Outline	Background	Applications	Spelling	Summary O

Event-Related Potentials in Brain-Computer Interfacing

Jeremy Hill

Max Planck Institute for Biological Cybernetics Tübingen, Germany

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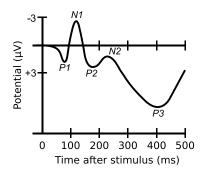






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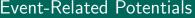
Event-Related Potentials

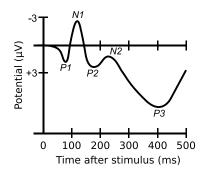


schematic figure from http://en.wikipedia.org/wiki/Event_related_potential

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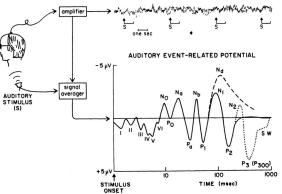
- N for negative, P for positive (beware: negative is sometimes plotted upwards, sometimes downwards).
- Numbered sequentially (P1, P2, P3, ...) or by typical latency in milliseconds (N140, P300, ...).

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Event-Related Potentials



ONGOING EEG

figure from Hillyard & Kutas (1983) Annual Review of Psychology.

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Event-Related Potentials

The EEG signal is a function of time and space. The positivity or negativity of a particular ERP peak depends on which electrode you measure.

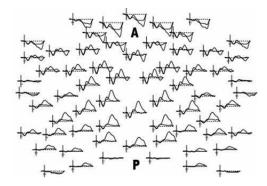


figure from Patel & Azzam (2005) Int. J. Medical Sciences. ・ロト ・ 日 ・ ・ ヨ ・ ・ ヨ ・

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"Event-related potential" (ERP) is a newer term than "evoked potential" (EP), intended to be more general, and open to connotations of the brain's *active* role in processing stimuli.

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 $\mathsf{Examples}$ of ERPs that are more than just "evoked" by physical stimulus properties:

• ELAN (Early Left-Anterior Negativity, latency 100–200 msec) is a correlate of syntactic processing:

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The boys heard Joe's about story

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The boys heard Joe's about story Africa.

• The N400 is a correlate of semantic processing:

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The boys heard Joe's about story Africa.

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- The P600 is a correlate of syntactic updating:

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- The N400 is a correlate of semantic processing: The boys heard Joe's orange about Africa.
- The P600 is a correlate of syntactic updating: The student

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- The N400 is a correlate of semantic processing: The boys heard Joe's orange about Africa.
- The P600 is a correlate of syntactic updating: The student forced to complete the assignment

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• ELAN (Early Left-Anterior Negativity, latency 100–200 msec) is a correlate of syntactic processing:

The boys heard Joe's about story Africa.

- The N400 is a correlate of semantic processing: The boys heard Joe's orange about Africa.
- The P600 is a correlate of syntactic updating: The student forced to complete the assignment passed.

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 $\mathsf{Examples}$ of ERPs that are more than just "evoked" by physical stimulus properties:

• ELAN (Early Left-Anterior Negativity, latency 100–200 msec) is a correlate of syntactic processing:

The boys heard Joe's about story Africa.

- The N400 is a correlate of semantic processing: The boys heard Joe's orange about Africa.
- The P600 is a correlate of syntactic updating:

The student forced to complete the assignment passed.

VS

The student forced the door open.

The student tried to complete the assignment.

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Examples of ERPs that are more than just "evoked" by physical stimulus properties:

• The P300 wave was originally discovered as a correlate of the amount of *uncertainty* resolved by presentating a stimulus (Sutton et al. 1965, Science).

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Examples of ERPs that are more than just "evoked" by physical stimulus properties:

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- P300s can also be elicited by the *absence* of a stimulus in an otherwise predictable sequence (Sutton et al. 1967, Science).

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More Than Just Evoked Potentials

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Sounds promising for BCI application: P300 appears to encode both the information content of stimulus changes, and their relevance to the observer.

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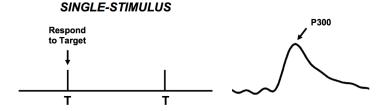
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Today, authors are still more likely to refer to event-related potentials when they are talking about correlates of higher-level (more "cognitive") stimulus processing, and to evoked potentials when they are assuming their phenomena reflect lower-level (earlier, more "sensory") processing.

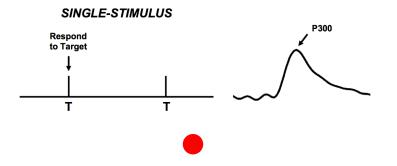
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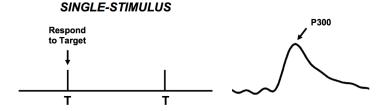


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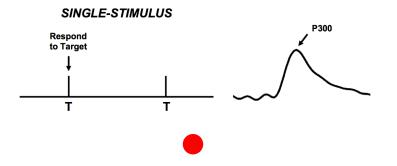


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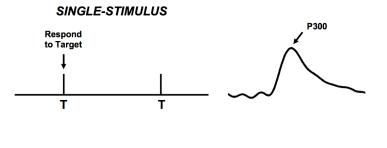
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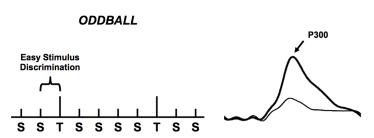
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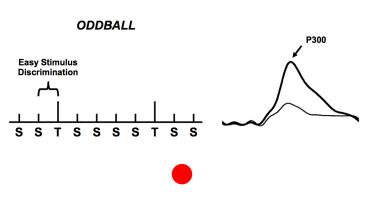
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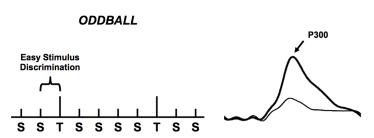


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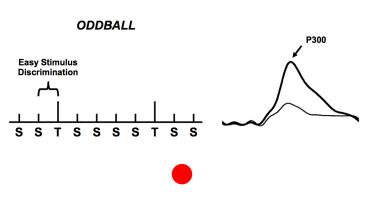


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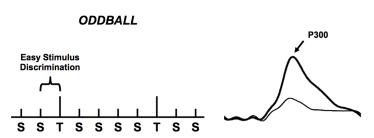


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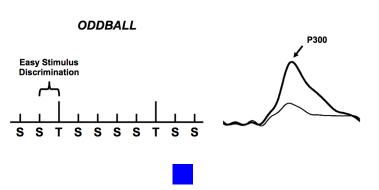


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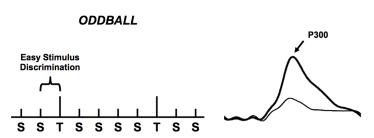


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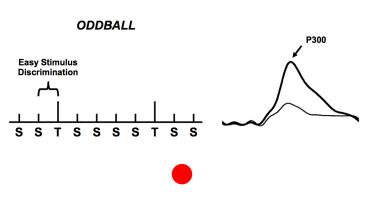


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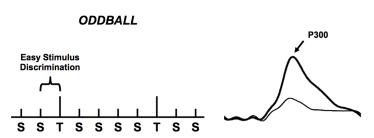


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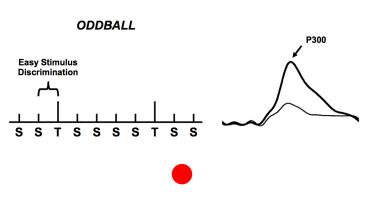


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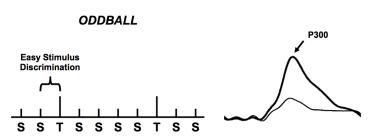


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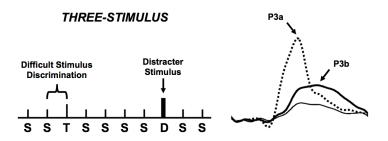
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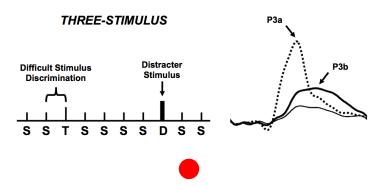
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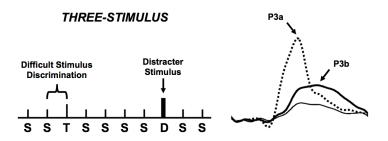


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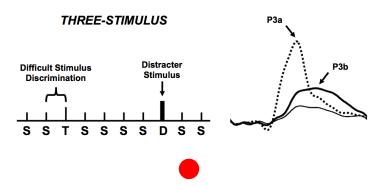


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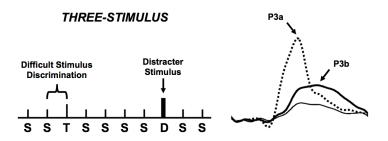


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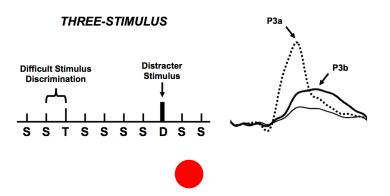


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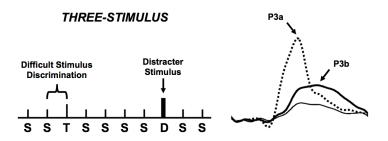
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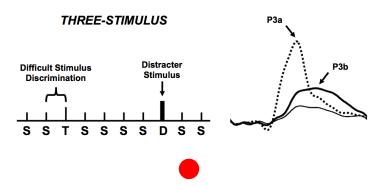
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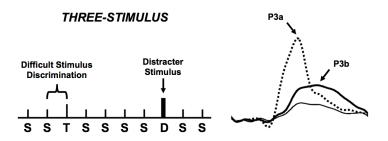


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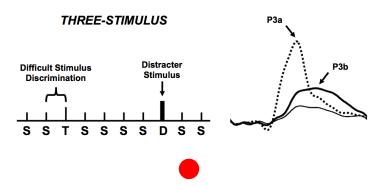


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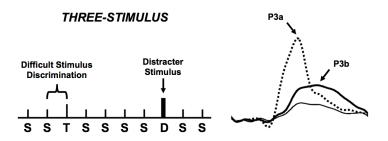


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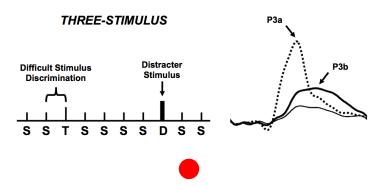


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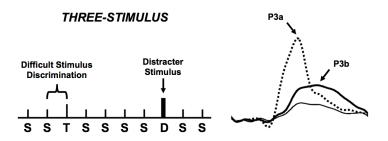


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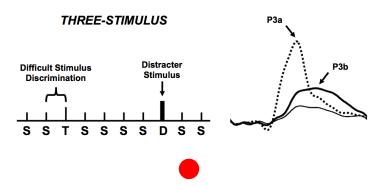


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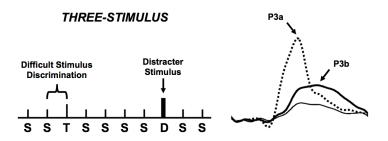


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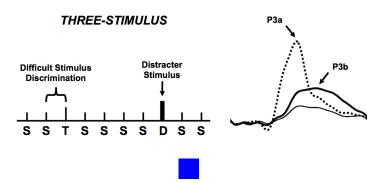


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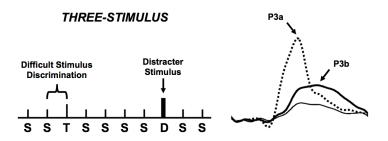
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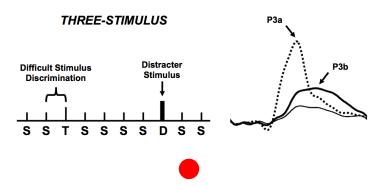
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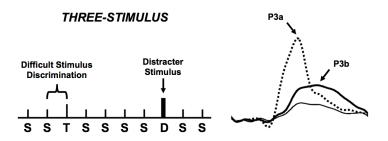


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figures from Polich (2007) Clinical Neurophysiology

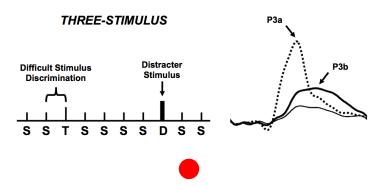
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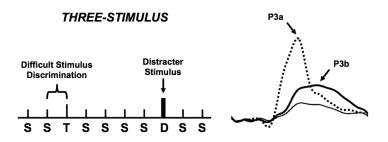
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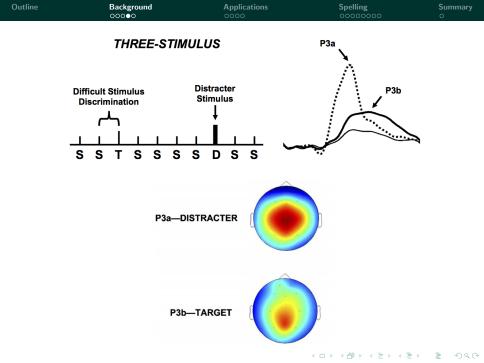
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My P300	's Bigger Tha	in Yours		

Amplitude and latency of ERP components vary between individuals, and there is evidence for effects of:

age;

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My P300)'s Bigger Tha	in Yours		

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- age;
- gender;

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My P300)'s Bigger Tha	in Yours		

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- age;
- gender;
- time of day, fatigue/arousal

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- age;
- gender;
- time of day, fatigue/arousal (coffee!);

Outline	Background ○○○○●	Applications	Spelling	Summary O
My P300)'s Bigger Tha	n Yours		

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- age;
- gender;
- time of day, fatigue/arousal (coffee!);
- schizophrenia, depression, alcoholism;

Outline	Background ○○○○●	Applications	Spelling 0000000	Summary O
My P300)'s Bigger Tha	n Yours		

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- gender;
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- schizophrenia, depression, alcoholism;
- . . .

Outline	Background	Applications ●○○○	Spelling	Summary O

• Visual perimetry, audiometry, etc. with infants, animals.

Average large numbers of ERPs

> Classify single ERPs

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Outline	Background	Applications •000	Spelling 0000000	Summary O

- Monitoring the depth of anaesthesia.
- Visual perimetry, audiometry, etc. with infants, animals.

Average large numbers of ERPs

Classify single ERPs

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- "Brain Fingerprinting": using P300 and later components, for forensic "guilty knowledge" testing—ruled admissable by US Supreme Court.
- Monitoring the depth of anaesthesia.
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Average large numbers of ERPs

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• Communication (e.g. the Farwell-Donchin speller).

Average large numbers of ERPs

Classify single ERPs

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• Communication (e.g. the Farwell-Donchin speller).

 Detection of mistakes (via "error-related negativity" or ERN) in BCI and other tasks. Average large numbers of ERPs

Classify single ERPs

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- "Brain Fingerprinting": using P300 and later components, for forensic "guilty knowledge" testing—ruled admissable by US Supreme Court.
- Monitoring the depth of anaesthesia.
- Visual perimetry, audiometry, etc. with infants, animals.

- Communication (e.g. the Farwell-Donchin speller).
- "Triage" of potential targets in human stimulus-processing tasks.
- Detection of mistakes (via "error-related negativity" or ERN) in BCI and other tasks.

Average large numbers of ERPs

Classify single ERPs

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Outline Background Applications Spelling Summary 0000

"Cortically Coupled Computer Vision"

figures from Parra et al. 2008 (IEEE Signal Processing Magazine)

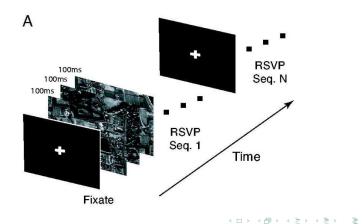


Credit: Digital Globe



"Cortically Coupled Computer Vision"

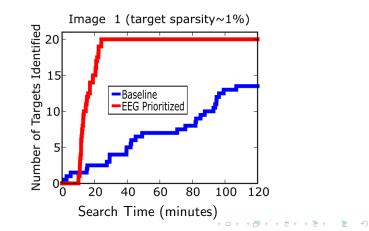
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Outline	Background	Applications ○○●○	Spelling	Summary O

 ERPs, and methods for detecting them, that produce reliable classification results after a relatively short time (i.e. small numbers of ERPs).

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 \bullet averaging \rightsquigarrow single-trial classification

Outline	Background	Applications ○○●○	Spelling	Summary O

- ERPs, and methods for detecting them, that produce reliable classification results after a relatively short time (i.e. small numbers of ERPs).
 - \bullet averaging \rightsquigarrow single-trial classification
- ERPs that can be modulated by the user's voluntary shifts of attention

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Outline	Background	Applications ○○●○	Spelling	Summary O

- ERPs, and methods for detecting them, that produce reliable classification results after a relatively short time (i.e. small numbers of ERPs).
 - \bullet averaging \rightsquigarrow single-trial classification
- ERPs that can be modulated by the user's voluntary shifts of attention

• overt attention (orientation of gaze, etc.)

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- overt attention (orientation of gaze, etc.)
- covert attention

Outline	Background	Applications ○○○●	Spelling 0000000	Summary O

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Potentially useful ERP components:

• N2b (I am concentrating on this stimulus)

Outline	Background	Applications ○○○●	Spelling 0000000	Summary O

 N2b (I am concentrating on this stimulus) (note: some authors have referred to this as "mismatch negativity", but now consensus applies the term MMN to a *non*-attentionally modulated component, N2a)

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• P3b (that's the stimulus I want)

Outline	Background	Applications ○○○●	Spelling 0000000	Summary O

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- ERN or error-related negativity (oops, that wasn't what I wanted)

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- P3b (that's the stimulus I want)
- ERN or error-related negativity (oops, that wasn't what I wanted)

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The Farwell-Donchin speller, or "P300 speller" was first described in

Farwell L & Donchin E (1988): Talking off the Top of your Head: toward a Mental Prosthesis Utilizing Event-Related Brain Potentials. *Electroencephalography and Clinical Neurophysiology* **70**: 510–523

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Outline	Background	Applications	Spelling ●○○○○○○○	Summary O
The Farv	well-Donchin S	Speller		

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Farwell L & Donchin E (1988): Talking off the Top of your Head: toward a Mental Prosthesis Utilizing Event-Related Brain Potentials. *Electroencephalography and Clinical Neurophysiology* **70**: 510–523

Demo movie courtesy of Femke Nijboer (University of Tübingen & Fatronik, San Sebastián).

See also http://www.youtube.com/watch?v=NlUPFpZswJk

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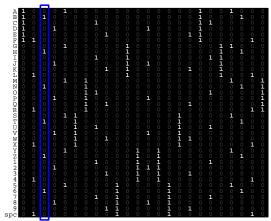
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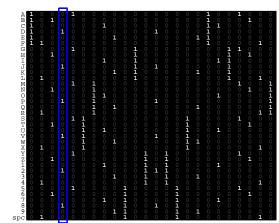
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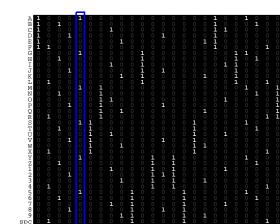
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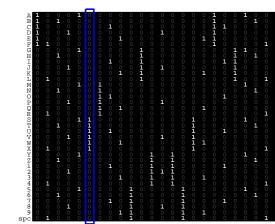
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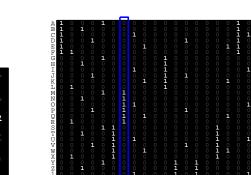


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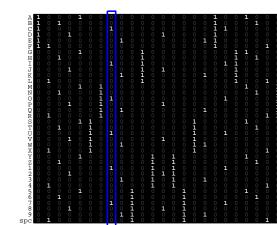
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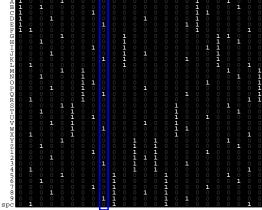
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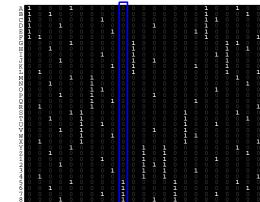
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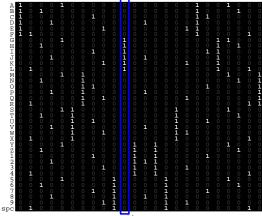
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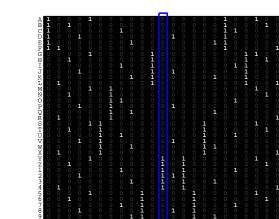
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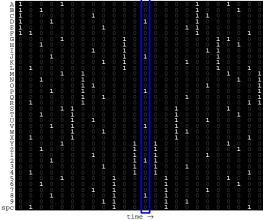
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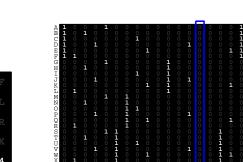
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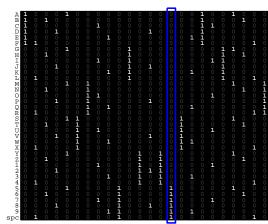
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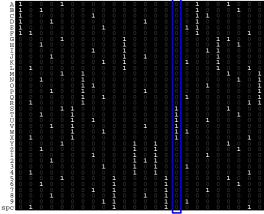
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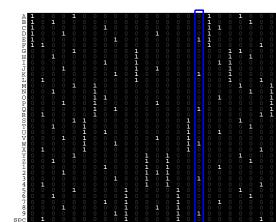




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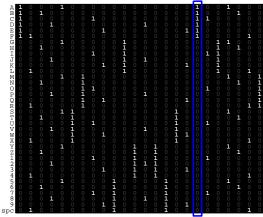
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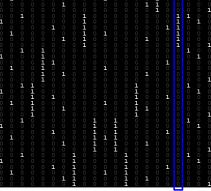
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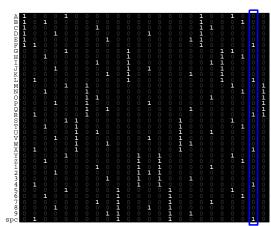
Spelling 0000000

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Background

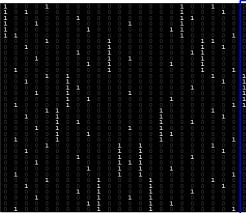
The Farwell-Donchin Speller

Applications

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Background

The Farwell-Donchin Speller

Applications

Outline	Background	Applications	Spelling ○○●○○○○○	Summary O

The Farwell-Donchin Speller

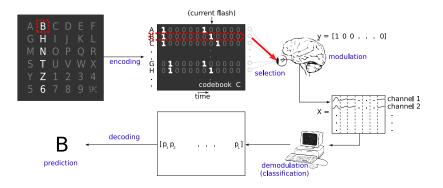


figure from Hill et al. 2009 Advances in Neural Information Processing Systems.

Outline	Background	Applications	Spelling ○○○●○○○○	Summary O
Terminolog	y			

Epoch: short period (500 to 1500 msec) following each stimulus, during which we look for ERPs. If we could classify ERPs perfectly, each epoch would give us one bit of information.

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Subtrial (variously also called **sequence**, **repetition**): one complete cycle of the rows and columns of the grid. If we could classify perfectly, this would be enough information to transmit any arbitrary letter.

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Outline	Background	Applications	Spelling ○○○●○○○○	Summary O
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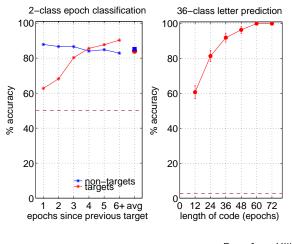
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Subtrial (variously also called **sequence**, **repetition**): one complete cycle of the rows and columns of the grid. If we could classify perfectly, this would be enough information to transmit any arbitrary letter.

Trial: One attempt to transmit a letter or symbol. Single ERPs, and hence single subtrials, can rarely be classified perfectly, so a trial often consists of multiple subtrials (error-correction by repetition).



From Single ERPs to Symbol Prediction



Data from Hill et al. 2009, Advances in Neural Information Processing Systems

Outline	Background	Applications	Spelling ○○○○○●○○	Summary O
Overtive	Covert Attent	ion		

Overt vs Covert Attention

Most P300-speller tests are performed with healthy subjects who look directly at (foveate) the target of interest.

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Outline	Background	Applications	Spelling ○○○○○●○○	Summary O
Overt vs	Covert Atten	tion		

For users who can do this:

• Are we relying (partially? mostly?) on gaze-dependent features of the EEG (e.g. visual evoked potentials from areas representing the fovea)?

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Outline	Background	Applications	Spelling ○○○○○●○○	Summary O
Overt vs	Covert Atten	tion		

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• Would an eye-tracking system do just as well, or better?

Outline	Background	Applications	Spelling ○○○○○●○○	Summary O
Overt vs	Covert Atten	tion		

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For users who cannot:

• Would the task become too difficult?

Outline	Background	Applications	Spelling ○○○○○●○○	Summary O
Overt vs	Covert Atten	tion		

For users who can do this:

- Are we relying (partially? mostly?) on gaze-dependent features of the EEG (e.g. visual evoked potentials from areas representing the fovea)?
- Would an eye-tracking system do just as well, or better?

For users who cannot:

- Would the task become too difficult?
- Would the system suffer interference from the evoked potentials caused by whatever the user *is* fixating?

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Outline	Background	Applications	Spelling ○○○○○●○○	Summary O
Overt vs	Covert Attent	tion		

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- Would an eye-tracking system do just as well, or better?

For users who cannot:

- Would the task become too difficult?
- Would the system suffer interference from the evoked potentials caused by whatever the user *is* fixating?

For anyone:

 Artefacts time-locked to the stimulus of interest will also lead to "successful" BCI performance.

Outline	Background	Applications	Spelling ○○○○○●○	Summary O
An Auditor	y P300 Speller			

Furdea et al. 2009, Psychophysiology:

Auditorily-presented numbers encode the rows and columns.

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Outline	Background	Applications	Spelling ○○○○○○●	Summary O

• Speed (shorter SOA is faster, but leads to overlapping epochs and smaller ERPs due to refractory effects)

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Outline	Background	Applications	Spelling ○○○○○○●	Summary O

- Speed (shorter SOA is faster, but leads to overlapping epochs and smaller ERPs due to refractory effects)
- Size and layout of stimulus array

Sellers E, Krusienski D, McFarland D, Vaughan T & Wolpaw J (2006): A P300 event-related potential brain-computer interface (BCI): The effects of matrix size and inter stimulus interval on performance. *Biological Psychology* **73**: 242–252.

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• Attentional resources diverted elsewhere (Isreal et al. 1980, Psychophysiology)

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- Codebook (temporal *and* spatial effects: Hill et al. 2009, Advances in Neural Information Processing Systems)

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Outline	Background	Applications	Spelling ○○○○○○●	Summary O

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- Attentional resources diverted elsewhere (Isreal et al. 1980, Psychophysiology)
- Codebook (temporal *and* spatial effects: Hill et al. 2009, Advances in Neural Information Processing Systems)
- Stimulus type (Martens et al. 2009, Journal of Neural Engineering)

Outline	Background	Applications	Spelling 0000000	Summary ●
Summary				

 ERPs are electrical signals which can be measured as peaks and troughs in the $\mathsf{EEG}.$

Outline	Background	Applications	Spelling 0000000	Summary •
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Outline	Background	Applications	Spelling	Summary ●
6				

 ERPs are electrical signals which can be measured as peaks and troughs in the $\mathsf{EEG}.$

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Each ERP component has a characteristic latency, shape and scalp distribution.

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Some ERP components' amplitude and latency can be influenced by endogenous factors (e.g. attentional state, arousal level, intentions, expectations) as well as exogenous factors (stimulus characteristics).

Outline	Background	Applications	Spelling	Summary ●

 ERPs are electrical signals which can be measured as peaks and troughs in the $\mathsf{EEG}.$

Their appearance is correlated in time with some stimulus event.

Each ERP component has a characteristic latency, shape and scalp distribution.

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However, classification of small numbers of these epochs is also possible, leading to applications in brain-computer interfacing.

Outline	Background	Applications	Spelling	Summary ●

 ERPs are electrical signals which can be measured as peaks and troughs in the $\mathsf{EEG}.$

Their appearance is correlated in time with some stimulus event.

Each ERP component has a characteristic latency, shape and scalp distribution.

Some ERP components' amplitude and latency can be influenced by endogenous factors (e.g. attentional state, arousal level, intentions, expectations) as well as exogenous factors (stimulus characteristics).

They can be extracted best by time-locked averaging of the voltage signal from a large numbers of epochs.

However, classification of small numbers of these epochs is also possible, leading to applications in brain-computer interfacing.

The most closely studied of these is the Farwell-Donchin speller, exploiting the user's (overt and covert) attention to one out of a set of visual stimuli.