University of Rouen**
Aalil Rakotoarisona

**University of Graz**
Daniela Klobassa
Christa Neuper

**QUASAR**
Peter Turner
Robert Matthews

**MGH/Harvard**
Leigh Hochberg
Syd Cash

**East Tennessee State University**
Nicholas Schwartz; Dave Ryan;
Daniel Berry; Juliana Armstrong;
Gerald Frye; Chris Hauser

**University of Tübingen**
Femke Nijboer
Niels Birbaumer

**University of South Florida**
Yael Arbel
Emanuel Donchin

**University of North Florida**
Dean Krusienski

**Wadsworth Center**
Chadwick Boulay
Peter Brunner
Steve Carmack
Dennis McFarland
Bill Samack
Gerwin Schalk
Theresa Vaughan
Jon Wolpaw

**Algoma University**
George Townsend

**Guger Technologies**
Christoph Guger

Support:
NCMRR, NICHD, NIH (HD39246), NIBIB/NINDS, NIH (EB00856); NINDS, NIH (1R41NS060348-01); ALS Hope Foundation; James S. McDonnell Foundation; Altran Foundation; NEC Foundation; Helen Hayes Hospital