Frontal alpha oscillations distinguish leaders from followers: Multivariate decoding of mutually interacting brains

Successful social interactions rely upon the abilities of two or more people to mutually exchange information in real-time, while simultaneously adapting to one another. The neural basis of social cognition has mostly been investigated in isolated individuals, and more recently using two-person paradigms to quantify the neuronal dynamics underlying social interaction. While several studies have shown the relevance of understanding complementary and mutually adaptive processes, the neural mechanisms underlying such coordinative behavioral patterns during joint action remain largely unknown. Here, we employed a synchronized finger-tapping task while measuring dual-EEG from pairs of human participants who either mutually adjusted to each other in an interactive task or followed a computer metronome. Neurophysiologically, the interactive condition was characterized by a stronger suppression of alpha and low-beta oscillations over motor and frontal areas in contrast to the non-interactive computer condition. A multivariate analysis of two-brain activity to classify interactive versus non-interactive trials revealed asymmetric patterns of the frontal alpha-suppression in each pair, during both task anticipation and execution, such that only one member showed the frontal component. Analysis of the behavioral data showed that this distinction coincided with the leader–follower relationship in 8/9 pairs, with the leaders characterized by the stronger frontal alpha-suppression. This suggests that leaders invest more resources in prospective planning and control. Hence our results show that the spontaneous emergence of leader–follower relationships in dyadic interactions can be predicted from EEG recordings of brain activity prior to and during interaction. Furthermore, this emphasizes the importance of investigating complementarity in joint action.
Scopus rating (2016): CiteScore 6.31 SJR 3.823 SNIP 1.752
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 4.48 SNIP 1.84 CiteScore 6.71
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 4.201 SNIP 2.029 CiteScore 6.9
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 4.376 SNIP 2.026 CiteScore 7.06
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 3.922 SNIP 1.937 CiteScore 6.86
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 3.626 SNIP 1.81 CiteScore 6.31
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 3.573 SNIP 1.866
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 3.859 SNIP 1.897
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 4.094 SNIP 1.765
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 3.7 SNIP 1.981
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 3.41 SNIP 1.924
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 3.703 SNIP 1.918
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 3.401 SNIP 1.794
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 1.974 SNIP 1.003
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.885 SNIP 0.403
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 0.526 SNIP 0.253
Web of Science (2001): Indexed yes
Scopus rating (2000): SJR 0.534 SNIP 0.341
Scopus rating (1999): SJR 0.41 SNIP 0.494

Original language: English
Social interaction, Dual EEG, Interpersonal coordination, Multivariate decoding, Leader–follower dynamics

Electronic versions:
prod11396022627003.dualEEGmanuscript_Neuroimage_final.pdf

DOIs:
10.1016/j.neuroimage.2014.03.003

Source: RIS
Source-ID: urn:8CB733D2C703C5A88913A6447D19D8E7
Publication: Research - peer-review › Journal article – Annual report year: 2014
Smartphones as pocketable labs: Visions for mobile brain imaging and neurofeedback

Mobile brain imaging solutions, such as the Smartphone Brain Scanner, which combines low cost wireless EEG sensors with open source software for real-time neuroimaging, may transform neuroscience experimental paradigms. Normally subject to the physical constraints in labs, neuroscience experimental paradigms can be transformed into dynamic environments allowing for the capturing of brain signals in everyday contexts. Using smartphones or tablets to access text or images may enable experimental design capable of tracing emotional responses when shopping or consuming media, incorporating sensorimotor responses reflecting our actions into brain machine interfaces, and facilitating neurofeedback training over extended periods. Even though the quality of consumer neuroheadsets is still lower than laboratory equipment and susceptible to environmental noise, we show that mobile neuroimaging solutions, like the Smartphone Brain Scanner, complemented by 3D reconstruction or source separation techniques may support a range of neuroimaging applications and thus become a valuable addition to high-end neuroimaging solutions.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Cognitive Systems, Language-Based Technology
Authors: Stopczynski, A. (Intern), Stahlhut, C. (Intern), Petersen, M. K. (Intern), Larsen, J. E. (Intern), Jensen, C. B. F. (Intern), Ivanova, M. G. (Intern), Andersen, T. (Intern), Hansen, L. K. (Intern)
Pages: 54–66
Publication date: 2014
Main Research Area: Technical/natural sciences

Publication information
Journal: International Journal of Psychophysiology
Volume: 91
Issue number: 1
ISSN (Print): 0167-8760
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 1.369 SNIP 1.091 CiteScore 2.82
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.514 SNIP 1.313 CiteScore 3.03
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.459 SNIP 1.105 CiteScore 2.79
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 1.303 SNIP 1.101 CiteScore 2.71
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 1.159 SNIP 0.928 CiteScore 2.37
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 1.139 SNIP 1.032 CiteScore 2.44
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.201 SNIP 0.992
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.624 SNIP 1.347
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.114 SNIP 0.963
Scopus rating (2007): SJR 1.062 SNIP 1.03
Scopus rating (2006): SJR 1.028 SNIP 1.111
The Smartphone Brain Scanner: A Portable Real-Time Neuroimaging System

Combining low-cost wireless EEG sensors with smartphones offers novel opportunities for mobile brain imaging in an everyday context. Here we present the technical details and validation of a framework for building multi-platform, portable EEG applications with real-time 3D source reconstruction. The system – Smartphone Brain Scanner – combines an off-the-shelf neuroheadset or EEG cap with a smartphone or tablet, and as such represents the first fully portable system for real-time 3D EEG imaging. We discuss the benefits and challenges, including technical limitations as well as details of real-time reconstruction of 3D images of brain activity. We present examples of brain activity captured in a simple experiment involving imagined finger tapping, which shows that the acquired signal in a relevant brain region is similar to that obtained with standard EEG lab equipment. Although the quality of the signal in a mobile solution using an off-the-shelf consumer neuroheadset is lower than the signal obtained using high-density standard EEG equipment, we propose mobile application development may offset the disadvantages and provide completely new opportunities for neuroimaging in natural settings.

General information

State: Published
Organisations: Department of Applied Mathematics and Computer Science, Cognitive Systems
Authors: Stopczynski, A. (Intern), Stahlhut, C. (Intern), Larsen, J. E. (Intern), Petersen, M. K. (Intern), Hansen, L. K. (Intern)
Number of pages: 10
Publication date: 2014
Main Research Area: Technical/natural sciences

Publication information

Journal: P L o S One
Volume: 9
Issue number: 2
Article number: e86733
ISSN (Print): 1932-6203
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 3.11 SJR 1.201 SNIP 1.092
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 1.414 SNIP 1.131 CiteScore 3.32
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 1.545 SNIP 1.141 CiteScore 3.54
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
A Hierarchical Bayesian M/EEG Imaging Method Correcting for Incomplete Spatio-Temporal Priors

In this paper we present a hierarchical Bayesian model, to tackle the highly ill-posed problem that follows with MEG and EEG source imaging. Our model promotes spatiotemporal patterns through the use of both spatial and temporal basis functions. While in contrast to most previous spatio-temporal inverse M/EEG models, the proposed model benefits of consisting of two source terms, namely, a spatiotemporal pattern term limiting the source configuration to a spatio-temporal subspace and a source correcting term to pick up source activity not covered by the spatio-temporal prior belief. Both artificial data and real EEG data is used to demonstrate the efficacy of the model.
A Neural Marker of Perceptual Consciousness in Infants

Consciousness Arrives Neurophysiological measures in human adults correspond to the transition between very brief, "unnoticeable," and slightly longer-lived visual stimuli that penetrate deeply enough to leave a conscious imprint that subjects report they "see." Kouider et al. (p. 376) have performed parallel behavioral and neurophysiological studies in infants to identify a similar neural signal that appears to mark the development of visual consciousness.

General information
State: Published
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Pages: 376-380
Publication date: 2013
Main Research Area: Technical/natural sciences
Expansion of the Variational Garrote to a Multiple Measurement Vectors Model

The recovery of sparse signals in underdetermined systems is the focus of this paper. We propose an expanded version of the Variational Garrote, originally presented by Kappen (2011), which can use multiple measurement vectors (MMVs) to further improve source retrieval performance. We show its superiority compared to the original formulation and demonstrate its ability to correctly estimate both the sources’ location and their magnitude. Finally evidence is given of the high performance of the proposed algorithm compared to other MMV models.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Cognitive Systems
Authors: Hansen, S. T. (Intern), Stahlhut, C. (Intern), Hansen, L. K. (Intern)
Pages: 105-114
Publication date: 2013

Host publication information
Title of host publication: Twelfth Scandinavian Conference on Artificial Intelligence
Publisher: IOS Press
Editor: Jaeger, M.
Series: Frontiers in Artificial Intelligence and Applications
Volume: 257
ISSN: 0922-6389
BFI conference series: Scandinavian Conference on Artificial Intelligence (5000106)
Main Research Area: Technical/natural sciences
Conference: 12th Scandinavian Conference on Artificial Intelligence (SCAI 2013), Aalborg, Denmark, 20/11/2013 - 20/11/2013
How about a Bayesian M/EEG imaging method correcting for incomplete spatio-temporal priors

In this contribution we present a hierarchical Bayesian model, sAquavit, to tackle the highly ill-posed problem that follows with MEG and EEG source imaging. Our model facilitates spatio-temporal patterns through the use of both spatial and temporal basis functions. While in contrast to most previous spatio-temporal inverse M/EEG models, the proposed model benefits of consisting of two source terms, namely, a spatio-temporal pattern term limiting the source configuration to a spatio-temporal subspace and a source correcting term to pick up source activity not covered by the spatio-temporal prior belief.

We have tested the model on both artificial data and real EEG data in order to demonstrate the efficacy of the model. The model was tested at different SNRs (-10.0, -5.2, -3.0, -1.0, 0, 0.8, 3.0 dB) using white noise. At all SNRs the sAquavit performs best in AUC measure, e.g. at SNR=0dB AUC is, 0.985 (sAquavit) and 0.857 (Bolstad et al., 2009).

Our results demonstrate that the sAquavit model is capable in balancing spatio-temporal prior guidance and source correction estimation to obtain superior estimates relative to current inverse methods.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Cognitive Systems, Convex Imaging, Visual Computing Group, Microsoft Research Asia, University of California, San Francisco, Tokyo Metropolitan University
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Number of pages: 1
Pages: 260
Publication date: 2013
Main Research Area: Technical/natural sciences

Publication information
Journal: Journal of Cognitive Neuroscience
Volume: Supplement
ISSN (Print): 0898-929X
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 2.414 SNIP 1.014 CiteScore 3.44
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 2.704 SNIP 1.175 CiteScore 3.83
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 3.129 SNIP 1.404 CiteScore 4.63
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 3.649 SNIP 1.709 CiteScore 5.44
Web of Science (2013): Indexed yes
Scopus rating (2012): SJR 3.601 SNIP 1.546 CiteScore 5.39
Scopus rating (2011): SJR 3.93 SNIP 1.774 CiteScore 5.71
ISI indexed (2011): ISI indexed yes
Scopus rating (2010): SJR 3.572 SNIP 1.758
Scopus rating (2009): SJR 4.031 SNIP 1.853
Scopus rating (2008): SJR 3.618 SNIP 1.658
Scopus rating (2007): SJR 3.857 SNIP 1.748
Scopus rating (2006): SJR 3.381 SNIP 1.693
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 3.761 SNIP 1.881
Scopus rating (2004): SJR 3.834 SNIP 1.833
Mobile real-time EEG imaging Bayesian inference with sparse, temporally smooth source priors

EEG based real-time imaging of human brain function has many potential applications including quality control, in-line experimental design, brain state decoding, and neuro-feedback. In mobile applications these possibilities are attractive as elements in systems for personal state monitoring and well-being, and in clinical settings were patients may need imaging under quasi-natural conditions. Challenges related to the ill-posed nature of the EEG imaging problem escalate in mobile real-time systems and new algorithms and the use of meta-data may be necessary to succeed. Based on recent work (Delorme et al., 2011) we hypothesize that solutions of interest are sparse. We propose a new Markovian prior for temporally sparse solutions and a direct search for sparse solutions as implemented by the so-called “variational garrote” (Kappen, 2011). We show that the new prior and inference scheme leads to improved solutions over competing sparse Bayesian schemes based on the “multiple measurement vectors” approach.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Cognitive Systems
Authors: Hansen, L. K. (Intern), Hansen, S. T. (Intern), Stahlhut, C. (Intern)
Pages: 6-7
Publication date: 2013

Host publication information
Title of host publication: 2013 International Winter Workshop on Brain-Computer Interface (BCI)
Publisher: IEEE
ISBN (Print): 978-1-4673-5974-0
Main Research Area: Technical/natural sciences
Conference: 2013 International Winter Workshop on Brain-Computer Interface (BCI), Gangwondo, Korea, Republic of, 18/02/2013 - 18/02/2013
DOIs: 10.1109/IWW-BCI.2013.6506608
Source: dtu
Source-ID: u::6707
Publication: Research - peer-review › Conference abstract in journal – Annual report year: 2013

Sparse Source EEG Imaging with the Variational Garrote

EEG imaging, the estimation of the cortical source distribution from scalp electrode measurements, poses an extremely ill-posed inverse problem. Recent work by Delorme et al. (2012) supports the hypothesis that distributed source solutions are sparse. We show that direct search for sparse solutions as implemented by the Variational Garrote (Kappen, 2011) provides excellent estimates compared with other widely used schemes, is computationally attractive, and by its separation of ‘where’ and ‘what’ degrees of freedom paves the road for the introduction of genuine prior information.

General information
State: Published
Organisations: Department of Applied Mathematics and Computer Science, Cognitive Systems
Authors: Hansen, S. T. (Intern), Stahlhut, C. (Intern), Hansen, L. K. (Intern)
Pages: 106-109
Publication date: 2013

Host publication information
Title of host publication: 2013 International Workshop on Pattern Recognition in Neuroimaging (PRNI)
Publisher: IEEE
ISBN (Print): 978-0-7695-5061-9
Main Research Area: Technical/natural sciences

Scopus rating (2003): SJR 4.336 SNIP 2.095
Scopus rating (2002): SJR 3.801 SNIP 1.895
Scopus rating (2001): SJR 3.607 SNIP 2.316
Scopus rating (2000): SJR 3.684 SNIP 2.518
Scopus rating (1999): SJR 3.832 SNIP 2.661
Original language: English
Electronic versions:
CNS2013abstract_sAquavit.pdf
Source: dtu
Source-ID: u::6707
Publication: Research - peer-review › Conference abstract in journal – Annual report year: 2013
Spatio temporal media components for neurofeedback

A class of Brain Computer Interfaces (BCI) involves interfaces for neurofeedback training, where a user can learn to self-regulate brain activity based on real-time feedback. These particular interfaces are constructed from audio-visual components and temporal settings, which appear to have a strong influence on the ability to control brain activity. Therefore, identifying the different interface components and exploring their individual effects might be key for constructing new interfaces that support more efficient neurofeedback training. We discuss experiments involving two different designs of neurofeedback interfaces and suggest further research to clarify the influence of different audiovisual components and temporal settings on neurofeedback effect.

A Cross-Platform Smartphone Brain Scanner

We describe a smartphone brain scanner with a low-cost wireless 14-channel Emotiv EEG neuroheadset interfacing with multiple mobile devices. This personal informaticssystem enables minimally invasive and continuous capturing of brain imaging data in natural settings. Thesystem applies an inverse Bayesian framework to spatially visualize the activation of neural sources real-time in a 3D brain model or to visualize the power of brainwaves with specific frequencies. We describe the architecture of the system and discuss initial experiments.

An Evaluation of EEG Scanner's Dependence on the Imaging Technique, Forward Model Computation Method, and Array Dimensionality

EEG source reconstruction involves solving an inverse problem that is highly ill-posed and dependent on a generally fixed forward propagation model. In this contribution we compare a low and high density EEG setup's dependence on correct
forward modeling. Specifically, we examine how different forward models affect the source estimates obtained using four inverse solvers Minimum-Norm, LORETA, Minimum-Variance Adaptive Beamformer, and Sparse Bayesian Learning.

Functional Brain Imaging by EEG: A Window to the Human Mind
This thesis presents electroencephalography (EEG) brain imaging by covering topics as empirical evaluation of source confusion, probabilistic inverse methods, and source analysis performed on infant EEG data. In terms of source confusion we inspect how current sources within the brain may be confused with each other as noise is present in the EEG recordings. Moreover, we examine how errors in the forward model affect the source confusion.

The primary aim of this thesis is to provide sharper EEG brain images by improving current inverse methods. In this relation we focus the attention on two topics in EEG source reconstruction, namely, the forward propagation model (describing the mapping from the current sources within the brain to the sensors at the scalp) and the temporal patterns present in the EEG.

As forward models may suffer from a number of errors including the geometrical representation of the human head, the tissue conductivity distribution, and electrode positions, we propose an algorithm which consider forward model uncertainties. Bayesian graphical models provide a powerful means of incorporating prior assumptions that narrow the solution space and lead to tractable posterior distributions over the unknown sources given the observed data. Here, we propose a hierarchical Bayesian model that attempts to minimize the influence of uncertainties associated with the forward model on the source estimates.

Similarly, we develop a hierarchical spatio-temporal Bayesian model that accommodates the principled computation of sparse spatial and smooth temporal EEG source reconstructions consistent with neurophysiological assumptions in a variety of event-related imaging paradigms.
Get Mobile – The Smartphone Brain Scanner

This demonstration will provide live-interaction with a smartphone brain scanner consisting of a low-cost wireless 14-channel EEG headset (Emotiv Epoc) and a mobile device. With our system it is possible to perform real-time functional brain imaging on a smartphone device, including stimulus delivery, data acquisition, logging, brain state decoding, and 3D visualization of the cortical EEG sources. Implementation of the smartphone brain scanner is based on the Qt framework and benefits from the cross-platform support of multiple hardware platforms (smartphones, tablet devices, netbooks and PCs) that are based on Linux operating systems. Thus our system runs on multiple platforms, including Maemo/MeeGo based smartphones, Android-based smartphones and tablet devices.

Probabilistic M/EEG source imaging from sparse spatio-temporal event structure

While MEG and EEG source imaging methods have to tackle a severely ill-posed problem their success can be stated as their ability to constrain the solutions using appropriate priors. In this paper we propose a hierarchical Bayesian model facilitating spatio-temporal patterns through the use of both spatial and temporal basis functions. We demonstrate the efficacy of the model on both artificial data and real EEG data.
Task-specific modulation of effective connectivity during two simple unimanual motor tasks: A 122-channel EEG study

Neural oscillations are thought to underlie coupling of spatially remote neurons and gating of information within the human sensorimotor system. Here we tested the hypothesis that different unimanual motor tasks are specifically associated with distinct patterns of oscillatory coupling in human sensorimotor cortical areas. In 13 healthy, right-handed subjects, we recorded task-induced neural activity with 122-channel electroencephalography (EEG) while subjects performed fast self-paced extension-flexion movements with the right index finger and an isometric contraction of the right forearm. Task-related modulations of inter-regional coupling within a core motor network comprising the left primary motor cortex (M1), lateral premotor cortex (lPM) and supplementary motor area (SMA) were then modeled using dynamic causal modeling (DCM). A network model postulating coupling both within and across frequencies best captured observed spectral responses according to Bayesian model selection. DCM revealed dominant coupling within the β-band (13–30 Hz) between M1 and SMA during isometric contraction of the forearm, whereas fast repetitive finger movements were characterized by strong coupling within the γ-band (31–48 Hz) and between the θ- (4–7 Hz) and the γ-band. This coupling pattern was mainly expressed in connections from IPM to SMA and from IPM to M1. We infer that human manual motor control involves task-specific modulation of inter-regional oscillatory coupling both within and across distinct frequency bands. The results highlight the potential of DCM to characterize context-specific changes in coupling within functional brain networks.

General information
State: Published
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Pages: 3187-3193
Publication date: 2012
Main Research Area: Technical/natural sciences

Publication information
Journal: NeuroImage
Volume: 59
Issue number: 4
ISSN (Print): 1053-8119
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Web of Science (2017): Indexed Yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 6.31 SJR 3.823 SNIP 1.752
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 4.48 SNIP 1.84 CiteScore 6.71
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 4.201 SNIP 2.029 CiteScore 6.9
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 4.376 SNIP 2.026 CiteScore 7.06
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 3.922 SNIP 1.937 CiteScore 6.86
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 3.626 SNIP 1.81 CiteScore 6.31
ISI indexed (2011): ISI indexed yes
Training your brain on a tablet

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling, Cognitive Systems, Technical University of Denmark
Authors: Jensen, C. B. F. (Intern), Ivanova, M. G. (Ekstern), Stopczynski, A. (Intern), Petersen, M. K. (Intern), Andersen, T. (Intern), Stahlhut, C. (Intern)
Number of pages: 1
Publication date: 2012
Event: Abstract from 34th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC), San Diego, CA, United States.
Main Research Area: Technical/natural sciences
Electronic versions:
EMBCpaper.pdf
Source: dtu
Source-ID: u::5664
Publication: Research - peer-review » Conference abstract for conference – Annual report year: 2012

A Smartphone Interface for a Wireless EEG Headset with Real-Time 3D Reconstruction
We demonstrate a fully functional handheld brain scanner consisting of a low-cost 14-channel EEG headset with a wireless connection to a smartphone, enabling minimally invasive EEG monitoring in naturalistic settings. The smartphone provides a touch-based interface with real-time brain state decoding and 3D reconstruction.
Demonstration: A smartphone 3D functional brain scanner
We demonstrate a fully portable 3D real-time functional brain scanner consisting of a wireless 14-channel 'Neuroheadset' (Emotiv EPOC) and a Nokia N900 smartphone. The novelty of our system is the ability to perform real-time functional brain imaging on a smartphone device, including stimulus delivery, data acquisition, logging, brain state decoding, and 3D visualization of the cortical EEG sources. Custom-made software realized in Qt has been implemented on the phone, which allow for either the phone to process the EEG data locally or transmit it to a server when more advanced machine learning tools are preferred. Source localization is implemented locally on the phone with a 3D brain model consisting of 1,028 vertices and 2,048 triangles stored in the mobile application.

Our system design benefits from the possibility of being able to integrate with multiple hardware platforms (smartphones, tablet computers, and netbooks) that are based on Linux operating systems.

Simultaneous EEG Source and Forward Model Reconstruction (SOFOMORE) using a Hierarchical Bayesian Approach
We present an approach to handle forward model uncertainty for EEG source reconstruction. A stochastic forward model representation is motivated by the many random contributions to the path from sources to measurements including the tissue conductivity distribution, the geometry of the cortical surface, and electrode positions. We first present a hierarchical Bayesian framework for EEG source localization that jointly performs source and forward model reconstruction (SOFOMORE). Secondly, we evaluate the SOFOMORE approach by comparison with source reconstruction methods that use fixed forward models. Analysis of simulated and real EEG data provide evidence that reconstruction of the forward model leads to improved source estimates.
**General information**

**State:** Published  
**Organisations:** Cognitive Systems, Department of Informatics and Mathematical Modeling  
**Authors:** Stahlhut, C. (Intern), Mørup, M. (Intern), Winther, O. (Intern), Hansen, L. K. (Intern)  
**Pages:** 431-444  
**Publication date:** 2011  
**Main Research Area:** Technical/natural sciences

**Publication information**  
**Journal:** Journal of Signal Processing Systems  
**Volume:** 65  
**Issue number:** 3  
**ISSN (Print):** 1939-8018

**Ratings:**
- **BFI (2018):** BFI-level 1  
- **Web of Science (2018):** Indexed yes  
- **BFI (2017):** BFI-level 1  
- **Web of Science (2017):** Indexed Yes  
- **BFI (2016):** BFI-level 1  
- **Scopus rating (2016):** SJR 0.226 SNIP 0.625 CiteScore 0.78  
- **BFI (2015):** BFI-level 1  
- **Scopus rating (2015):** SJR 0.228 SNIP 0.639 CiteScore 0.7  
- **Web of Science (2015):** Indexed yes  
- **BFI (2014):** BFI-level 1  
- **Scopus rating (2014):** SJR 0.292 SNIP 1 CiteScore 0.99  
- **Web of Science (2014):** Indexed yes  
- **BFI (2013):** BFI-level 1  
- **Scopus rating (2013):** SJR 0.27 SNIP 0.858 CiteScore 0.97  
- **ISI indexed (2013):** ISI indexed yes  
- **BFI (2012):** BFI-level 1  
- **Scopus rating (2012):** SJR 0.281 SNIP 0.869 CiteScore 1.04  
- **ISI indexed (2012):** ISI indexed yes  
- **BFI (2011):** BFI-level 1  
- **Scopus rating (2011):** SJR 0.252 SNIP 0.717 CiteScore 0.92  
- **ISI indexed (2011):** ISI indexed yes  
- **Web of Science (2011):** Indexed yes  
- **BFI (2010):** BFI-level 1  
- **Scopus rating (2010):** SJR 0.288 SNIP 0.829  
- **BFI (2009):** BFI-level 1  
- **Scopus rating (2009):** SJR 0.293 SNIP 0.849  
- **BFI (2008):** BFI-level 1  
- **Scopus rating (2008):** SJR 0.314 SNIP 0.661  
- **Scopus rating (2007):** SJR 0.34 SNIP 1.021  
- **Scopus rating (2006):** SJR 0.261 SNIP 0.688  
- **Scopus rating (2005):** SJR 0.379 SNIP 0.914  
- **Scopus rating (2004):** SJR 0.384 SNIP 1.05  
- **Scopus rating (2003):** SJR 0.561 SNIP 1.024  
- **Scopus rating (2002):** SJR 0.475 SNIP 1.004  
- **Scopus rating (2001):** SJR 0.316 SNIP 0.752  
- **Scopus rating (2000):** SJR 0.21 SNIP 0.592  
- **Scopus rating (1999):** SJR 0.189 SNIP 0.569

**Original language:** English  
**Inverse problem, Distributed models, Variational Bayes, Forward model reconstruction, EEG, Source localization**

**DOI's:**

10.1007/s11265-010-0527-0

**Source:** orbit

**Source-ID:** 257413
Smartphones Get Emotional: Mind Reading Images and Reconstructing the Neural Sources

Combining a 14 channel neuroheadset with a smartphone to capture and process brain imaging data, we demonstrate the ability to distinguish among emotional responses reflected in different scalp potentials when viewing pleasant and unpleasant pictures compared to neutral content. Clustering independent components across subjects we are able to remove artifacts and identify common sources of synchronous brain activity, consistent with earlier findings based on conventional EEG equipment. Applying a Bayesian approach to reconstruct the neural sources not only facilitates differentiation of emotional responses but may also provide an intuitive interface for interacting with a 3D rendered model of brain activity. Integrating a wireless EEG set with a smartphone thus offers completely new opportunities for modeling the mental state of users as well as providing a basis for novel bio-feedback applications.

Task-dependent modulation of oscillatory neural activity during movements: Abstract

Neural oscillations in different frequency bands have been observed in a range of sensorimotor tasks and have been linked to coupling of spatially distinct neurons. The goal of this study was to detect a general motor network that is activated during phasic and tonic movements and to study the task-dependent modulation of frequency coupling within this network. To this end we recorded 122-multichannel EEG in 13 healthy subjects while they performed three simple motor tasks. EEG data source modeling using individual MR images was carried out with a multiple source beamformer approach. A bilateral motor network connecting frontal, cerebellar and central motor regions, was consistently activated throughout the motor tasks. Quantification of observed spectral responses using dynamic causal modeling revealed strong coupling in the c-band (30–48 Hz) between frontal and central motor regions when a slow finger movement had to be adjusted to an external trigger. During a self-paced fast finger tapping (presumably sensory) coupling was strongest in the h-band (4–7 Hz), while b-band (13–30 Hz) coupling was dominant during an isometric contraction of the forearm. During these two highly automatic movements effective connectivity was strongest between central and cerebellar regions. Our results show that neural coupling within motor networks is modulated in distinct frequency bands depending on the motor task. They provide evidence that dynamic causal modeling in combination with EEG source analysis is a valuable tool for inferring on architecture and coupling parameters of neural networks.
Introduction

Electro-encephalography (EEG) holds great promise for functional brain imaging, due to its high temporal resolution, low cost equipment and the possibility of performing the experiments under much more realistic conditions as compared to functional magnetic resonance imaging and positron emission tomography. Today's EEG brain imaging

Evaluation of the influence of uncertain forward models on the EEG source reconstruction problem

Original language: English
underdetermined inverse problems, M/EEG source reconstruction, probabilistic graphical models, variational Bayes, ARD

DOIs: 10.1007/978-3-642-15948-0_20

Links: http://dx.doi.org/10.1007/978-3-642-15948-0_20

Source: orbit

Source-ID: 267514

Publication: Research - peer-review » Conference article – Annual report year: 2010
methods operate with the assumption that the forward model is known when the source estimation is performed. Many sources of uncertainty are involved in the formulation of the forward model like tissue segmentation, tissue conductivities, and electrode locations. In this contribution we investigate how forward model uncertainty influences source localization. Methods The analysis were based on 3-spheres models, where a high-resolution reference head model denoted as the ‘true forward model’ were compared with lower resolution forward models with and without erroneous tissue conductivity values. Conductivities brain:skull:scalp=0.33:0.004:1.0.33S/m (ratio 1:1/80:1), were used in the true forward model and 1:1/15:1 in an erroneous model. To reveal the influence of the forward fields on the source estimates, we base our analysis on a simple ‘stepwise’ selection procedure, where a squared error function is used. For simplicity we assume that the true source configuration consists of a single dipole i and we now evaluate the cost estimate of a single dipole solution located at the site j. This allows us to examine how the dipoles are confused in the different areas of the brain when noise is present. Results Due to mismatch between the true and experimental forward model, the reconstruction of the sources is determined by the angles between the i'th forward field associated with the true source and the j'th forward field in the experimental forward model. Figure 1a shows two examples of confusion of the reconstructed sources when the true source is located in left frontal region (Source 1) and left temporal lobe (Source 2). The left side on the vertical lines indicates trusted regions where the cost of selecting one of the sources is smaller than the contribution from noise. As confusion measure we use: The positive prediction value PPV=TP/(TP+FP), where TP is true positives (distanceless-than- or-equals, slant≤20mm) and FP is false positives (distance>20mm) both with angular factors smaller than the effective noise level. Figure 1b-1c show the PPV's for the whole brain with the true and erroneous conductivities, respectively. White areas indicate that no TP or FP has been detected. Generally, small signals from sulci and from cortical regions at a large distance from the sensors are more likely to be confused since the differences in angular factors can be small compared to the effective noise level. Increasing ‘white’ areas are found in figure 1c as a result of the poorer signal-to-noise ratio. Confusion is smaller for sources in the parietal region with the erroneous conductivity model, however, the angular factors also increases indicating a poorer representation of the signal. Conclusions This analysis demonstrated that caution is needed when evaluating the source estimates in different brain regions. Moreover, we demonstrated the importance of reliable forward models, which may be used as a motivation for including the forward model uncertainty into the source reconstruction methods.

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling
Authors: Stahlhut, C. (Intern), Mørup, M. (Intern), Winther, O. (Intern), Hansen, L. K. (Intern)
Publication date: 2009

Host publication information
Title of host publication: NeuroImage
Volume: 47
Publisher: Organization for Human Brain Mapping
Main Research Area: Technical/natural sciences
source localization, EEG, uncertain forward models
Electronic versions:
HBM2009_abstract.pdf
DOIs:
10.1016/S1053-8119(09)70145-4
Source: orbit
Source-ID: 240479
Publication: Research - peer-review › Conference abstract in proceedings – Annual report year: 2009

Hierarchical Bayesian Model for Simultaneous EEG Source and Forward Model Reconstruction (SOFOMORE)
In this paper we propose an approach to handle forward model uncertainty for EEG source reconstruction. A stochastic forward model is motivated by the many uncertain contributions that form the forward propagation model including the tissue conductivity distribution, the cortical surface, and electrode positions. We first present a hierarchical Bayesian framework for EEG source localization that jointly performs source and forward model reconstruction (SOFOMORE). Secondly, we evaluate the SOFOMORE model by comparison with source reconstruction methods that use fixed forward models. Simulated and real EEG data demonstrate that invoking a stochastic forward model leads to improved source estimates.

General information
State: Published
Organisations: Cognitive Systems, Department of Informatics and Mathematical Modeling
Authors: Stahlhut, C. (Intern), Mørup, M. (Intern), Winther, O. (Intern), Hansen, L. K. (Intern)
Pages: 1-6
Publication date: 2009
SOFOMORE: Combined EEG source and forward model reconstruction

We propose a new EEG source localization method that simultaneously performs source and forward model reconstruction (SOFOMORE) in a hierarchical Bayesian framework. Reconstruction of the forward model is motivated by the many uncertainties involved in the forward model, including the representation of the cortical surface, conductivity distribution, and electrode positions. We demonstrate in both simulated and real EEG data that reconstruction of the forward model improves localization of the underlying sources.

Projects:

Præcis og hurtig neurofeedback med billeddannelse EEG

Technical University of Denmark
Period: 15/03/2013 → 29/07/2016
Number of participants: 6
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Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)

Relations
Publications:
EEG Based Inference of Spatio-Temporal Brain Dynamics
Project: PhD

Probabilistic Methods for Biomedical Signals
Department of Informatics and Mathematical Modeling
Period: 15/02/2008 → 31/08/2011
Number of participants: 6
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Sörnmo, Leif (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD