Cognition On The Run
Testing a New Mobile Brain Imaging Modality

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Brains have evolved to control behavior in an ever changing 3-D environment.

- Cognition evolved in organisms with specific physical attributes and is therefore shaped by and to take advantage of these features for cognitive ends.
- Cognition developed in the context of reliable environmental features.
- Cognition is for action and must be understood in its ultimate contribution to situation-appropriate behavior (Wilson, 2002),
- The development of mobile brain imaging is therefore essential for understanding natural human cognition.
We record brain dynamics with millions of bits of information per second.

- However, standard analysis of data reduces this information to single channels,
- and further averages across trials, and
- finally compares the brain dynamics to ~1 bit of information from human behavior (usually button press).

The ultimate goal is to analyze the full bandwidth of brain dynamics together with the full range of complex human behavior on single-trial level.
The ultimate goal is to analyze active cognition and the accompanying distributed brain dynamics.
The Traditional Approach to Active Cognition - Caveats (3)

- Sensors are too heavy (MEG, PET, MRI) to follow movements of the subjects.
- Rigidly static positions (sitting or lying) are required to avoid movements.
  - Movement is not allowed and considered as source of artifacts.
  - Even eye-movement is considered as an artefact in EEG experiments.
- New technologies have to be developed and integrated to allow for recordings of active cognition.
How to Image The Mobile Brain - Technology

Developments

EEG data are sent to a cell phone
New motion capture systems are available offering wireless transmission of inertial information about movement of the limbs and head, plus absolute position of the subject in an environment.
How to Image Mobile Cognition - Technology

Developments

- From Remote Device
  - UDP/IP
  - VR Model
  - Device 2
  - Device 3

- Local Devices
  - 256 channel EEG
  - Motion Capture
  - Responses

- To Remote Device
  - UDP/IP
  - to Client 1
  - to Client 2
  - to Client 3

- Local Clients
  - Viewer
  - Recorder
  - RT analysis

DataRiver

Ethernet
How to Image Mobile Cognition - Data Analyses

Developments

ITC

ERD

ERS

ERSP (ΔdB)

Base

PPR

ERP

ERD

ERS

ERSP (ΔdB)

Frequency

Makeig et al. (2004). TICS
How to Image Mobile Cognition - 
Data Analyses

Developments

A First Experiment Using MoBI

First Results
A First Experiment Using MoBI

First Results
What Kind Of ‘Artifactual Activity’ is Measured With EEG?

Flexion/Extension

- Trapezius
- Semispinalis Capitis (bilateral)
- Splenius Capitis (bilateral)
- Rectus Posterior (Minor & Major)
- Rectus Oblique Superior

Neck Extension

- Longus Capitis
- Longus Colli
‘Artefacts’ (?)
During Natural Movements

Background

Developments

First Results

Future Directions

Discussion
Muscles Attached To The Occipital Bone

- Obliquus capitis superior
- Rectus capitis posterior major
- Rectus capitis posterior minor
- Semispinalis capitis
- Trapezius
- Sternocleidomastoideus
- Splenius capitis
- Longissimus capitis
- Rectus capitis posterior minor
- Rectus capitis posterior major
- Splenius capitis superior
- Obliquus capitis superior

Sections:
- Background
- Developments
- First Results
- Future Directions
- Discussion
Neck Muscles Activity During Looking and Pointing Movements

First Results

<table>
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<tr>
<th>+</th>
<th>Location</th>
<th>+</th>
<th>Action</th>
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Frequency (Hz)

2000 3000 4000 5000 6000 7000 8000 9000 ms

-5 0 dB 5

Discussion

Future Directions

First Results

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Background

Neck Muscles Activity During Looking and Pointing Movements

-5 0 dB 5

First Results

Future Directions

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Neck Muscles Activity During Looking and Pointing Movements

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Frequency (Hz)
- 5
- 12
- 27
- 63
- 150

-1 0
-5 0 dB
5 10

-1 0
-5 0

-1 0
-5 0 dB
5 10

Neck Muscles Activity During Looking and Pointing Movements

First Results

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Discussion

onset head rotation
max. velocity head rotation
offset head rotation

onset of head movement
max. velocity of head movement
offset of head movement

0 500 1000 1500 2000 ms
Neck Muscles Activity During Looking and Pointing Movements

First Results

Look / point to left

Look / point to right

Difference

Onset of head rotation

Max. velocity of head rotation

Offset of head rotation
Brain Dynamics During Looking and Pointing Movements

- **First Results**

  ![Brain Imaging Results](image)

  - Frequency (Hz)
  - Time (ms)

- **Background**
- **Developments**
- **Future Directions**
- **Discussion**
Brain Dynamics During Looking and Pointing Movements

First Results
Brain Dynamics During Looking and Pointing Movements

First Results

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Frequency (Hz)

2000 3000 4000 5000 6000 7000 8000 9000 ms

Discussion

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First Results
Brain Dynamics During Looking and Pointing Movements

First Results

- Onset of head movement
- Max. velocity of head movement
- Offset of head movement

Frequency (Hz)

0 500 1000 1500 2000 ms
Brain Dynamics During Looking and Pointing Movements

First Results

Frequency (Hz)

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Brain Dynamics During Looking and Pointing Movements

First Results

Frequency (Hz)

Brain Dynamics During Looking and Pointing Movements

First Results

Frequency (Hz)
Brain Dynamics During Looking and Pointing Movements

First Results

onset of head movement
max. velocity of head movement
offset of head movement

Frequency (Hz)

0 500 1000 1500 2000 ms
Cognition on the Run
Which Electrodes are Likely to Make Trouble?

Background

Developments

First Results

Future Directions

Discussion
Which Electrodes are Likely to Make Trouble?
Power Increase of Step Frequency

**Background**

**Developments**

**First Results**

**Future Directions**

**Discussion**
Cognition on the Run?

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**First Results**

- **A**: EEG waveforms with markers for left toe off, right heel strike, right toe off, and left heel strike.
- **B**: EEG waveforms with markers for left toe off, right heel strike, right toe off, and left heel strike.
- **C**: Vertical center of mass displacement.

**Future Directions**

- 150 µV
- 0.1 m
Cognition on the Run

Background

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First Results

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Discussion

256 channel EEG

Subject Reaction (Wii)

EMG:
- Tibialis anterior
- Soleus
- Gastrocnemius
  - lateralis
  - medials

Force Platform

motion capture sensors
P300 while Standing, Walking and Running

Background

Developments

First Results

Future Directions

Discussion
P300 Contribution of Non-Brain Activity to the Surface Potential

Background

Developments

First Results

Future Directions

Discussion
Contributions of Non-Brain Activity to the Surface Potential

- **Background**
- **Developments**
- **First Results**
- **Future Directions**
- **Discussion**

**Slow Walking** (0.8 m/s)
P300 while Standing

Background

Developments

First Results

Future Directions

Discussion

Future Directions
P300 while Slow Walking (0.8 m/s)

Background

Developments

First Results

Future Directions

Discussion
P300 while Fast Walking (1.2 m/s)
Reliable Reconstruction of a Late Positive Complex

![Graphs showing time (s) vs. potential (uV) for different walking conditions: Standing, Slower Walking (0.8 m/s), and Faster Walking (1.2 m/s). Each graph includes labels for different classes (Cls 9, Cls 10, Cls 11) with respective min. & max. values.](image)

**Background**

**Developments**

**First Results**

**Future Directions**

**Discussion**
Reliable Reconstruction of a Late Positive Complex

**Background**

**Developments**

**First Results**

**Future Directions**

**Discussion**

**Standing**

Slow walking (0.8 m/s)

Fast walking (1.3 m/s)

ERP envelope (µV)
Reliable Reconstruction of a Late Positive Complex

Background

Developments

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- ERP envelope (µV)
  - 0
  - 200
  - 400
  - 600 ms

- Fast walking (1.3 m/s)

- Slow walking (0.8 m/s)

- Standing

- Targets

- Non-Targets

- P3
First (pilot) studies clearly demonstrate that we are able to record and analyze cognitive processes during active motor behavior of subjects.

- Restrictions apply to excessive movements that are associated with cable sway.
- Future wireless technology is likely to overcome these restrictions.
- MoBI demonstrates that the timing of movements and/or different phases of spatially extended movement is essential and reflected in brain dynamics.
Future studies need to:
- extend data analysis including head models that integrate muscles in source space,
- add recordings of eye movements for integrated analysis,
- make use of developments in data-driven signal analyses to gain insights into the relation of active motor behavior and brain dynamics,
- identify levels of comparison for different data models.