EEG brain state monitoring in the wild

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Conventional EEG system

Wearable EEG system

Ear-EEG/Hyposafe device

High-performance research and clinical EEG system

Smartphone data

Discreet, unobtrusive and user-friendly assistive devices for everyday life
How did you sleep last night?

..we have only limited quantitative self insight...

hard to explain your “state” to services, psychiatrists, caretakers etc

My working hypothesis: In the wild brain scanning has the potential to help us infer brain states, plans and wishes, and in this way improve services, diagnosis, medication, and rehabilitation
Why sampling in the wild?
   A science of the individual - new research questions..
   ‘cognition is action’ (Engell et al, 2013)
   ‘Most neurons showed more than a doubling of visually evoked firing rate as the animal transitioned from standing still to running.’
   (Niell, Stryker, 2010)

Our current EEG in the wild tools:
   Imaging with the smartphone brain scanner (SBS YouTube link)
   EarEEG non-invasive, discrete
   Hyposafe's subcutaneous electrode device

Example SBS: engagement in the classroom
Example EarEEG: the scalp to ear link
Example Hyposafe device: 40+ days sampling in the wild

"Oticon Tego is directed by the DecisionMaker system, driven by (AI) Artificial Intelligence that processes sound intelligently. This super advanced form of computer processing. Artificial Intelligence is the process of performing logical operations enthused by the human brain.

The difference between AI-based and conventional instruments is distinct: AI-based instruments constantly adapt to particular situation where conventional instruments provide only a fixed response to selected types of sounds. AI-based, Oticon Tego evaluates the different sound processing options and selects the one guaranteed to give the clearest sound quality.

Just like the brain, Oticon Tego filters out the noise so you can concentrate on the speech you like to hear. The DecisionMaker system evaluates and decides exactly when and how to apply the various features to get the best speech understanding and sound quality in any situation. All the processing happens automatically, so you need not lift a finger at all! Completely hands-free Oticon Tego is an ideal hearing solution for the active you!"

http://www.hearingaids123.com/oticon-tego
Why brain state decoding?

Human senses & brains are not optimal from a behavioral point of view...

..e.g. the list of cognitive biases in Wikipedia

“When we look at living creatures from an outward point of view, one of the first things that strike us is that they are bundles of habits.”

“In wild animals, the usual round of daily behavior seems a necessity implanted at birth; in animals domesticated, and especially in man, it seems, to a great extent, to be the result of education. The habits to which there is an innate tendency are called instincts; some of those due to education would by most persons be called acts of reason.”

“It thus appears that habit covers a very large part of life, and that one engaged in studying the objective manifestations of mind is bound at the very outset to define clearly just what its limits are.”

William James, The Principles of Psychology (1890)
CHAPTER IV “Habit”
Limits of Predictability in Human Mobility

Chaoming Song,1,2 Zehui Qu,1,2,3 Nicholas Blumm,1,2 Albert-László Barabási1,2*

Fig. 1. (A) Trajectories of two anonymized mobile phone users who visited the vicinity of $N = 22$ and 76 different towers during the 3-month-long observational period. Each dot corresponds to a mobile phone tower, and each time a user makes a call, the closest tower that routes the call is recorded, pinpointing the user’s approximate location. The gray lines represent the Voronoi lattice, approximating each tower’s area of reception. The colored lines represent the recorded movement of the user between the towers. (B) Mobility networks associated with the two users shown in (A). The area of the nodes corresponds to the frequency of calls the user made in the vicinity of the respective tower, and the widths of line edges are proportional to the frequency of the observed direct movement between two towers. (C) A week-long call pattern that captures the time-dependent location of the user with $N = 22$. Each vertical line corresponds to a call, and its color matches the tower from where the call was placed. This sequence of locations serves as the basis of our mobility prediction. (D) The distribution of the time intervals between consecutive calls, $\tau$, across the whole user population, documenting the nature of the call pattern as coming in bursts (11). (E) The distribution of the fraction of unknown locations, $q$, representing the hourly intervals when the user did not make a call, and thus his or her location remains unknown to us.
Basic data collection with the "Context Logger" tool (Nokia N95).

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Sampling</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accelerometer</td>
<td>30/minute</td>
<td>3D Accelerometer values</td>
</tr>
<tr>
<td>GSM</td>
<td>1/minute</td>
<td>CellID of GSM base transceiver station</td>
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<tr>
<td>GPS</td>
<td>2–3/hour</td>
<td>Longitude, Latitude, and Altitude</td>
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<td>Bluetooth</td>
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<td>Bluetooth MAC, friendly name, and device type</td>
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<tr>
<td>WLAN</td>
<td>1/minute</td>
<td>Access Point MAC address, SSID, and RX level</td>
</tr>
<tr>
<td>Phone activity</td>
<td>Event</td>
<td>Phone number and direction of call or message</td>
</tr>
</tbody>
</table>

Table 1. List of embedded mobile phone sensors used for collecting data


Participants were students and staff members from The Technical University of Denmark volunteering to be part of the experiment. Thus mainly situated in the greater Copenhagen area, Denmark.

N= 14 participants took part in the experiment between 31 to 71 days, resulting in approximately 472 days of data covering data collection periods totalling 676 days. The average duration was 48.2 days.
Predictability vs time scale

Fig. 5. Predictive Information (normalized) vs. window length (log scale). Participant 3 is left out.
24/7 Neurotechnology - Aim: Connect cognitive neuroscience and normal behaviors

Conventional EEG system

Wearable EEG system

Ear-EEG/Hyposafe device

Discreet, unobtrusive and user-friendly assistive devices for everyday life

High-performance research and clinical EEG system

Smartphone data

Brain state representations connected by machine learning
DTU mobility projects

Social EEG-
- Leaders and followers
- Joint attention

Mobile real-time EEG Imaging
- Neurofeedback
- Digital media & emotion
- Bhutan Epilepsy Project

Ivana Konvalinka
Simon Kamronn
Andreas Trier Poulsen

Farrah J. Mateen, Massachusetts General Hospital
Machine learning to decode personal states

Aims to extract the mutual information between personal state and quantifiable behavior

- **Personal state**: Macroscopic variables, tags, behavioral categories ... \( s(t) \)

- **Sensed behaviors**: Micro/meso-scopic data/variables ... \( x(t) \)

- **Mutual information** is captured in the joint distribution ... \( p(x,s) \).

Supervised machine learning methods assume \( s(t) \) or parts of \( s(t) \) known ... unsupervised methods consider \( s(t) \) “hidden”....

and builds predictive models of the relation
24/7 Neurotech – the devices

EmoCap

Emotiv EEG headset

Ear-EEG device

Smartphone mental state monitor

Location information

Hyposafe subcutaneous device

Social media

Stefan Debener’s mobile EEG devices

Maarten De Vos, Oxford + 
Neuropsychology at the University of Oldenburg, 
CRITIAS and Sonomax, Canada.

Towards a truly mobile auditory brain–computer interface: Exploring the P300 to take away
Maarten De Vos, Katharina Gandras, Stefan Debener

Fig. 1. The mobile EEG system as proposed by Debener et al. (2011) consists of an amplifier– 

cap that is attached to the cap at the back of the head (weight 46 g, size 30 × 40 × 23 mm).
Smartphone Brain Scanner

Based on the Emotiv wireless transmission mechanism w/ the EPOC head set or modified EasyCaps (Stefan Debener, Oldenburg)

Version SBS2.0 for generic Android platforms (Tested in Galaxy Note, Nexus 7,...)

https://github.com/SmartphoneBrainScanner


SBS2 functions current

Real time system
- Bayesian minimum norm 3D reconstruction with a variety of forward models (N=1024).
- Adaptive SNR model ($\beta, \alpha$) estimated every 10 sec.
- Update speed ~ 40 fps (Emotiv sample rate 128Hz, blocks of 8 samples)
- Selected frequency band option
- Spatial averaging in "named" AAL regions

Mobile experiment set-ups, so far...
- Common spatial pattern- BCI
- Stimulus presentation options: video, image, text, audio
- Neuro-feedback
EEG imaging

Linear ill-posed inverse problem

\[ X: \ N \times T \]
\[ Y: \ K \times T \]
\[ A: \ K \times N \]

\[ N \gg K \]

Need priors to solve!

\[ Y_{k,t} = \sum_{n=1}^{N} A_{k,n} X_{n,t} + E_{k,t}. \]

Why 3D real-time imaging?

Enable on-line visual quality control

Neurofeed applications can be based on activity in specific brain structures/networks

Context priors may relate to 3D location (from meta analysis)

Evidence that BCI/decoding can be improved by 3D representation


Source representation can improve decoding

Besserve et al. (2011)
... reconstructing the underlying cortical network dynamics significantly outperforms a usual electrode level approach in terms of information transfer and also reduces redundancy between coherence and power features, supporting a decrease of volume conduction effects. Additionally, the classifier coefficients reflect the most informative features of network activity, showing an important contribution of localized motor and sensory brain areas, and of coherence between areas up to 6 cm distance.

Ahn et al. (2012)
... source imaging may enable noise filtering, and in so doing, make some invisible discriminative information in the sensor space visible in the source space.

Do we get meaningful 3D reconstructions?

Imagined finger tapping
Left or right cued (at t=0)

Signal collected from an AAL region (n=80)


Imaging engagement in the classroom

JP. Dmochowski et al, "Correlated components of ongoing EEG point to emotionally laden attention—a possible marker of engagement?" Frontiers of Human Neuroscience, 6:112, April 2012.


Neurotech for 24/7 brain state monitoring: EarEEG

Aim:
A discrete, non-invasive solution for long time recording in the wild

Status
EarEEG is a well-established technology
Classical EEG reproduced: Sustained and event related responses to audio and visual stimulus

To appear:
High mutual information between ear and scalp EEG

Neurotech for 24/7 brain state monitoring: EarEEG

On the keyhole hypothesis: High mutual information between Ear and Scalp EEG

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Figure 2: Short snippets of ear-EEG measurements together with their predictions.

Figure 4: Prediction correlation, $\rho$, as a function of time since training (in blue). Shown in red is prediction correlation for a model trained on data within the last 10 minutes. Gaps correspond to data missing in the original data set.

(a) Using only the left ear.
(b) Decoupled ears.
(c) Coupled ears, with common reference.
Neurotech for 24/7 brain state monitoring: Hyposafe

Aim:
Permanent recording in the wild - Decoding hypoglaemia risk

Status
Very stable subcutaneous electrode
Magnetic coupling (signal / power) with outside ear piece
Signal is highly correlated with surface electrode in same location

Duun-Henriksen, Jonas, et al.
"EEG Signal Quality of a Subcutaneous Recording System Compared to Standard Surface Electrodes."
Ultra long term brain decoding in healthy control: Hyposafe device

How does (partial) mind wandering vary during the day?

How does a brain on vacation differ from a working brain?

Methods:
Power spectrum over 3 sec windows as basic features
Fit 15 clusters. Manually identify (2) alpha clusters;
Assign 3 sec power spectra over 45 days to clusters…

Privacy... it’s human to share

Intuitive data
Images, speech, economical, commercial, location, individual thoughts

Non-intuitive data
Health: diet, complete motion patterns
Physiology: heart beat, skin resistance, gaze, brain data, your mind set

Sandy Pentland calls for “a new deal on data” with three basic tenets:
1) you have the right to possess your data,
2) to control how it is used,
3) to destroy or distribute it as you see fit.

Privacy for Personal Neuroinformatics
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Conclusion

Human behavior is increasingly quantified, modeled and predicted

The key technology is machine learning

Decoding the brain is imminent: Simple brain states can be decoded with high accuracy...

... More complex mechanisms may be revealed with non-linear decoders even in high dimensional settings ... and some care!

Not so distant future: Permanent 24/7 brain state decoding
Acknowledgment & Qs

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