Mining EEG Brain Dynamics: New Directions in Functional Brain Imaging

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Human Functional Brain Imaging

EEG  fMRI  fEEG  MoBI  BCI  ESI

Electromagnetic imaging
= imaging local cortical synchrony
3-D imaging more difficult, but quite fast & direct.

Hemodynamic imaging
= imaging brain energy
Direct 3-D imaging, but quite slow & indirect.
Human EEG History

Some EEG milestones

1926  ~1st human functional brain ‘imaging’
1938  1st EEG spectral analysis
   ‘reading the EEG’
1962  1st computer for EP averaging (CAT)
   ‘event-related potential (ERP) averaging’
1995  1st multisource EEG filtering by ICA
   ‘functional EEG brain imaging’
2009  ~1st commercial dry electrode devices
   ‘mobile, wireless, wearable MoBI’
201?  ~1st extremely high density ECoG system
   ‘electrocortical source imaging (ESI)’
The generation and modulation of EEG / LFP is COMPLEX

Corticothalamic

Value System Modulations

Excitatory Inhibitory

Ephaptic Modulations

Neuroglial?

Corticocortical

S. Makeig 2007
Brain dynamics are inherently multi-scale.

At each spatial recording scale, the signal is produced by active partial coherence of distributed activities at the next smaller scale.

Scale chauvinism

Scott Makeig 2007
Phase cones (Freeman)
Avalanches (Plenz)
scalp signals ≠ source signals!
The very broad EEG point-spread function
Human Electroencephalogram (EEG)
The Dome of the Sky

Scott Makeig 2008
3-D structure of the Universe
2-D Interpretation of Scalp EEG Signals
Electromagnetic source localization

Solve the forward problem using realistic head models (BEM)

Mesh generation

Sensor Localization

Simple Map

Signal Processing

Source Image

MRI

Segmentation

EEG/MEG

Zeynep Akalin Acar, & Scott Makeig ’06
Blind EEG Source Separation by Independent Component Analysis

S. Makeig (2000)
Independent Component Analysis of Electroencephalographic Data

Abstract

...a summary of the differences between... 

Infomax ICA
Are EEG source outputs (nearly) independent?

Independent Domains of Local Synchrony

Cortex

Thalamus

Freeman - phase cones

Plenz - avalanches

S. Makeig (2007)
ICA in practice

Onton & Makeig, 2006
Compact cortical EEG sources

Equivalent dipoles

Single dipole source

Dual-symmetric dipole source

Julie Onton & S. Makeig (2006)
Independent muscle signals

S. Makeig, J. Onton 2005
EEGLAB
An open-source signal processing environment for Matlab

http://sccn.ucsd.edu/eeglab

S. Makeig 2007
 EEGLAB

An open-source signal processing environment for Matlab

http://sccn.ucsd.edu/eeglab
Equivalent dipole density

Visual Working Memory

Onton et al., 2005
Equivalent dipole density

Auditory Novelty
Equivalent dipole density
Emotion Imagination

Onton et al., 2005
Equivalent dipole density
Task A – Old/New Word Memory

dipoledensity()
Equivalent dipole density
Task B – Cued finger movements

dipole_density()
Modeling Spatiotemporal Variability

3-Model AMICA Decomposition

Model Log Likelihood

Time-on-Task (1.5 hours)

Grainne MacLoughlin & Jason Palmer, 2010
EEG States of Emotion Imagination

Suggest the imaginative experience of 15 different emotions:

- initial relaxation
- alternate positive and negative emotions
- relaxation between emotion episodes
- obtained 1-5 min periods of eyes-closed spontaneous EEG
- 33 subjects

Onton & Makeig, *Frontiers* 2009
Independent Modulators
Independent modes of spectral modulation

Onton & Makeig, *Frontiers in Human Neuroscience* ’09
Changes in broadband power with imagined emotion

Julie Onton & Scott Makeig, *Frontiers in Human Neuroscience*, 2009
Distribution of broadband modes

Onton & Makeig, *Frontiers in Human Neuroscience* ‘09
Positive and negative valence modes

Onton & Makeig, Frontiers in Human Neuroscience ‘09
Just: A Suite for Flute, Violin, Cello, and Brain

Fourth International BCI Meeting
Asilomar Meeting Grounds, Pacific Grove, CA
June, 2010
Distributed Brain Dynamic Events

Who am I?
I realized that ...

It struck me that ...

I wondered if ...

All of a sudden ...

I looked to see if ...

I noticed that ...

I looked again at ....

I decided that ...

It occurred to me that ...

I imagined ...

I searched my memory for ...

S. Makeig, 2001
Distributed muscle / movement events
Brain processes have evolved and function to optimize the outcome of our behavior in response to perceived challenges and opportunities.
The brain & body together respond to the challenge of each moment.

**Mobile Brain/Body Imaging**

But human brain activity during natural motor actions and interactions in 3-D space has never been observed or modeled!
Brain imaging during natural behavior?

- Nearly all brain imaging studies (MEG, PET, fMRI, and EEG) are conducted in rigidly static seated or prone positions with only the most minimal free or mover allowed.

Why?

- In all modalities but EEG emitters are heavy.
- Muscle and movements contribute (‘noise’) signals.

- But this limitation is highly artificial. Nearly all our life involves active movements and interactions within a 3-D environment.
- ⇒ Brain activity during free movement in 3-D space has never been observed or modeled!

Scott Makeig 2008
BRAIN \leftrightarrow BEHAVIOR

SPIKES

LFP

ECOG

EEG

MACRO

Recorded !?

RT

~1 Hz

Observable

?? Hz

~1 MHz

~1,000,000 GHz

S. Makeig 2007
Mobile Brain/Body Imaging

- Record what the brain does,
- What the brain experiences,
- And what the brain controls.
MoBI Lab at SCCN, UCSD

http://thesciencenetwork.org/programs/inc-sccn-open-house/inc-sccn-open-house-hi-lite-reel
MoBI Systems for Cognitive Monitoring

- Alertness
- Arousal
- Attention
- Anticipation
- Agency
- Affect
Brain-Computer Interface (BCI) Systems for willed control...
Electrocortical source imaging (ESI) systems for clinical research, diagnosis, and treatment

• EEG & MoBI are low-cost relative to other brain imaging systems;
• This allows future wide distribution of these systems,
• And their use in very large research studies.
• Very large online data resources are possible (HeadIT);
• These may be improve the speed and quality of BCI,
  cognitive monitoring, and clinical imaging systems.
• Extremely high-density EEG & MoBI imaging systems are possible;
• These may allow new discoveries – in electro-acupuncture, etc.
Electrocortical source imaging (ESI) systems for clinical research, diagnosis, and treatment
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Functional EEG brain imaging

Paradigm shift!

- EEG is something to use, not just something to inspect ...

Goals:

1. Modeling dynamic, distributed brain/body events to understand how the brain works!
2. Mobile Brain/Body Imaging (MoBI) for cognitive monitoring.
3. Brain-Computer Interface (BCI) for willed control.