Donders Institute
for Brain, Cognition and Behaviour

Introduction to BCI

Auditory Brain-Computer Interfaces

Radboud University Nijmegen

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October 25, 2011

Content

- Introduction
  - Brief history of EEG and music
  - From the ear to the brain
  - Towards auditory BCIs
- Real auditory BCIs
- BCI in the real world…

By the end of the lecture you should:

- Know what an auditory BCI is and why it is a topic of research
- Understand the basics of the auditory pathway and auditory brain mechanisms
- Have an overview of auditory BCI paradigms
- Understand the conflict between optimized coding and mental effort

EEG and music

- EEG sonification

  Counting task:

  (Charles Anderson & Michael Kirby, Colorado State University)

- Composing music from EEG:

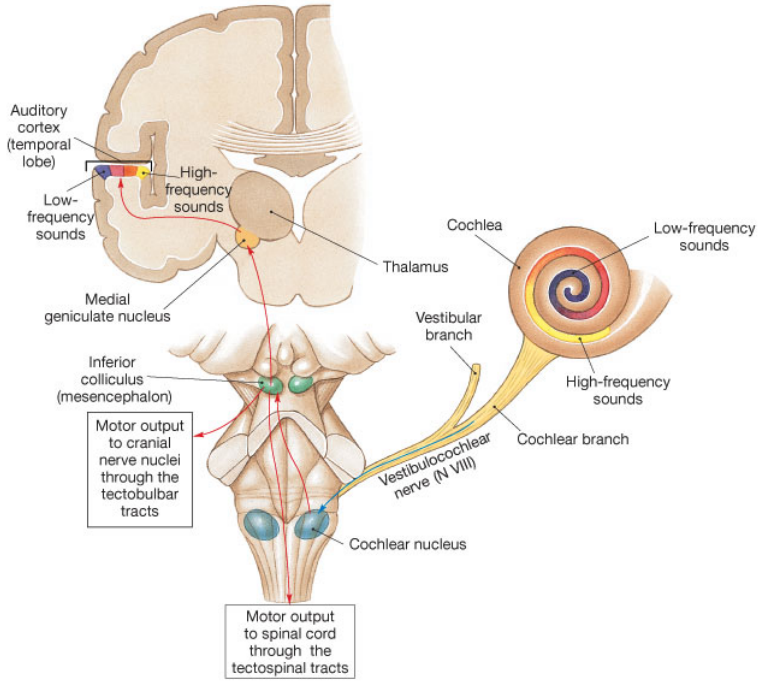
  “Music for Solo Performer” – Alvin Lucier (1965)

  Performed by Andrew Brouse (1999)

From the ear to the brain

Auditory pathway

- Acoustics/binaural hearing
- Frequency spreading on Basilar Membrane
- Neural coding by hair cells (code still not fully understood!)
- Interaural differences, phase/level (superior olivary complex)
- Tonotopic mapping in brain
- Interaction ear-brain (feedback loop)



From the ear to the brain

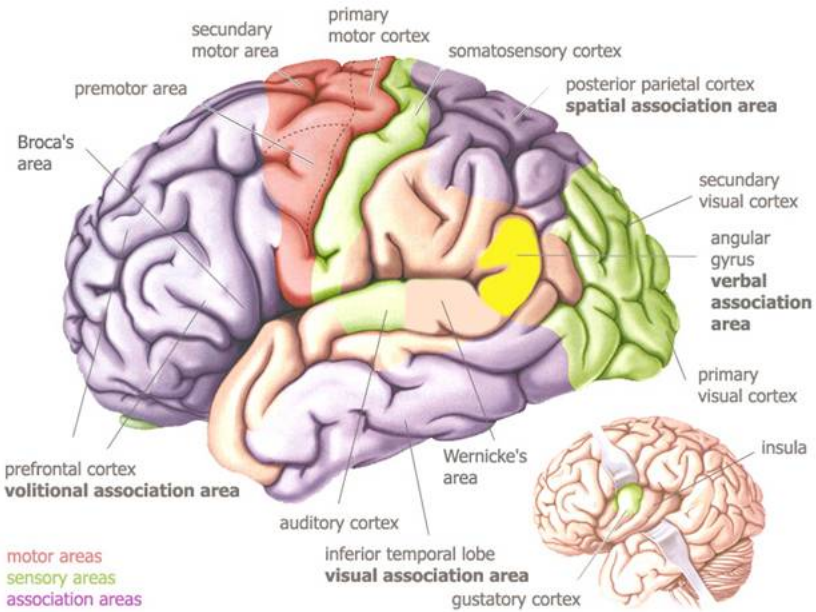
Perception in the brain

- Absolute pitch: “the ability to identify pitch of a musical note without reference” (Bach, Beethoven, Mozart, Chopin, Ray Charles, Art Tatum, Stevie Wonder)
- Amusia: “not being able to perceive music as music”
- Synaesthesia: “stimulation of one sensory modality leads to experience of stimulation in a second modality”
- Musical savants “overall cognitive impairment accompanied by exceptional musical skills”
- Music therapy (Parkinson’s, dementia, Gilles de la Tourette-syndrome)
- Capability to recognize complex harmonic structures:

Related (tonic)

Less related (sub-dominant)

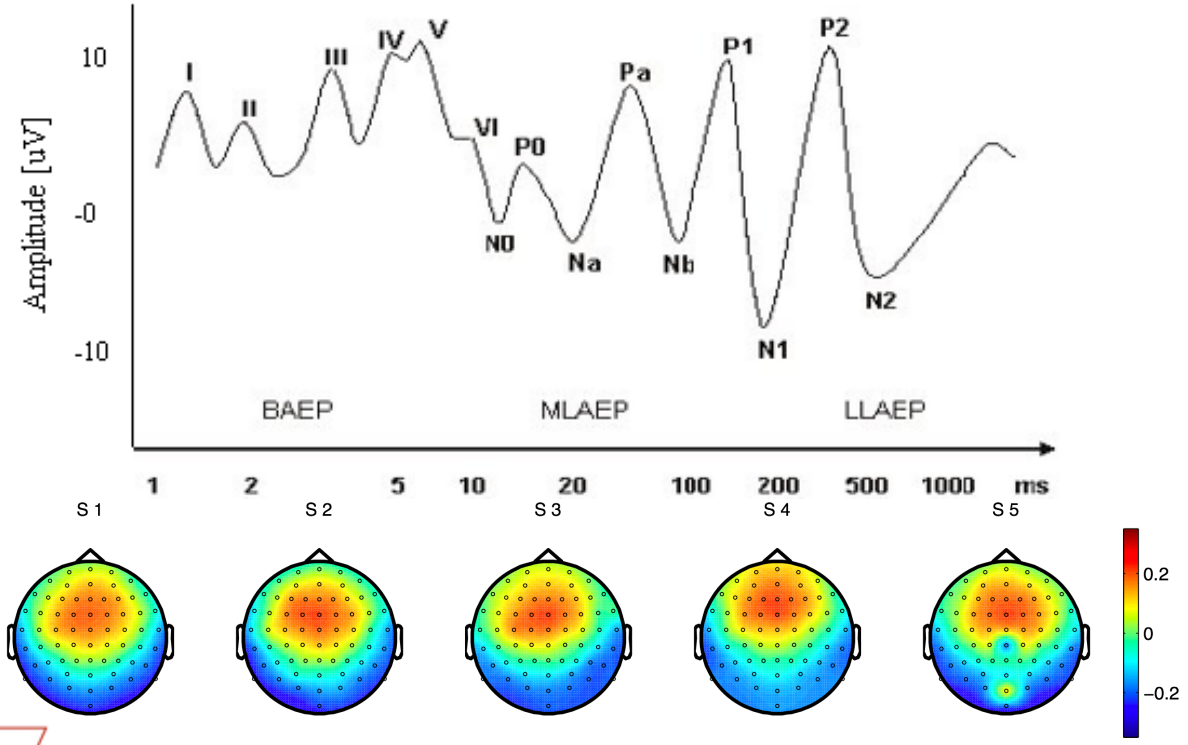
Tillman et al.



The auditory evoked potential

Can be evoked by:

- onset of sounds
- offset of sounds
- large changes in amplitude or spectral content



Towards auditory BCIs

Why are auditory BCIs useful?

- Making BCI available to those suffering from visual impairment (e.g. blind, late stage ALS)
- When visual/tactile/motor-control modality is occupied with other task (e.g. while driving a car, or while playing a computer game)
- As a new paradigm in general, with a potential to:
  - help to overcome BCI ‘illiteracy’
  - yield better signals, contributing to faster or more reliable BCIs
  - be easier to use, less fatiguing
  - yield lower inter- and intra-subject variability

Towards auditory BCIs

- "Fake" auditory BCIs: just normal BCIs generating audio output

- What makes the first movie into a scientifically better presentation of the BCI?

Towards auditory BCIs

- “Fake” auditory BCIs: just normal BCIs generating audio output

- What makes the first movie into a scientifically better presentation of the BCI? The ability to verify the correctness of the BCI output

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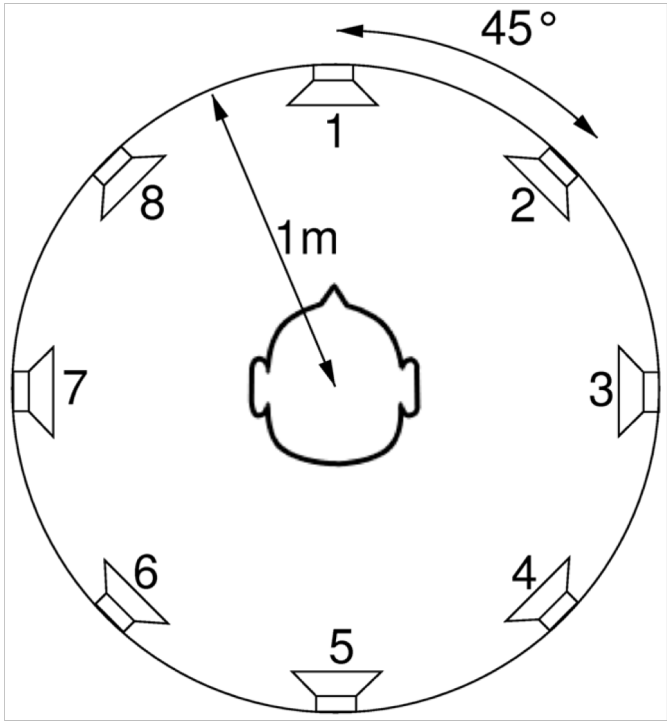
Real auditory BCIs

"Real" auditory BCIs, where an auditory mental task drives the system:

- P300 with auditory cues
  - spatial hearing (using short noise+tone) Schreuder et al. (2010)
  - spoken numbers (1…6) Belitski et al. (2011)



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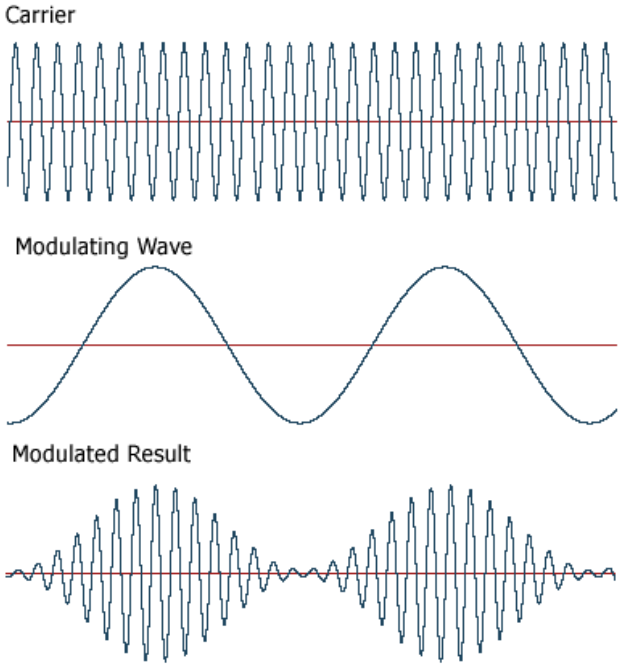
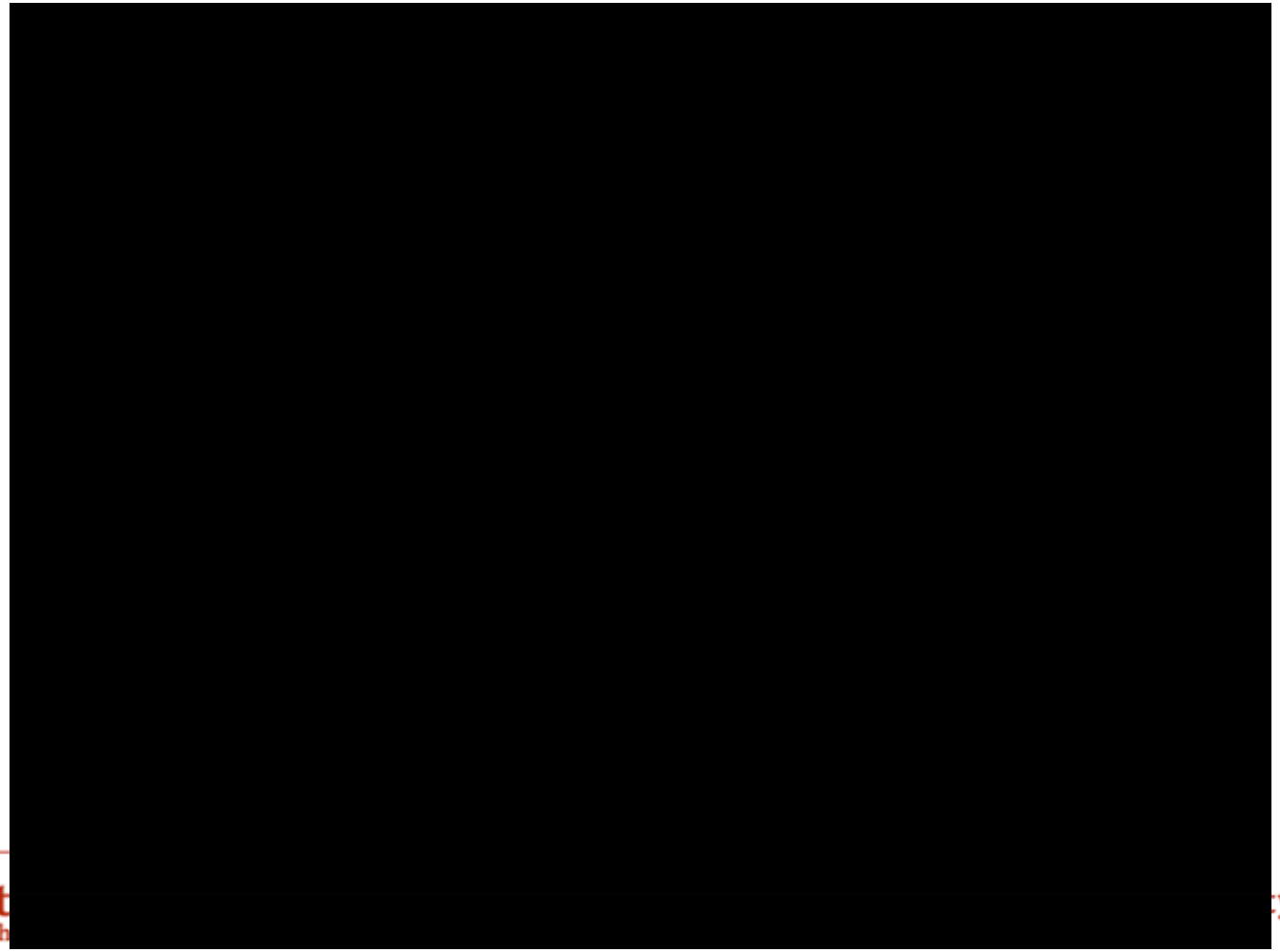


Real auditory BCIs

- Attempt towards new auditory BCI: Imagined Music (rich stimuli)



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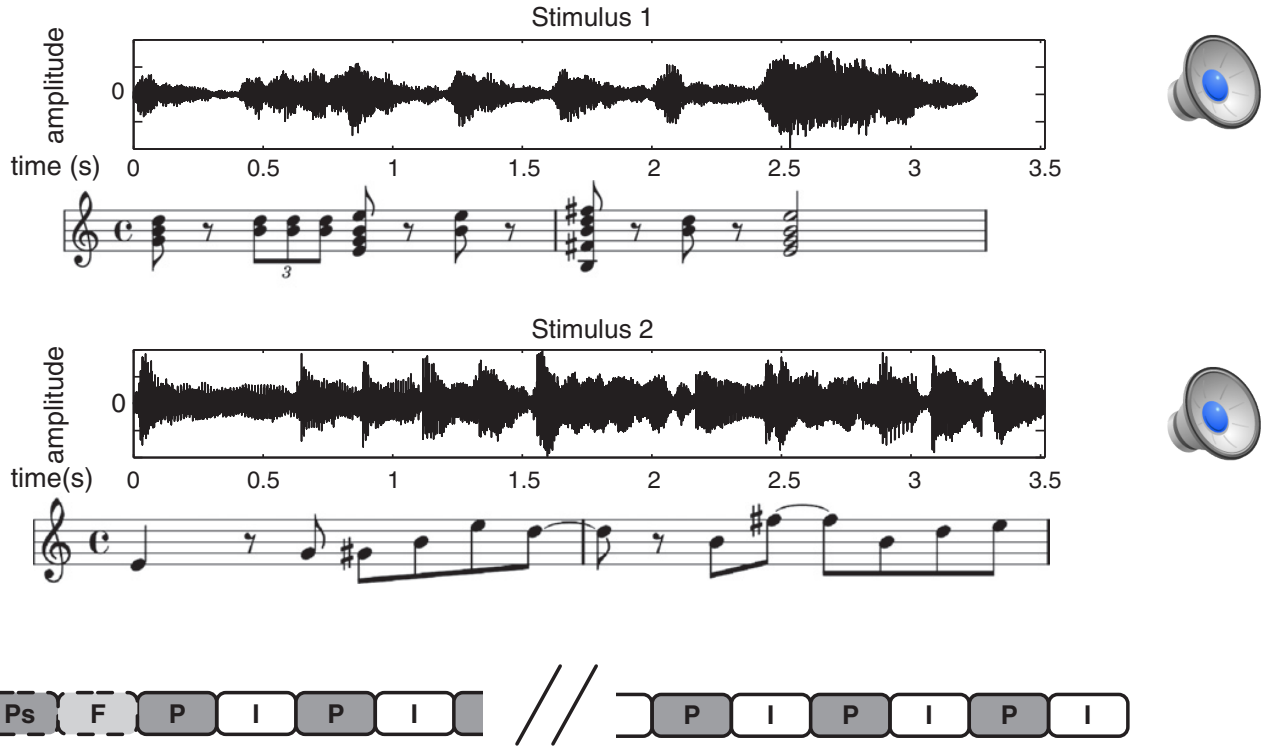
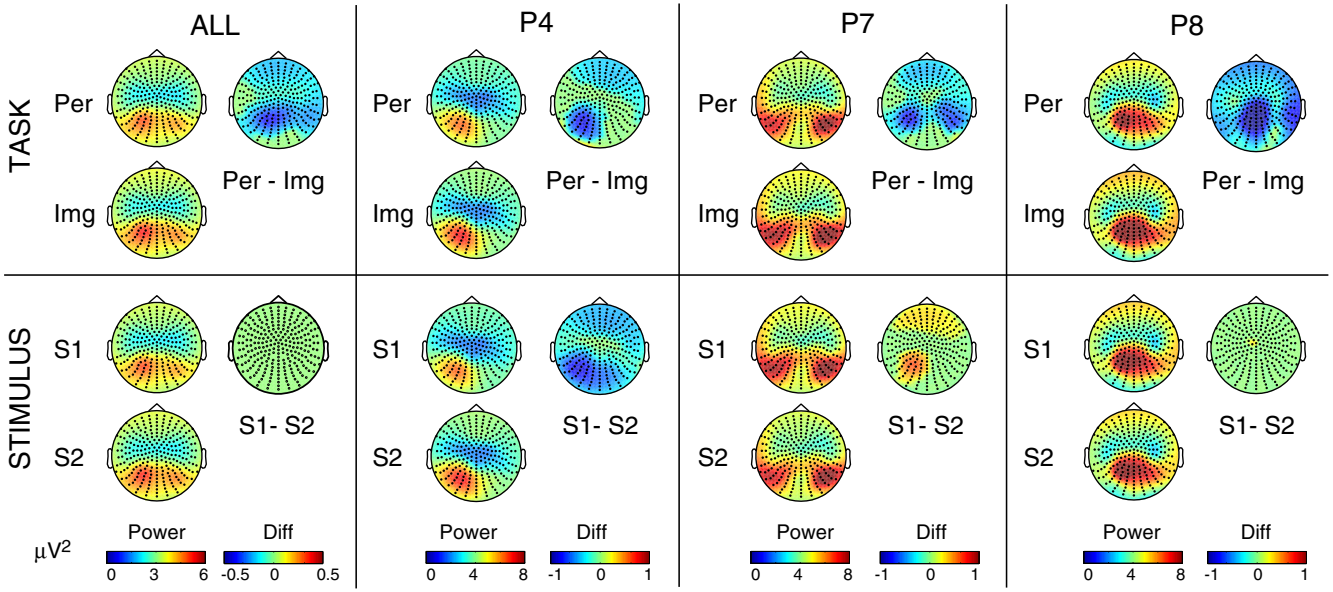


Real auditory BCIs

- Attempt towards new auditory BCI: Imagined Music (rich stimuli)
- Results:
  - imagery not useful for BCI
  - perception very good for “brain reading” Schaefer et al. (2011)
  - interesting attention mechanism related to imagery



Schaefer et al. (in press)

Real auditory BCIs

- Attempt towards new auditory BCI: subjective rhythmization

Imagine listening to a clock:

tick-tick-tick-tick becomes tick-tock-tick-tock

The brain is 'adding' accents subjectively:

Subjective rhythmization

Voluntary control of subjective accents makes it interesting for BCI!

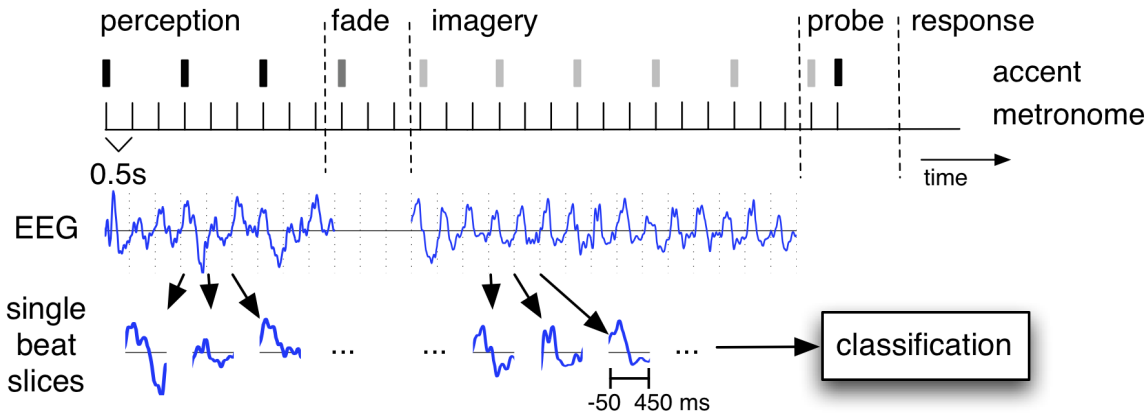
tick-tock-tick-tock …

tick-tock-tock-tick-tock-tock …

tick-tock-tock-tock-tick-tock-tock-tock …

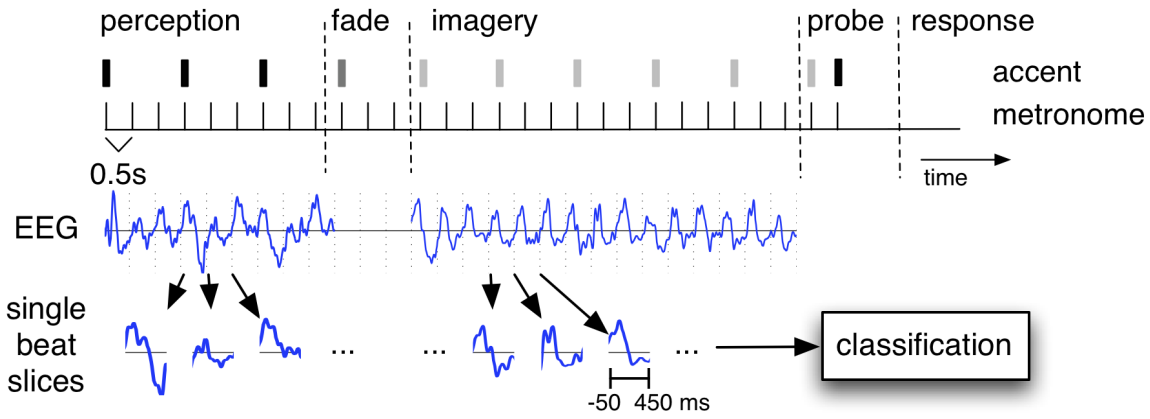
Offline study: experimental design

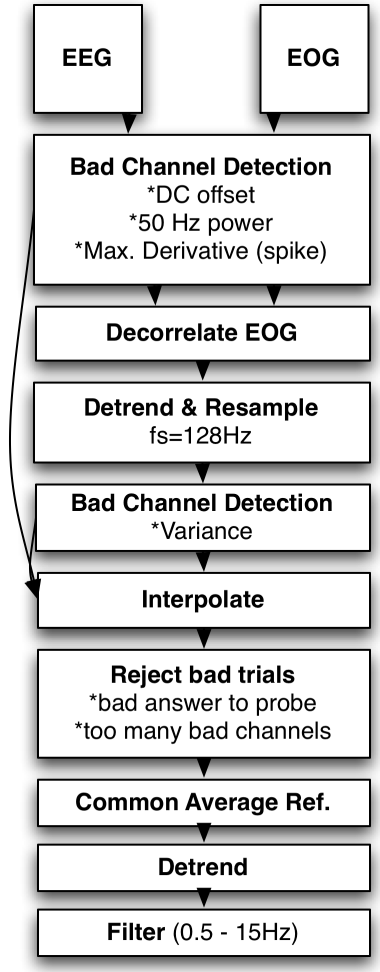
- Can subjective accents be decoded from single-trial EEG data?
- Can sequences of subjective accents be reliably decoded?
- What performance can we expect with this paradigm for BCI?



Offline study: data acquisition and preprocessing

- Participants: 10
- 64-channel EEG, 4-channel EOG
- Preprocessing per trial (0.5s)

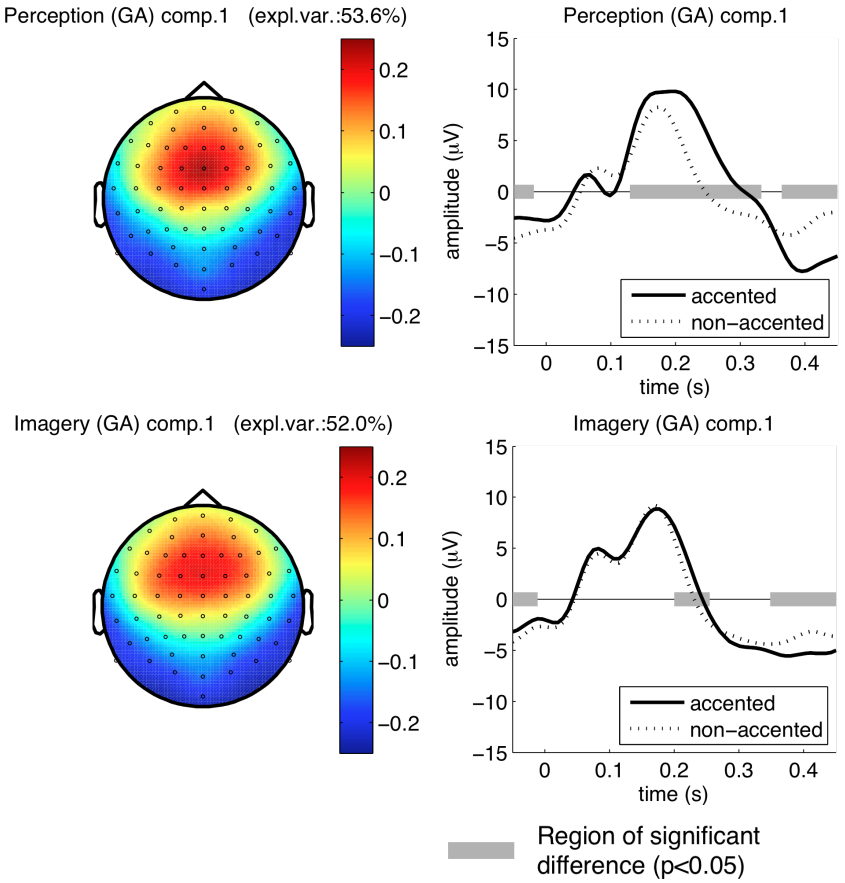




Offline study: results 1/3

- PCA decomposition of grand average data
- Note:
  - Difference between:

    accented and non-accented
  - Similarity of responses in perception and imagery



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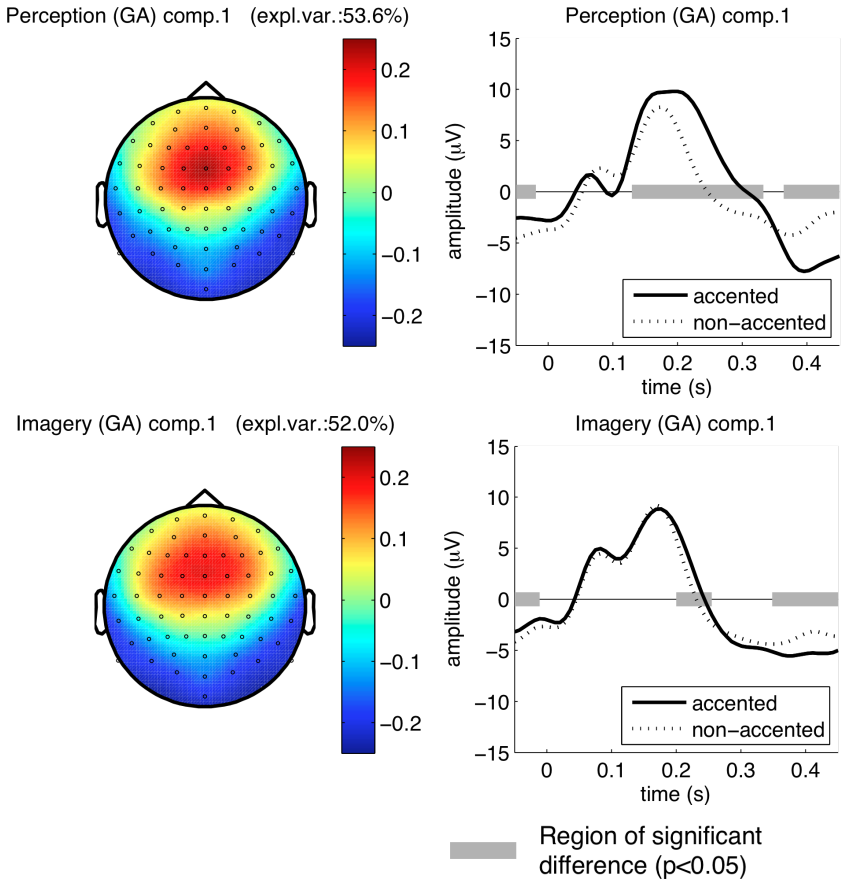
  - Supports hypothesis of shared mechanisms in auditory perception and imagery



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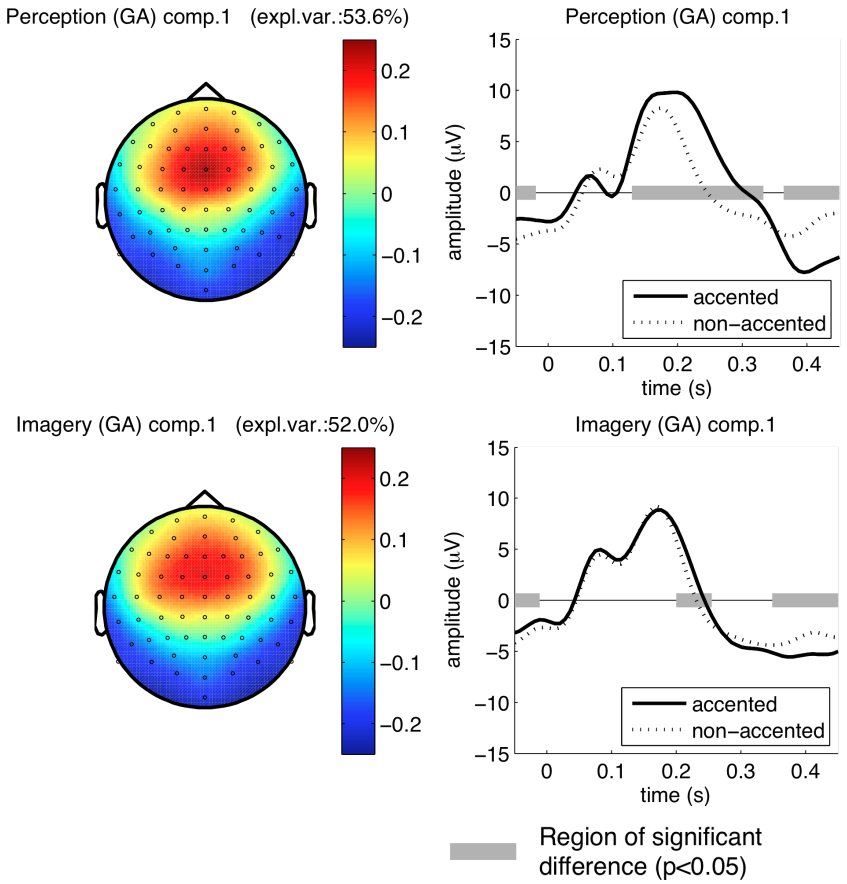
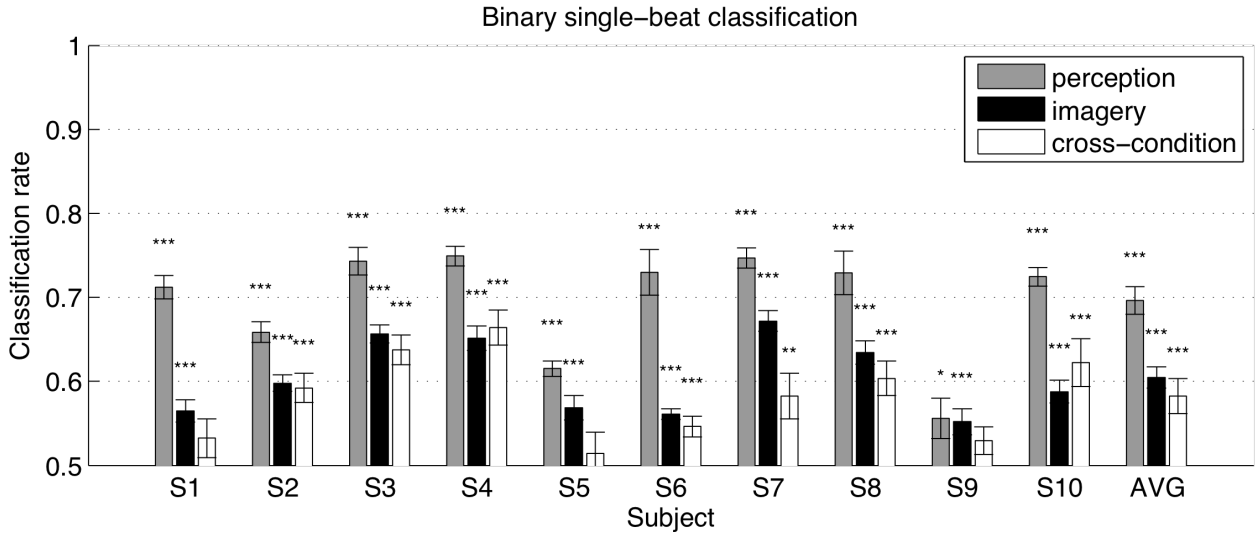
- Practically interesting:
  - Cross-condition classification: Train on perception, test on imagery

Vlek et al. (2011a)



Offline study: results 2/3

Classification: *Regularized (L_2) logistic regression*



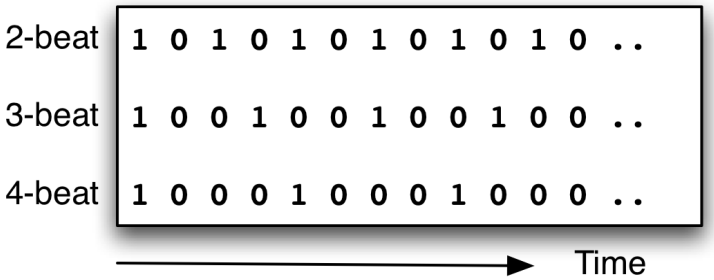
2-class problem:
chance level 50%

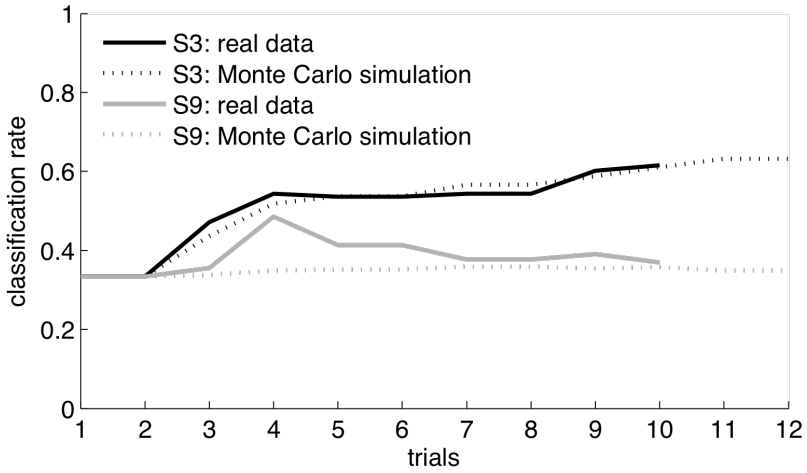
Classification	Average over subjects (n=10)	Best subject (Sn)
Perception	70% (SD=6%)	75% (S4)
Imagery	61% (SD=4%)	67% (S7)
Cross-condition	58% (SD=5%)	66% (S4)

Offline study: results 3/3

Sequence classification (5s):

$$\Pr(C_i|X_1, X_2, \ldots) = \prod_{n=1,2,\ldots} \Pr(C_{in}|X_n)$$





3-class problem: chance level 33%

Classification	Average over subjects (n=10)	Best subject (Sn)
Imagery	51% (SD=7%)	62% (S7)
Cross-condition	44% (SD=5%)	50% (S3)

Vlek et al. (2011b)

Real auditory BCIs

"Real" auditory BCIs, where an auditory mental task drives the system:

- ✓ P300 with auditory cues
- ▪ Selective attention effects on SSAEP of frequency/noise-tagged audio streams
- ▪ Imagined music
- ✓ Subjective rhythmization

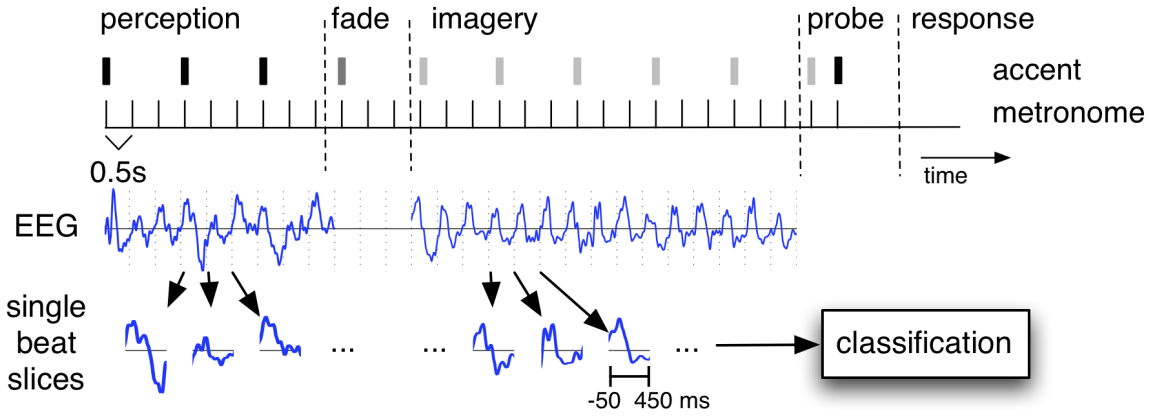
Real auditory BCIs

How to turn subjective rhythmization into an online BCI?

- Explore different imagery strategies for strongest signal
- Explore more rhythms for optimal coding and user friendliness

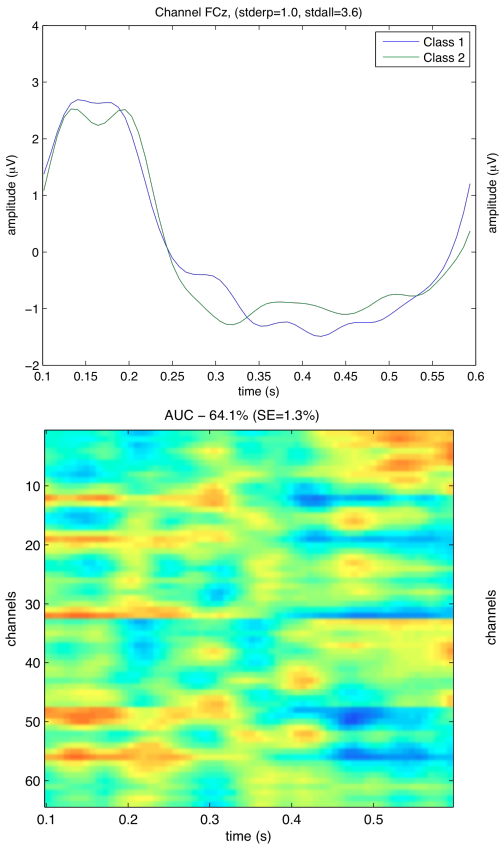
Recent pilot: experimental design

- One subject (representative in offline study)
- Only 3-beat patterns
- Similar sequences of perception-fade-imagery
- 4 conditions of perception stimuli:
  - C1: volume difference high contrast
  - C2: volume difference low contrast
  - C3: timbre difference high contrast
  - C4: timbre difference low contrast

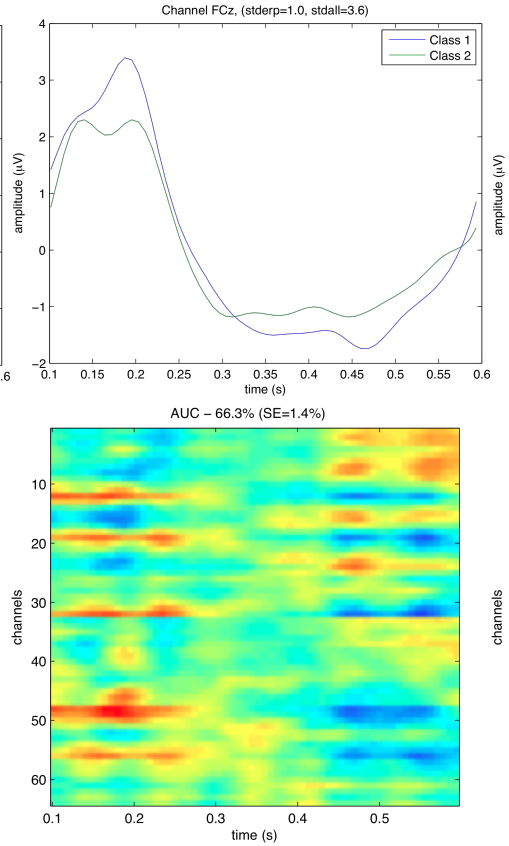


Recent pilot: preliminary results

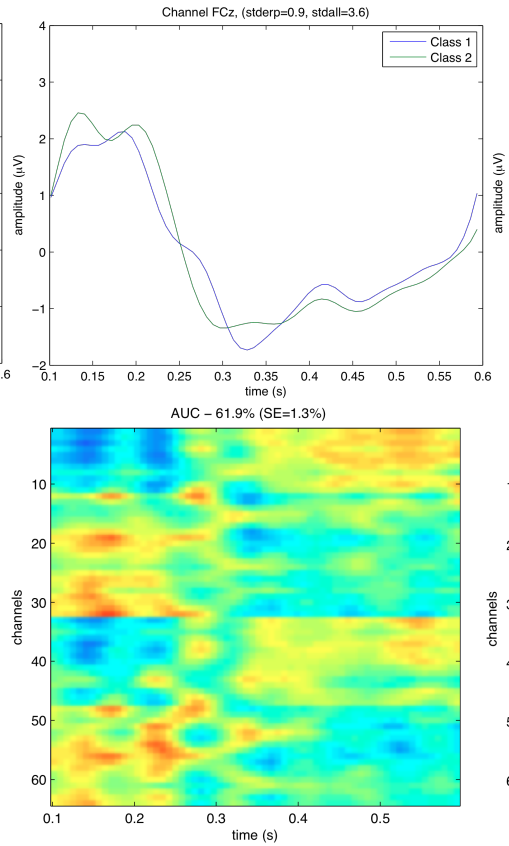
C1: vol. high contrast



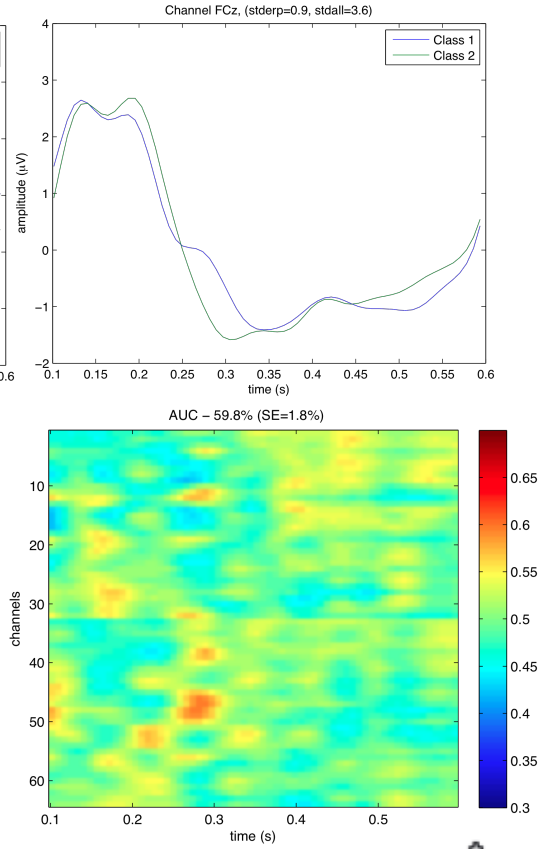
C2: vol. low contrast



C3: tim. high contrast



C4: tim. low contrast



Real auditory BCIs

How to turn subjective rhythmization into an online BCI?

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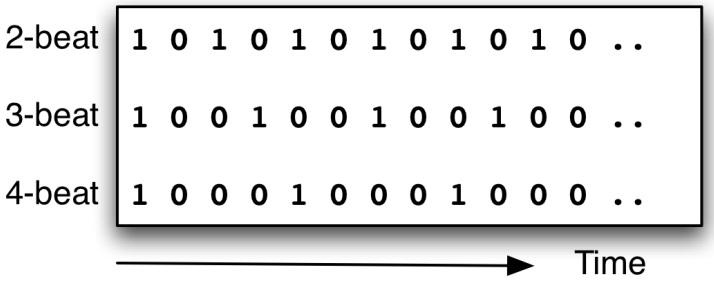
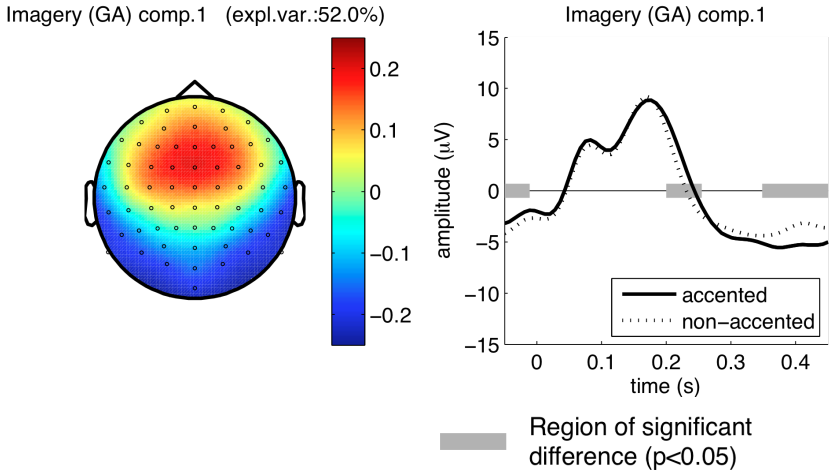
Real auditory BCIs

The big trade-off!

Quality of coding versus ease mental task

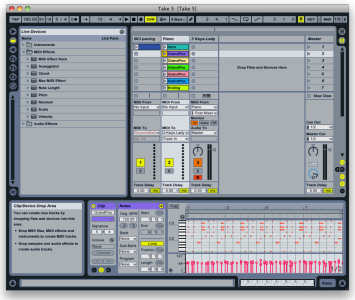


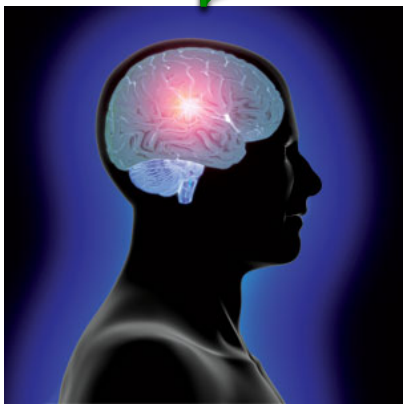


("fake" auditory) BCI in the real world…

A lesson on the importance of the cognitive aspects of the BCI

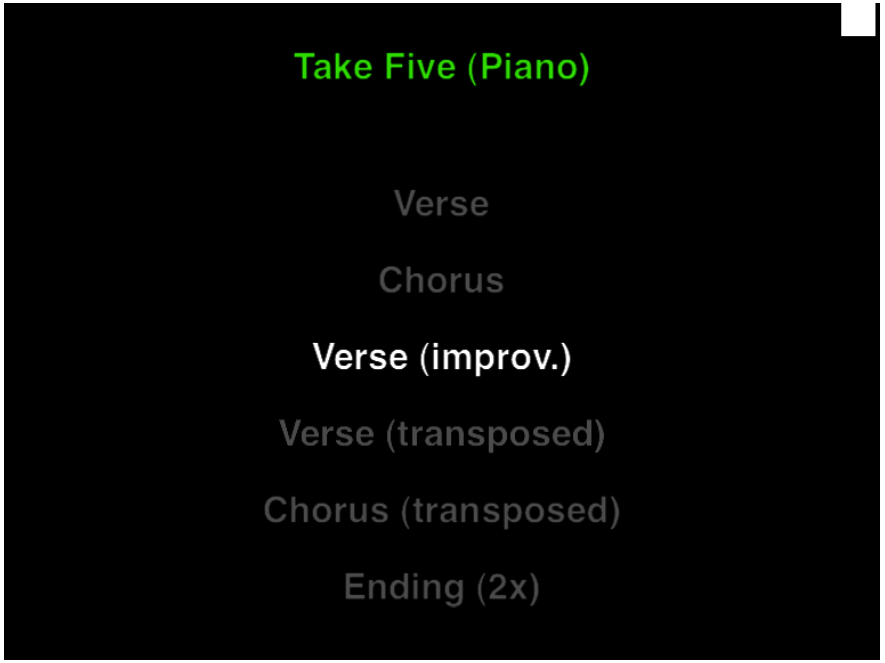
Brain-controlled musical instruments





Brain-controlled musical instruments

- Currently based on P300 paradigm
- Instead of letters, names of musical fragments are subsequently flashed
- P300 response is classified
- Corresponding musical fragment is cued for next loop cycle



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