Outline	Background	Applications	Spelling	Summary O

# Event-Related Potentials in Brain-Computer Interfacing

#### Jeremy Hill

Max Planck Institute for Biological Cybernetics Tübingen, Germany

◆□ > ◆□ > ◆豆 > ◆豆 > ̄豆 = つへぐ

Outline	Background	Applications	Spelling	Summary





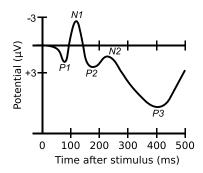






Outline	Background ●○○○○	Applications	Spelling 00000000	Summary o

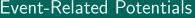
### **Event-Related Potentials**

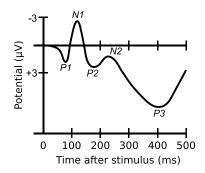


schematic figure from http://en.wikipedia.org/wiki/Event\_related\_potential

◆□ > ◆□ > ◆豆 > ◆豆 > ̄豆 = つへぐ

Outline	Background ●○○○○	Applications	Spelling 0000000	Summary O
Evont P	Polatod Datantia			





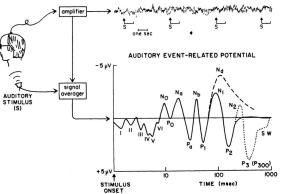
- N for negative, P for positive (beware: negative is sometimes plotted upwards, sometimes downwards).
- Numbered sequentially (P1, P2, P3, ...) or by typical latency in milliseconds (N140, P300, ...).

▲日▼ ▲□▼ ▲ □▼ ▲ □▼ ■ ● ○○○

schematic figure from http://en.wikipedia.org/wiki/Event\_related\_potential

Outline	Background ●○○○○	Applications	Spelling	Summary O

## **Event-Related Potentials**



ONGOING EEG

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

・ロト ・ 一下・ ・ ヨト ・ 日 ・

э.

Outline	Background ●○○○○	Applications	Spelling	Summary O

#### 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.

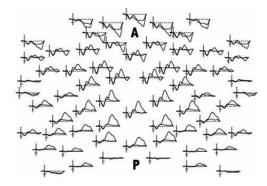


figure from Patel & Azzam (2005) Int. J. Medical Sciences. ・ロト ・ 日 ・ ・ ヨ ・ ・ ヨ ・

э

Outline	Background ○●○○○	Applications	Spelling 0000000	Summary O

"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.

◆□▶ ◆□▶ ◆臣▶ ◆臣▶ □臣 = のへで

Outline	Background ○●○○○	Applications	Spelling 0000000	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

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

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

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

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

The boys heard Joe's about story

Outline	Background ○●○○○	Applications	Spelling 0000000	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

The boys heard Joe's about story Africa.

• The N400 is a correlate of semantic processing:

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

The boys heard Joe's about story Africa.

• The N400 is a correlate of semantic processing: The

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

The boys heard Joe's about story Africa.

• The N400 is a correlate of semantic processing: The boys

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

The boys heard Joe's about story Africa.

• The N400 is a correlate of semantic processing: The boys heard

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

The boys heard Joe's about story Africa.

• The N400 is a correlate of semantic processing: The boys heard Joe's

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

The boys heard Joe's about story Africa.

• The N400 is a correlate of semantic processing: The boys heard Joe's orange

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

The boys heard Joe's about story Africa.

• The N400 is a correlate of semantic processing: The boys heard Joe's orange about

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲日▼ ▲□▼ ▲ □▼ ▲ □▼ ■ ● ○○○

The boys heard Joe's about story Africa.

• The N400 is a correlate of semantic processing: The boys heard Joe's orange about Africa.

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

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:

▲日▼ ▲□▼ ▲ □▼ ▲ □▼ ■ ● ○○○

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

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

- 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

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

- 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

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

- 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

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

- 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

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

- 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

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

- 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

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

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:

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

- 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

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

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.

< □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

 $\mathsf{Examples}$  of  $\mathsf{ERPs}$  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.

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

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).

Outline	Background ○●○○○	Applications	Spelling 0000000	Summary O

"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.

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

< □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

Outline	Background ○●○○○	Applications	Spelling	Summary O

"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.

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).
- P300s can also be elicited by the *absence* of a stimulus in an otherwise predictable sequence (Sutton et al. 1967, Science).
- P300 amplitude correlates with the magnitude of a stimulus's reward value, for both positive and negative outcomes (Yeung & Sanfey 2004, J. Neuroscience).

< □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

Outline	Background ○●○○○	Applications	Spelling	Summary O

## More Than Just Evoked Potentials

"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.

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).
- P300s can also be elicited by the *absence* of a stimulus in an otherwise predictable sequence (Sutton et al. 1967, Science).
- P300 amplitude correlates with the magnitude of a stimulus's reward value, for both positive and negative outcomes (Yeung & Sanfey 2004, J. Neuroscience).

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

Outline	Background ○●○○○	Applications	Spelling 0000000	Summary O
	 . –			

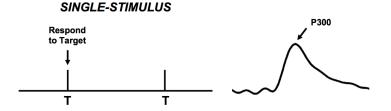
## More Than Just Evoked Potentials

"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.

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.

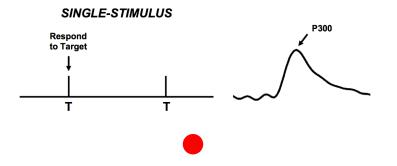
▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

Outline	Background ○○●○○	Applications	Spelling 0000000	Summary O

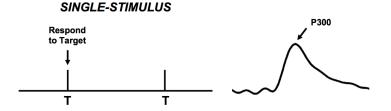


◆□▶ ◆□▶ ◆臣▶ ◆臣▶ 臣 のへぐ

Outline	Background ○○●○○	Applications	Spelling	Summary O

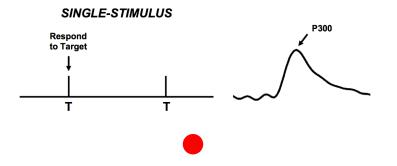


Outline	Background ○○●○○	Applications	Spelling 0000000	Summary O



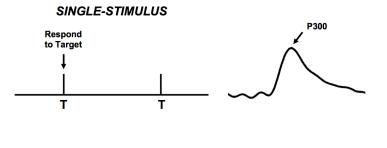
◆□▶ ◆□▶ ◆臣▶ ◆臣▶ 臣 のへぐ

Outline	Background ○○●○○	Applications	Spelling	Summary O



Outline	Background ○○●○○	Applications	Spelling 0000000	Summary O

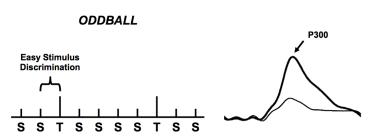
◆□▶ ◆□▶ ◆臣▶ ◆臣▶ 臣 のへぐ



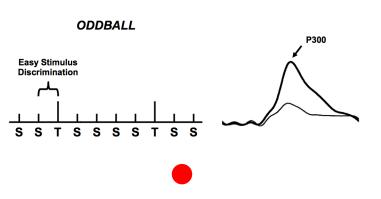
. . .

Outline	Background ○○●○○	Applications	Spelling	Summary O

▲ロト ▲圖ト ▲屋ト ▲屋ト

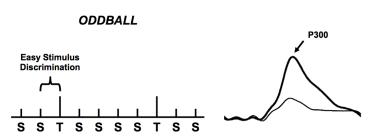


Outline	Background ○○●○○	Applications	Spelling	Summary O

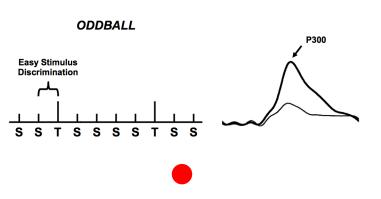


Outline	Background ○○●○○	Applications	Spelling	Summary O

▲ロト ▲圖ト ▲屋ト ▲屋ト

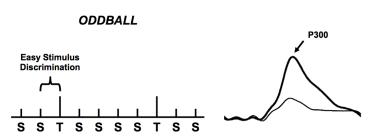


Outline	Background ○○●○○	Applications	Spelling	Summary O

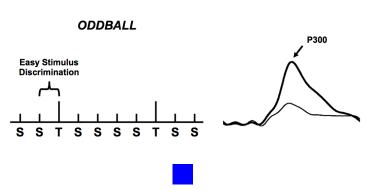


Outline	Background ○○●○○	Applications	Spelling	Summary O

▲ロト ▲圖ト ▲屋ト ▲屋ト

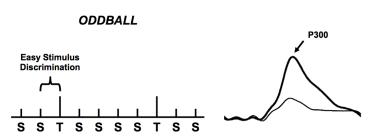


Outline	Background ○○●○○	Applications	Spelling	Summary O

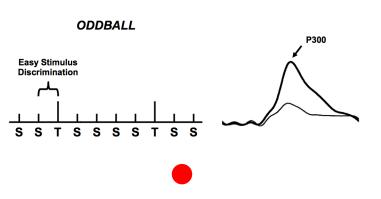


Outline	Background ○○●○○	Applications	Spelling	Summary O

▲ロト ▲圖ト ▲屋ト ▲屋ト

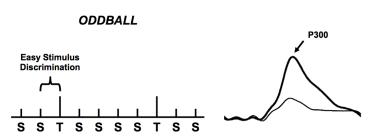


Outline	Background ○○●○○	Applications	Spelling	Summary O

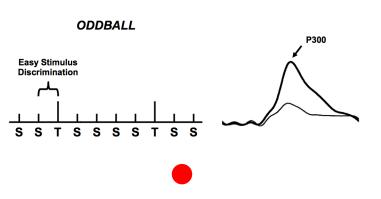


Outline	Background ○○●○○	Applications	Spelling	Summary O

▲ロト ▲圖ト ▲屋ト ▲屋ト

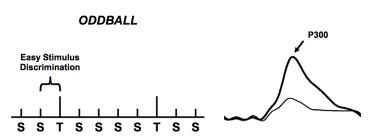


Outline	Background ○○●○○	Applications	Spelling	Summary O



Outline	Background ○○●○○	Applications	Spelling	Summary O

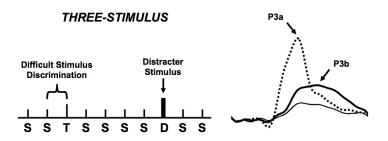
◆□▶ ◆□▶ ◆臣▶ ◆臣▶ = 臣 = のへで



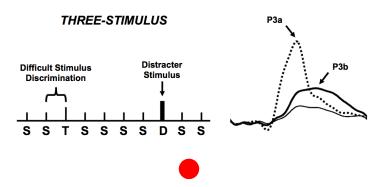
. . .

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

・ロト ・ 御 ト ・ ヨ ト ・ ヨ ト

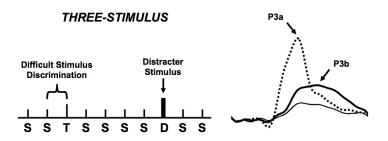


Outline	Background ○○●○○	Applications	Spelling	Summary O
				,

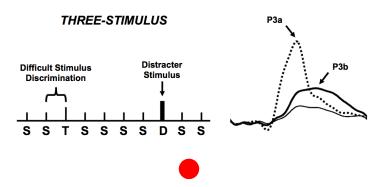


Outline	Background ○○●○○	Applications	Spelling	Summary O
				,

・ロト ・ 御 ト ・ ヨ ト ・ ヨ ト

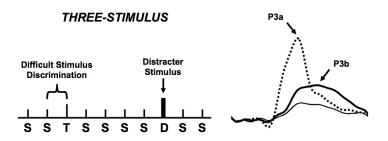


Outline	Background ○○●○○	Applications	Spelling	Summary O
				,

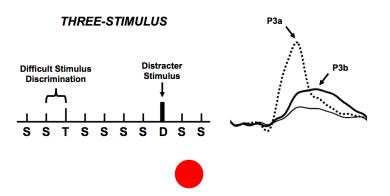


Outline	Background ○○●○○	Applications	Spelling	Summary O
				,

・ロト ・ 御 ト ・ ヨ ト ・ ヨ ト



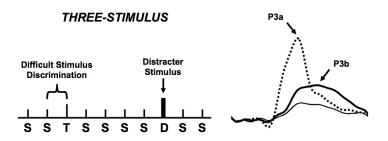
Outline	Background ○○●○○	Applications	Spelling	Summary O
				,



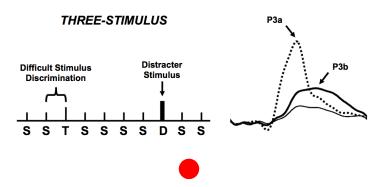
◆□ > ◆□ > ◆豆 > ◆豆 > ̄豆 = つへぐ

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

・ロト ・ 御 ト ・ ヨ ト ・ ヨ ト

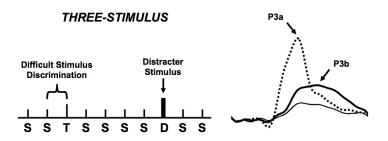


Outline	Background ○○●○○	Applications	Spelling	Summary O
				,

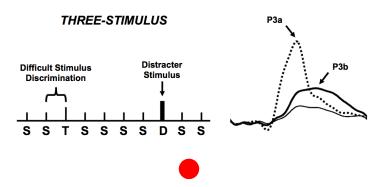


Outline	Background ○○●○○	Applications	Spelling	Summary O
				,

・ロト ・ 御 ト ・ ヨ ト ・ ヨ ト

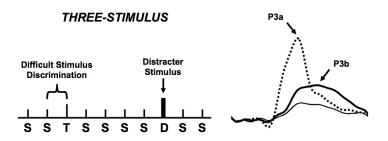


Outline	Background ○○●○○	Applications	Spelling	Summary O
				,

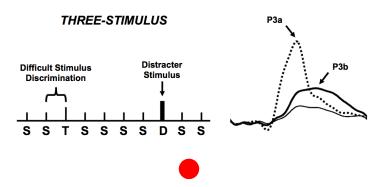


Outline	Background ○○●○○	Applications	Spelling	Summary O
				,

・ロト ・ 御 ト ・ ヨ ト ・ ヨ ト

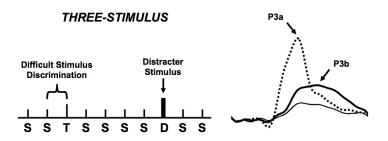


Outline	Background ○○●○○	Applications	Spelling	Summary O
				,

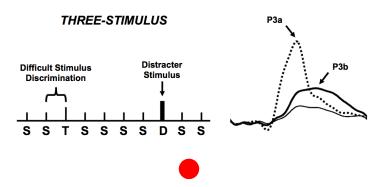


Outline	Background ○○●○○	Applications	Spelling	Summary O
				,

・ロト ・ 御 ト ・ ヨ ト ・ ヨ ト

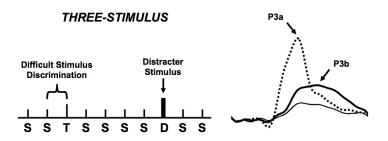


Outline	Background ○○●○○	Applications	Spelling	Summary O
				,

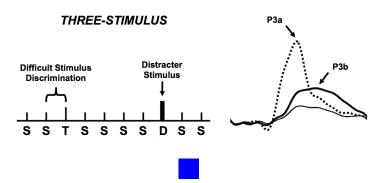


Outline	Background ○○●○○	Applications	Spelling	Summary O
				,

・ロト ・ 御 ト ・ ヨ ト ・ ヨ ト



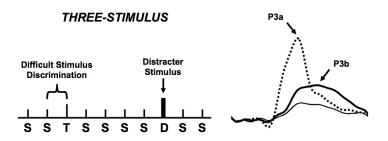
Outline	Background ○○●○○	Applications	Spelling	Summary O



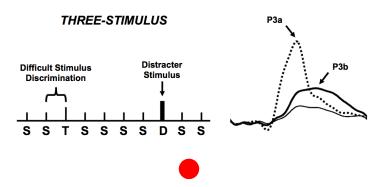
▲□▶ ▲□▶ ▲三▶ ▲三▶ 三三 のへで

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

・ロト ・ 御 ト ・ ヨ ト ・ ヨ ト



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

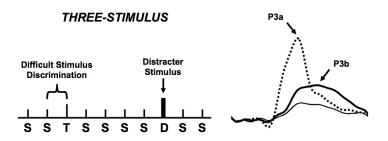


Outline	Background ○○●○○	Applications	Spelling	Summary O
				,

figures from Polich (2007) Clinical Neurophysiology

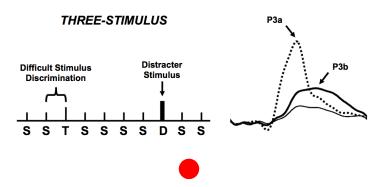
・ロト ・ 御 ト ・ ヨ ト ・ ヨ ト

€ 990



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

figures from Polich (2007) Clinical Neurophysiology



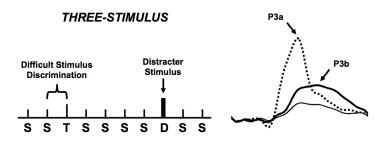
◆□▶ ◆□▶ ◆臣▶ ◆臣▶ = 臣 = のへで

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

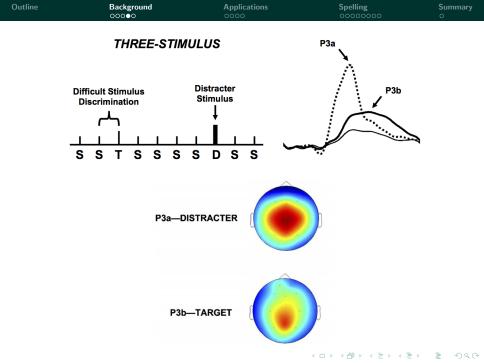
figures from Polich (2007) Clinical Neurophysiology

ヘロト ヘロト ヘヨト ヘヨト

€ 990



. . .



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

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

age;

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

◆□▶ ◆□▶ ◆臣▶ ◆臣▶ 臣 の�?

- age;
- gender;

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

◆□ > ◆□ > ◆豆 > ◆豆 > ̄豆 = つへぐ

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

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

◆□ > ◆□ > ◆豆 > ◆豆 > ̄豆 = つへぐ

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

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

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

- 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		

◆□▶ ◆□▶ ◆三▶ ◆三▶ ・三 ・ つへぐ

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

Outline	Background	Applications ●○○○	Spelling	Summary O

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

Average large numbers of ERPs

> Classify single ERPs

◆□▶ ◆□▶ ◆三▶ ◆三▶ - 三 - のへぐ

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

◆□ > ◆□ > ◆豆 > ◆豆 > ̄豆 = つへぐ



- "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.

#### Average large numbers of ERPs

Classify single ERPs

▲日▼▲□▼▲□▼▲□▼ □ − つくで



- "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).

Average large numbers of ERPs

Classify single ERPs

▲日▼▲□▼▲□▼▲□▼ □ − つくで



- "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).

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

Classify single ERPs

▲日▼ ▲□▼ ▲ □▼ ▲ □▼ ■ ● ○○○



- "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

▲日▼ ▲□▼ ▲ □▼ ▲ □▼ ■ ● ○○○

Outline Background Applications Spelling Summary 0000

## "Cortically Coupled Computer Vision"

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

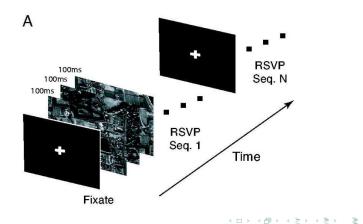


Credit: Digital Globe



## "Cortically Coupled Computer Vision"

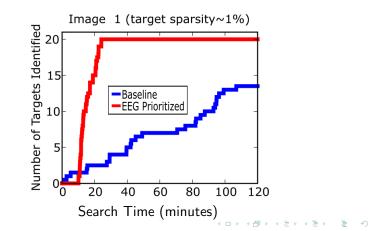
figures from Parra et al. 2008 (IEEE Signal Processing Magazine)





## "Cortically Coupled Computer Vision"

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



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).

◆□▶ ◆□▶ ◆臣▶ ◆臣▶ 三臣 - のへで

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).

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

 $\bullet$  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

< □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

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.)

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.)
- covert attention

Outline	Background	Applications ○○○●	Spelling 0000000	Summary O

◆□▶ ◆□▶ ◆臣▶ ◆臣▶ 臣 のへぐ

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)

◆□ > ◆□ > ◆豆 > ◆豆 > ̄豆 = つへぐ

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)

< □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

• P3b (that's the stimulus I want)

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

< □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

Outline	Background	Applications ○○○●	Spelling 0000000	Summary ○

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

< □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

• ...?

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

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

< □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

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

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

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

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

А	в	C	D	Е	F
G					L
Μ					R
S					
Y					4
5					spc

1111110000	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	
		1															1		
1							1										1	1	
1			1									1					1		
1								1								1	1		
1	1																1		
				1						1 1									
		0 1 0								1									
							1			1								1	
			1							1 1		1							
								1		1						1			
	1			0 1						1									
				1		1													
		1				11111													
						1	1											1	
			1			1						1							
						1		1								1			
	1																		
				1	1										1				
		1			1 1										1 1				
					1		1								1			1	
			1		1 1							1			1 1				
					1			1							1	1			
	1				1										1				
				1							1		1						
		1									1		1						
							1				1		1					1	
			1								1	1	1						
								1			1		1			1			
	1										1		1						

1

78 ğ spc

# The Farwell-Donchin Speller



111

ヘロン 人間 と 人 ヨン 人 ヨン

1

æ

Outline

F	Ε	D	С	В	A
L					G
R					M
х					S
4					Y
spc					5

	_				_													_						
A	11		0		1													111111			100	0		
B	1		1					0 1										÷	0			1		
C D	1			ĭ				0					1					÷	1					
5	1			0					1				0				1	÷						
E	i	ĭ							1								1	÷					1	
Ĝ	0	Ō			ĭ															ĭ	ĭ		0	
			ĭ		1												00001			ーーーーーー	1	000	000000	
H I J								1			1								1	1				
J				1					0		1		1						1 0 0	1				
ĸ									1		1						1			1				
K L M		<b>1</b> 0			0 1		01111111				1									1	0 1 0	00	0	
М					1		1														1			1
N			1				1															1		1
0				0			1	1					0						1					1
P				1			1		0				1				0							1
ğ		0 1		0100			1		1								1						0	1
PORSTUV		Ō			ĩ	1	0									00111					1	000	01000	000000000000 <b>011111111</b> 0000000000000000
2			1													÷					100	1		
1			1			÷		0 1								÷			0			0		
v				ĭ		î		0					ĭ			î			0					
Ŵ				1		ī			0 1				0			ī	0							
x		1				1										11100							1	
Y			0 1		i									1 1							1	0		
YZ123456			1											1								1		
1								1				1	0 1	1					1					
2				0 1 0								1	1	1 1 1										
3									1			1		1			1							
4		1			0 1							1		1							0 1	0 0 1	00	
5					1					1					1						1			
6 7			1					0		1					1				0					
8				0 1				1		1			0 1		1				1					
9										÷														
		1							1	1					1		1						0	
spc				0	0	J	0	0	0	1	0	0	0	0	1	0	J	0	0	0	J	0	-	0

## The Farwell-Donchin Speller



 $ue \rightarrow$ 

Outline

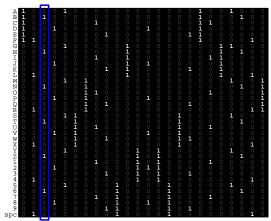
ackgroun

Applications

Spelling ○●○○○○○○

A	в	С	D	Ε	F
	н				
	N				
	т				
	z				
	6				

The Farwell-Donchin Speller



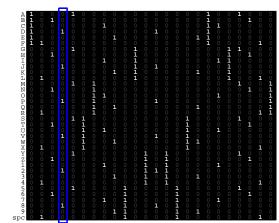
time  $\rightarrow$ 

Outline

Background

Applications

A		D	F
G		J	L
Μ		Р	R
S		v	X
Y		2	4
5		8	spc



time  $\rightarrow$ 

(日) (四) (三) (三)

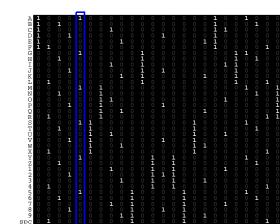
# The Farwell-Donchin Speller

Outline

Background

Applications

A			
G			
м			
S			
Y			
5			



time  $\rightarrow$ 

(日) (四) (三) (三)

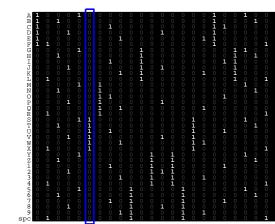
э

# The Farwell-Donchin Speller

Outline

Background

A					
G					
M					
s	т	U	v	W	х
s Y	T Z	<b>บ</b> 1	<b>v</b> 2	<b>W</b> 3	<b>X</b> 4



The Farwell-Donchin Speller

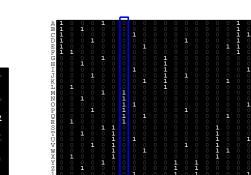


Ð

Background

Applications

A					F
G					
м	N	0	Ρ	Q	R
S					
Y					4
5					spc



1

56

89 spc

# The Farwell-Donchin Speller



Outline

Background

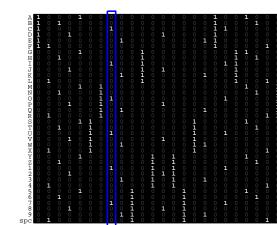
Applications

Spelling 0000000

1

1

A	С		
G	I		
Μ	0		
S	U		
Y	1		
5	7		



# The Farwell-Donchin Speller





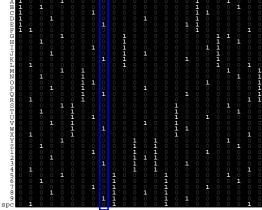
Outline

Background

Applications

EF		A
K L		G
QR		Μ
X W		S
<b>3</b> 4		Y
9 spc		5





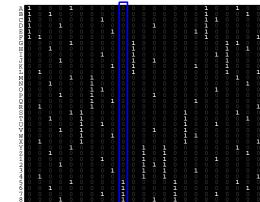
(日) (四) (三) (三)

Background

The Farwell-Donchin Speller

Applications

A	В	С	D	Ε	F
G					
Μ					
S					
Y					
5	6	7	8	9	spc



9 spc

time  $\rightarrow$ 

(日) (四) (三) (三)

# The Farwell-Donchin Speller

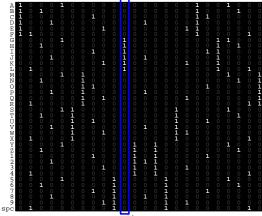
Outline

Background

Applications

A					
G	1\$1	I	J	ĸ	L
Μ					
S					
Y					
5					





Ð

(日) (四) (三) (三)

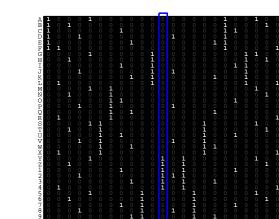
Outline

Background

The Farwell-Donchin Speller

Applications

A					
G					
Μ					
S					
Y	Z	1	2	3	4
5					



The Farwell-Donchin Speller

Background

Applications

spc

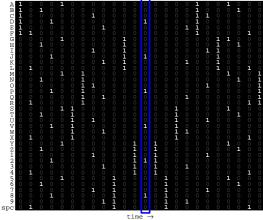
Spelling

Summary

◆ロト ◆母 ト ◆臣 ト ◆臣 ト ◆ 国 ト ◆ の へ の

A	В	С	D	Ε	F
G			J		L
Μ			Р		R
S			v		X
Y			2		4
5			8		spc





# The Farwell-Donchin Speller

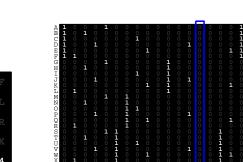
Summa

Outline

Background

Applications

5					
Y	Z	1	2	3	4
S					
м					
G					
A		С	D	Е	F



The Farwell-Donchin Speller

1

1 1 1

1

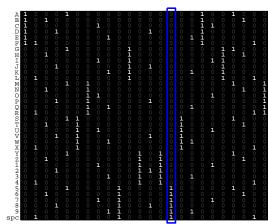
1

1

Background

8 9 spc

5	6	7	8	9	spc
Y					
S					
Μ					
G					
A	В	С	D	Ε	F



me →

Background

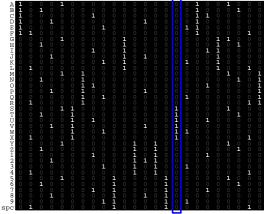
The Farwell-Donchin Speller

Applications

Spelling ○●○○○○○○○ Summary

A	В	С			
G					
м					
s	т	U	v	W	x
s T	T Z	<b>บ</b> 1	<b>v</b> 2	<b>W</b> 3	<b>X</b> 4

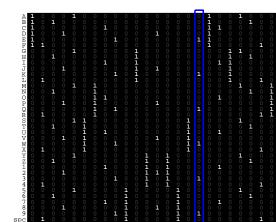




Background

Applications

С	В	A	вC	D	Е	F
		G			K	L
		Μ			Q	R
		S			W	X
		Y			3	4
		5			9	spc



# The Farwell-Donchin Speller

Outline

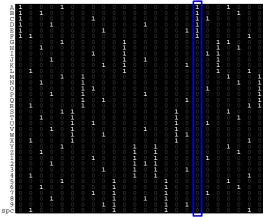
Background

Applications

Spelling ○●○○○○○○

A	в	С	D	Е	F
G					L
Μ					R
5					X
Y					4
5					spc





(日) (四) (三) (三)

Ð

Spelling ○●○○○○○○ Summary

Outline

Background

Applications

A	В	C	D	Е	F
G		Ι			
Μ		0			
S		U			
Y		1			
5		7			





Background

The Farwell-Donchin Speller

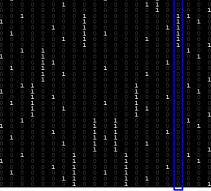
Applications

A	В	С	D	Ε	F
G	1\$1	I	J	ĸ	L
Μ					
S					
Y					
5					



v

8 9 spc



The Farwell-Donchin Speller

time  $\rightarrow$ 

0000000

1

Outline

Background

Applications

A	В	С	D	Ε	F
G					
м					
S					
Y					
5					

spc

				1													1		
1		1															1 1		
1							1										1	1	
1			1									1					1		
1								1								1	1 1		
1	1																1		
				1						1 1									1 1
0		1								1									1
							1			1								1	1111
			1							1110		1							1
								1		1						1			1
0	1									1									1
				1		1													
0		1				1													
						1	1											1	
			1			1						1							
						1		1								1			
	1					1													
				1	1 1 1										1				
		1			1										1				
0					1		1								1			1	
7 0			1		1 1							1			1 1				
10					1			1							1	1			
0	1				1										1				
				1							1		1						
0		1									1 1		1						
							1				1 1		1 1					1	
00000			1								1	1	1						
								1			1		1			1			
0	1										1		1						
0				1					1					1					
0		1							1					1					

The Farwell-Donchin Speller

Outline

1

・ロト ・ 日 ト ・ モ ト ・ モ ト æ

A	в		
G	Ħ		
Μ	N		
S	т		
Y	z		
5	б		

	A	1111	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	в	1		1															1	
	C	1							1										1	1
	D	1			1									1					1	
	E	1								1								1	1	
	F	1	1																1	
	G					1						1								
	H			1								1								
	I								1			1								1
	J				1							1		1						
	K									1		1						1		
	L		1									1								
	М					1		1												
	N			1				1												
	0							1	1											1
	P				1			1						1						
	Q							1		1								1		
	R		1					1												
	S					1	1										1			
	т			1			1										1			
	U						1		1								1			1
	v				1		1							1			1			
	W						1			1							1	1		
	Х		1				1										1			
	Y					1							1		1					
	Z			1									1		1					
	1								1				1		1					1
-	2			000 <b>1</b> 00000 <b>1</b> 00000 <b>1</b> 0000 <b>1</b> 000	1000001000001000001000010	0001000010000100001000010000		00000000 <b>011111110</b> 00000000000					1	-1	1		000000000000000 <b>111111</b> 00000			
	A B C D E F G H H J K L MN O P Q R S T U V W X Y Z 1 2 3 4 5 6 7		0 <b></b>				00000000000000000000000000000000000000		00 <b>-</b> 100000-10000-10000-10000-10000-	0 <b>-1</b> 00000-100000-10000-10000-100	00000000000000000000000000000000000000	000000 <b>111111</b> 0000000000000000000000000	00000000000000000000000000000000000000	<b>H</b> 00000 <b>H</b> 00000 <b>H</b> 00000 <b>H</b> 0000 <b>H</b> 00000	00000000000000000000000000000000000000	00000000000000000000000000000000000000		0000 <b>-</b> 00000-000-000-0000-0000-00000-00000-0000	<b></b>	00 <b>1</b> 00000 <b>1</b> 00000 <b>1</b> 0000 <b>1</b> 0000 <b>1</b> 00000
	4		1	0010		0							1		1					
	5					-1					1					1				
	6			-1							-1					-1				
	- 7								1		1					1				- 1

spc

1



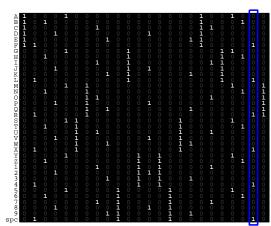
Spelling 0000000

1

1

1111

F	Ε	D	С	В	A
L					G
R					M
х					S
4					Y
spc					5



Background

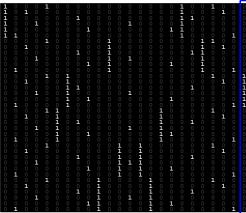
The Farwell-Donchin Speller

Applications

A	В	С	D	Ε	F
G					
м	N	0	Ρ	Q	R
S					
Y					
5					

			1	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0
		A B C	1		ĭ		0											
		C	11			0 1				1					0			
		D E F	i			0					ĭ				0			
		F	1	1														
		G H J					1						1					
		н			1					0			1					
		Ť				1				1			1 1		1			
		7									ĭ		i					
		K		ĭ							0		î					
		M		0			ĭ		ĭ				0					
		Ν			1				1									
		0							1	1								
		D				1			1						1			





(日) (四) (三) (三)

Background

The Farwell-Donchin Speller

Applications

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

### The Farwell-Donchin Speller

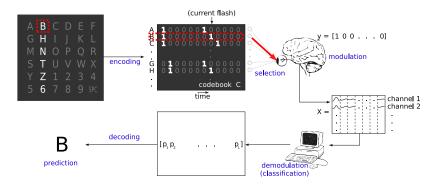


figure from Hill et al. 2009 Advances in Neural Information Processing Systems.

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.

▲ロト ▲帰 ト ▲ 三 ト ▲ 三 ト の Q ()

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.

**Stimulus Onset Asynchrony (SOA)**: the time from the start of one stimulus event (flash) to the start of the next (sometimes wrongly called "inter-stimulus interval" or ISI).

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

Outline	Background	Applications	Spelling ○○○●○○○○	Summary O
Terminolog	(V			

**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.

**Stimulus Onset Asynchrony (SOA)**: the time from the start of one stimulus event (flash) to the start of the next (sometimes wrongly called "inter-stimulus interval" or ISI).

**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.

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

Outline	Background	Applications	Spelling ○○○●○○○○	Summary O
Terminolog	(V			

**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.

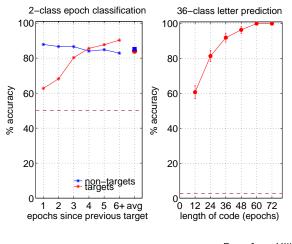
**Stimulus Onset Asynchrony (SOA)**: the time from the start of one stimulus event (flash) to the start of the next (sometimes wrongly called "inter-stimulus interval" or ISI).

**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.

◆□▶ ◆□▶ ◆臣▶ ◆臣▶ □臣 = のへで

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)?

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

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)?

◆□▶ ◆□▶ ◆三▶ ◆三▶ ・三 ・ つへぐ

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

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)?

▲ロト ▲帰ト ▲ヨト ▲ヨト - ヨ - の々ぐ

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

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?

◆□▶ ◆□▶ ◆三▶ ◆三▶ ・三 ・ つへぐ

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

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.

BRAINPOWER (B)						
		- <b>(</b> 1)				
	6	7	8	9	10	
<b>(</b> (()) <b>1</b>						
2						
3						
4						
5						

◆□▶ ◆□▶ ◆臣▶ ◆臣▶ 臣 の�?

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

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

◆□ > ◆□ > ◆豆 > ◆豆 > ̄豆 = つへぐ

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.

▲日▼▲□▼▲□▼▲□▼ □ − つくで

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.

• Task difficulty (increases N2 amplitude and P3 latency) (Senkowski & Hermann 2002, Clinical Neurophysiology)

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.

• Task difficulty (increases N2 amplitude and P3 latency) (Senkowski & Hermann 2002, Clinical Neurophysiology)

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

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.

- Task difficulty (increases N2 amplitude and P3 latency) (Senkowski & Hermann 2002, Clinical Neurophysiology)
- Attentional resources diverted elsewhere (Isreal et al. 1980, Psychophysiology)
- Codebook (temporal *and* spatial effects: Hill et al. 2009, Advances in Neural Information Processing Systems)

< □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > < □ > <

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.

- Task difficulty (increases N2 amplitude and P3 latency) (Senkowski & Hermann 2002, Clinical Neurophysiology)
- 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				

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

Outline	Background	Applications	Spelling 0000000	Summary •
Summary				

 $\mathsf{ERPs}$  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.

Outline	Background	Applications	Spelling	Summary ●
6				

 $\mathsf{ERPs}$  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.

◆□▶ ◆□▶ ◆臣▶ ◆臣▶ 臣 の�?

Outline	Background	Applications	Spelling	Summary ●

 $\mathsf{ERPs}$  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).

Outline	Background	Applications	Spelling	Summary ●

 $\mathsf{ERPs}$  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.

▲□▶ ▲□▶ ▲□▶ ▲□▶ ▲□ ● ● ●

Outline	Background	Applications	Spelling	Summary ●

 $\mathsf{ERPs}$  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.

Outline	Background	Applications	Spelling	Summary ●

 $\mathsf{ERPs}$  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.