Steady-State Evoked Potentials

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What is the SSEP

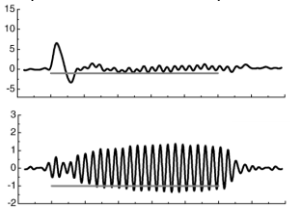
- Frequency tagging
  - Present stimulus with constant frequency
  - Frequency of stimulus in EEG signal
  - (Sub) Harmonics
- 3 Modalities
  - Visual
  - Auditory
  - Tactile

What is the SSEP

- Steady state response vs transient response

20 Hz lowpass

18- 30 Hz bandass

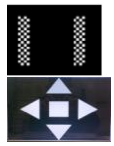


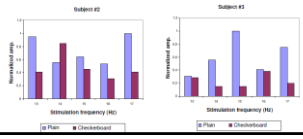
Nangini et al. 2006

- Neural basis:
  - synchronization / entrainment

Visual Modality

- Steady State Visual Evoked Potential (SSVEP)
- Flickering/oscillating stimuli
  - Checkerboxes
    - Pattern reversal
  - Plain textures
    - On/off pattern

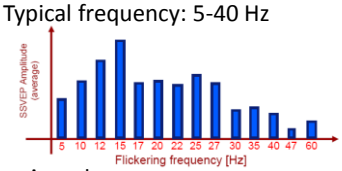




Allison et al. 2008a

Visual Modality

- Typical frequency: 5-40 Hz

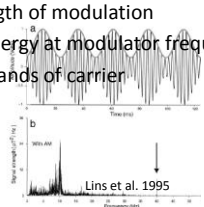


Pastor et al. 2003

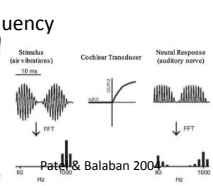
  - Annoying
  - Photosensitive epilepsy (16-25 Hz)
  - Use of higher frequencies: not visible
- Occipital electrodes

Auditory Modality

- Auditory Steady State Response (ASSR)
- Tone (carrier)
- amplitude modulation (frequency tag)
  - Strength of modulation
  - No energy at modulator frequency
  - Sidebands of carrier



Lins et al. 1995



Pate & Balaban 2004

Auditory Modality

- Frequencies:
  - Carrier: 500-4000 Hz
  - Modulator: 25-100 Hz, maximum at +/- 40 Hz
- Example sound:
- Source: primary auditory cortices

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Tactile Modality

- Steady State Somatosensory Evoked Potential (SSSEP, or sometimes SSEP)
- Stimulators
  - Mechanical
  - Electrical stimulation
- Stimuli pattern:
  - Carrier with amplitude modulation
  - Only base frequency

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Tactile Modality

- Frequencies:
  - 15-30 Hz, maximum around 21 Hz
- Source:
  - (Contralateral) Somatosensory cortex

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Use in neurology / psychology

- Visual:
  - Diagnosing optic neuritis, multiple sclerosis and other neurological disorders.
  - Contrast sensitivity in infants and MS
  - Research: memory, aging, movement processing, attention
- Auditory:
  - Estimate frequency specific audiogram :
    - Infants
    - Coma patients
    - Medical examination
    - For installation/adjustment of hearing aids
  - Research: aging, hearing loss, anesthesia, attention
- Tactile:
  - Neuromonitoring during surgery
  - Mapping of finger representation areas
  - Research: changes in cortex excitability, anesthesia

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Known influences

- Age => ASSR amplitude increases with age
- Gender => SSVEP stronger in women
- Neurological disorders (schizophrenia)
- Cannabis => similar as schizophrenics (auditory and visual)
- Nicotine => SSVEP amplitude increases
- attention

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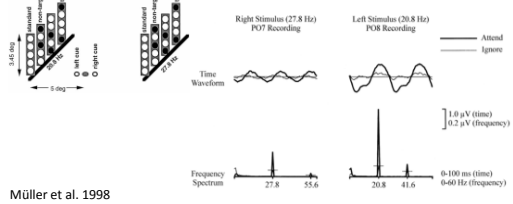
Attentional Modulation: Visual

Parallel stimulation:

-Target detection



Müller et al. 1998

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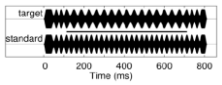
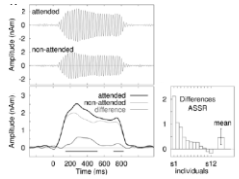
Attentional Modulation: Auditory

- Serial stimulation
  - Attention condition:
    - Target detection task



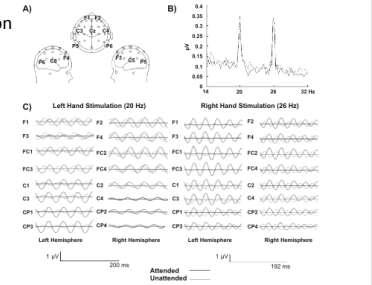
  - Non-attention condition:
    - Visual target detection task



Ross et al. 2004

Attentional Modulation: Tactile

- Parallel stimulation
- Detect amplitude modulation



Giabbiconi et al. 2004

Fig. 1. (A) Schematic representation of electrodes on the scalp surface. (B) Spectrogram across all subjects at fronto and fronto-central electrode sites. Attended left finger condition is plotted by the dotted line and attended right finger condition by the solid line (for further details see Results). (C) Representative moving window averages SSSEPs of one subject. Solid lines represent the attended condition, dotted lines the ignored condition.

Attential modulation: Theory

- Sensory gain model (Hillyard and Anllo-Vento 1998)
  - Gain control affects the overall neural response in a particular brain region without changing the time course or pattern of the neural activity
    - no change in the waveform
    - no change in the latency
    - no change in scalp voltage topography of this component
    - no change in cortical sources within a certain time window
- Top down control from other areas (prefrontal cortex)
- (Modulation) frequency is not used for directing attention

How can you use this in a BCI?

- Attention modulates the SSEP
  - Present N classes of stimuli (serial, parallel)
    - (Sub) Harmonics
  - Let participant attend to one of the stimuli
    - (Counting) task makes it easier
  - Detect attentional modulation

Relation to P3

- Similarities:
  - Event related response
  - Attention
  - Correlation (or template matching) with stimulus
- Differences:
  - Transient vs sustained
  - Serial vs parallel

SSVEP based BCI

- Visual: most popular SSEP BCI

Characteristics of recent BCI systems based on SSVEPs. ITRs are computed using Eq. (2).

Authors	Stimuli	Method	C	E	Accuracy (M subjects)	ITR bit/min
Gao et al. (2003)	LED	Large number of targets	48	2	87.5% (M = 1)	68
Kelly et al. (2005)	Flicker	Attentional effect	2	NC[a] (≤64)	≈71%; 63–85% (M = 10)	Off[b]: ≈2.3; 0.9–6.4
Lalor et al. (2005)	Chkb	AR models, Immersive game	2	2	≈89%; 71–100% (M = 6)	NC[a]; ≈15.5; 3.8–30.0
Maggi et al. (2006)	LED	Portable device	2	2	NC; 80–100% (M = 5)	≈17.2
Trejo et al. (2006)	Chkb	KPLS classifier	4	12	NC; 80–100% (M = 3)	NC[a]; ≈5.5; 3.8–8.0
Müller-Putz et al. (2005)	LED	Visual feedback	4	4	≈64%; 42–94% (M = 5)	≈5.8; 0.4–32.0
Nielsen et al. (2006)	Flicker	Auditory feedback	9	1	≈80%; 58–100% (M = 7)	≈21.0; 8.7–33
Wang et al. (2006)	Flicker	Time buffer, ICA lead selection, High pass threshold	13	32	NC (M = 16)	≈43; 29.0–63.1
Friman et al. (2007)	LED	Electrode combination	6	6	≈84%; 59–100% (M = 10)	Off[a,b]; ≈3.2; 1.3–5.2
Martínez et al. (2007)	Chkb	Visual feedback, Video game	4	6	≈96.5%; 82.3–100% (M = 6)	≈29.6; 17.0–38.7
Müller-Putz and Pfurtscheller (2008)	LED	Visual feedback, Commanding a hand prosthesis	4	4	≈74.7%; 55.2–90.0% (M = 4)	≈19.7; 4.1–34.2
Parini et al. (2009)	LED	Window length control, auditory feedback	4	8	≈97.5%; 95–100% (M = 11)	≈51.5; 17.0–70.0
Bin et al. (2009a)	Flicker	Lead selection	6	9	≈95%; 83–100% (M = 12)	≈58; 54.0–67.0
Bin et al. (2009b)	Flicker	Pseudorandom sequences	16	47	95 ± 6%	92.8 ± 14.1

Chkb, LED, and Flicker = checkerboard reversal, light-emitting diode (LED), and flickering rectangles, respectively, produced by an LCD screen. NC = not communicated by the authors; Off = offline study; C = number of commands accessible through the BCI system; E = the number of electrodes used to record the EEG; ITR = Shannon's information transfer rate.

[a] The authors selected a subset of electrodes out of 64.

[b] The purpose of this paper was to compare electrode combination methods, not to obtain a fast response.

Vialatte et al. 2009 *Progress in Neurobiology*

Example of SSVEP based BCI

- Instructions: look at the desired stimulus

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Example SSVEP based BCI

- Mind Balance

Lalor et al. 2004

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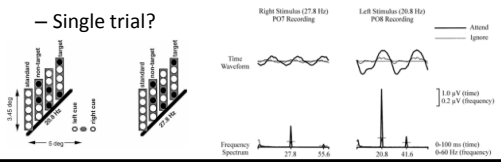
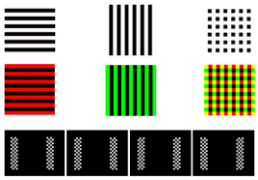
SSVEP based BCI

- Dependent BCI:
  - Use features that depend on (eye) muscle activity
  - Does it work in patients that cannot control gaze?
- Covert attention
  - (Müller et al. 1998)
  - Single trial?



SSVEP based BCI

– Overlapping stimuli (Allison et al. 2008b)



SSVEP differences across the three conditions

Condition	Low (R^2 below .08)	Moderate (R^2 .08 –.15)	High (R^2 .15–.30)	Very high (R^2 above .30)
BW checkerboard	1	1	5	7
BW linebox	6	4	4	0
Color linebox	7	4	2	1

Subjects' SSVEP differences were grouped into one of four categories based on the maximum R^2 difference produced by selective attention to one of two images. These groups correspond to a maximum R^2 difference of less than .08 (low), .08–.15 (medium), .15–.30 (high), and above .30 (very high). Numbers reflect how many subjects were in each category for each display type.

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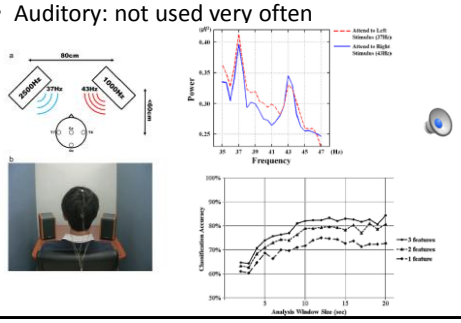
Example ASSR based BCI

- Auditory: not used very often



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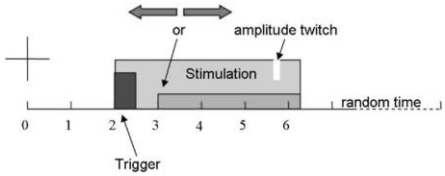
Example of SSSEP based BCI

- Müller-putz et al. (2006)
  - Mechanical tactile stimulation of left and right index finger
  - Task: count amplitude twitch



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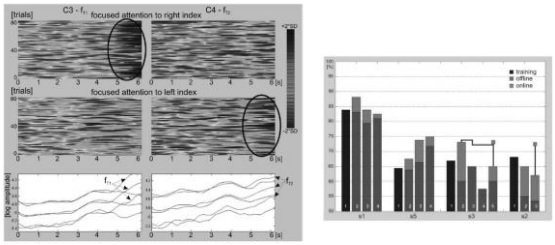
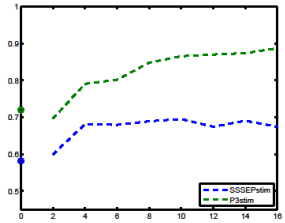
Example of SSSEP based BCI



Comparison with P3



- Interindividual differences

Conclusion

- Potential use for BCI
- Advantages:
  - Speed
  - Easy instructions (with task)
  - Multi-classes
- Disadvantages:
  - Annoying
  - Stimulus may intervene with normal interaction/communication

Questions?

References

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