What's "Advanced" fMRI?

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Section on Functional Imaging Methods

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&

Functional MRI Facility

http://fmrif.nimh.nih.gov

Overview of fMRI

Functional Contrast:

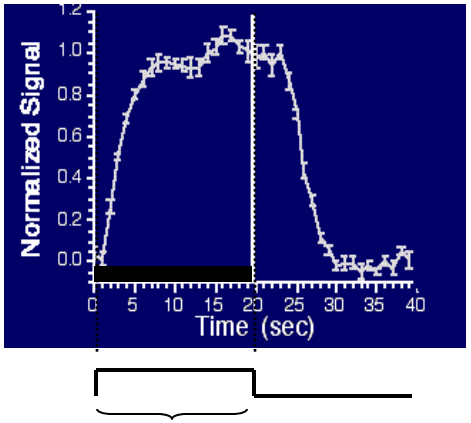
- Blood flow/perfusion
- Blood oxygenation

Sensitivity (CNR)

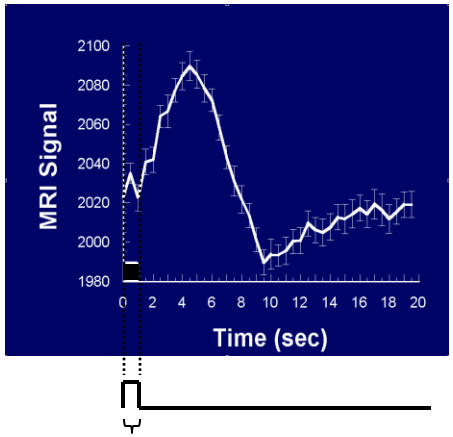
2/1 to 5/1

Spatial resolution:

- Typical: 3 mm^3
- Upper: 0.5 mm^3



task



task

Temporal resolution:

- Minimum duration: < 16 ms
- Minimum onset diff: 100 ms to 2 sec

Interpretability:

- Neurovascular coupling, vascular sampling, blood
- physiologic noise, motion and other artifacts, etc..

What fMRI Can Routinely Do

Help in understanding healthy brain organization

- -map networks involved with specific behavior, stimulus, or performance
- -characterize changes over time (seconds to years)
- -determine functional correlates of behavior

Current Clinical Applications

- -presurgical mapping (CPT code in place as of Jan, 2007)

Current Clinical Research

- -assessment of recovery and plasticity
- -clinical population characterization with probe task or resting state

How most fMRI studies are performed

MRI parameters:
1.5T - 3T, 64 x 64 matrix, 3mm x 3mm x 5mm voxel size, whole brain, TR = 2 sec.

Paradigm:
Block design or event-related, single or multiple conditions.

Analysis:
Motion correct, multi-regression, spatial smoothing and spatial normalization, standard classical statistical tests, multi-subject averaging.

Hypothesis:
A region or network of regions show modulation with a task. This modulation is unique to the task and/or population.

Problems/Shortcomings of fMRI

- Too low SNR for routine clinical use (takes too long)
- Requires patient cooperation (too sensitive to motion)
- Too low spatial resolution (each voxel has several million neurons)
- Too low temporal resolution (hemodynamics are variable and sluggish)
- Too indirectly related to neuronal activity
- Too many physiologic variables influence signal
- Too inconsistent of an activation pattern
- Anatomical images for fMRI are low quality (dropout/distortion)
- Requires a task (BOLD cannot look at baseline maps)
- Too confined space and high acoustic noise.

How fMRI might be be performed

MRI parameters:

3T - 11.7T, 256 x 256 matrix, 0.5 x 0.5 x 0.5 voxel size, whole brain TR = 1sec or select slab TR = 100 ms.

Paradigm:

Natural, continuous, or no stimuli/task. Simultaneous multi-modal, or multiple contrast measurements.

Analysis:

Motion correct, dynamic Bo-field correction, no spatial or temporal smoothing, machine learning algorithms, pattern classification, hemodynamic parameter assessment, correlation with behavior.

Hypothesis:

Similar to previous but using the high resolution patterns, fluctuations, dynamics, and contrast mechanisms that we are still figuring out how to interpret and extract.

Technology

- Coil arrays
- High field strength
- High resolution
- Novel functional contrast

Methodology

- Novel processing methods/paradigms
- Multi-modal integration/comparison
- Real time feedback
- Calibration methods
- Characterizing/Reducing Fluctuations
- Comparison of subject/group data
- Connectivity assessment

- Magnitude
- Dynamics
- Cross - modal comparison
- Resting state fluctuations
- Default Network

Interpretation

- Basic and Cognitive Neuroscience
- Behavior correlation/prediction
- Pathology assessment

Applications

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Applications

fMRI Contrast

- Volume (gadolinium)
- BOLD
- Perfusion (ASL)
- $\Delta CMRO_2$
- ΔVolume (VASO)
- Neuronal Currents
- Diffusion coefficient
- Temperature

Novel Contrasts / Techniques:

(272 TH-PM) Pass-band SSFP fMRI: BOLD Sensitivity with Various MR Parameters
Taek S. Kim , Jongho Lee , John M. Pauly

(275 TH-AM) Event-related Single-shot Volumetric Functional Magnetic Resonance Inverse Imaging in the Human Brain
Fa-Hsuan Lin , Lawrence Wald , Joseph Mandeville , Thomas Witzel , et al.

(303 TH-AM) Stimulus Induced Rotary Saturation (SIRS); a new method for the direct detection of neuronal currents
Thomas Witzel , Bruce Rosen , Fa-Hsuan Lin , Lawrence Wald

(297 TH-AM) Optimizing the Combination of Spiral-In/Out Images for BOLD and Perfusion fMRI
B.T. Stokes , T. Ernst , L. Chang , R. Yakupov , et al.

(111 TH-AM) Functional BOLD Signal Relationships to Perfusion Signal During Associative Encoding in Medial Temporal Lobe Structures based on Alzheimer and rsquo;s Disease Genetic Risk
Adam Fleisher , Katie Bangen , Katherine Podraza , Curtis Taylor , et al.

(30 M-PM) Real-time Human Brain Mapping
Jean-Philippe Lachaux , Karim Jerbi , Olivier Bertrand , Lorella Minotti , et al.

(265 TH-AM) Is ASL-BOLD equivalent to standard BOLD?
Yufen Chen , Todd Parrish

(370 W-PM) Effects of CBV and Capillary Permeability on ASL Signal
Chang-Wei Wu , Jyh-Horng Chen , Yihong Yang

(264 TH-PM) Functional MRI Measurement of Venous Cerebral Blood Volume Measurement at 3 Tesla
Jean J. Chen , G. Bruce Pike

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Applications

Methodology

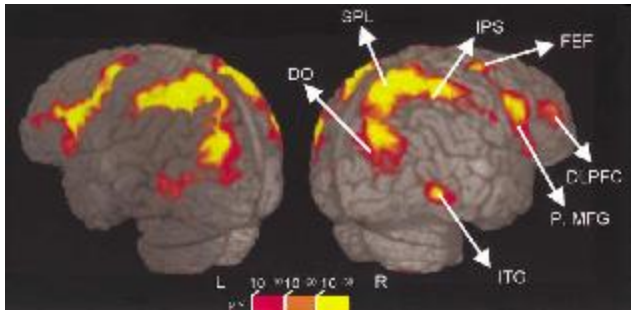
Mapping ⟷ "Reading"

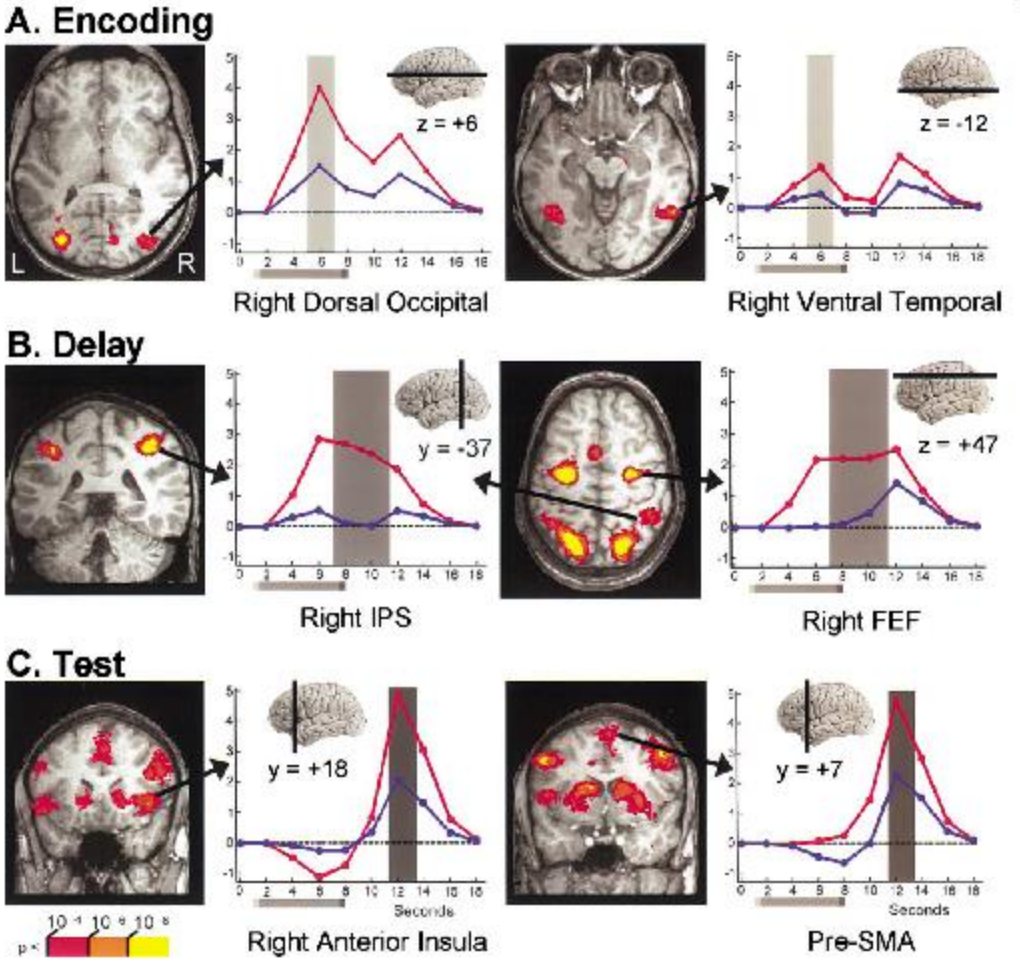
Methodology

Neuron, Vol. 35, 975–987, August 29, 2002, Copyright ©2002 by Cell Press

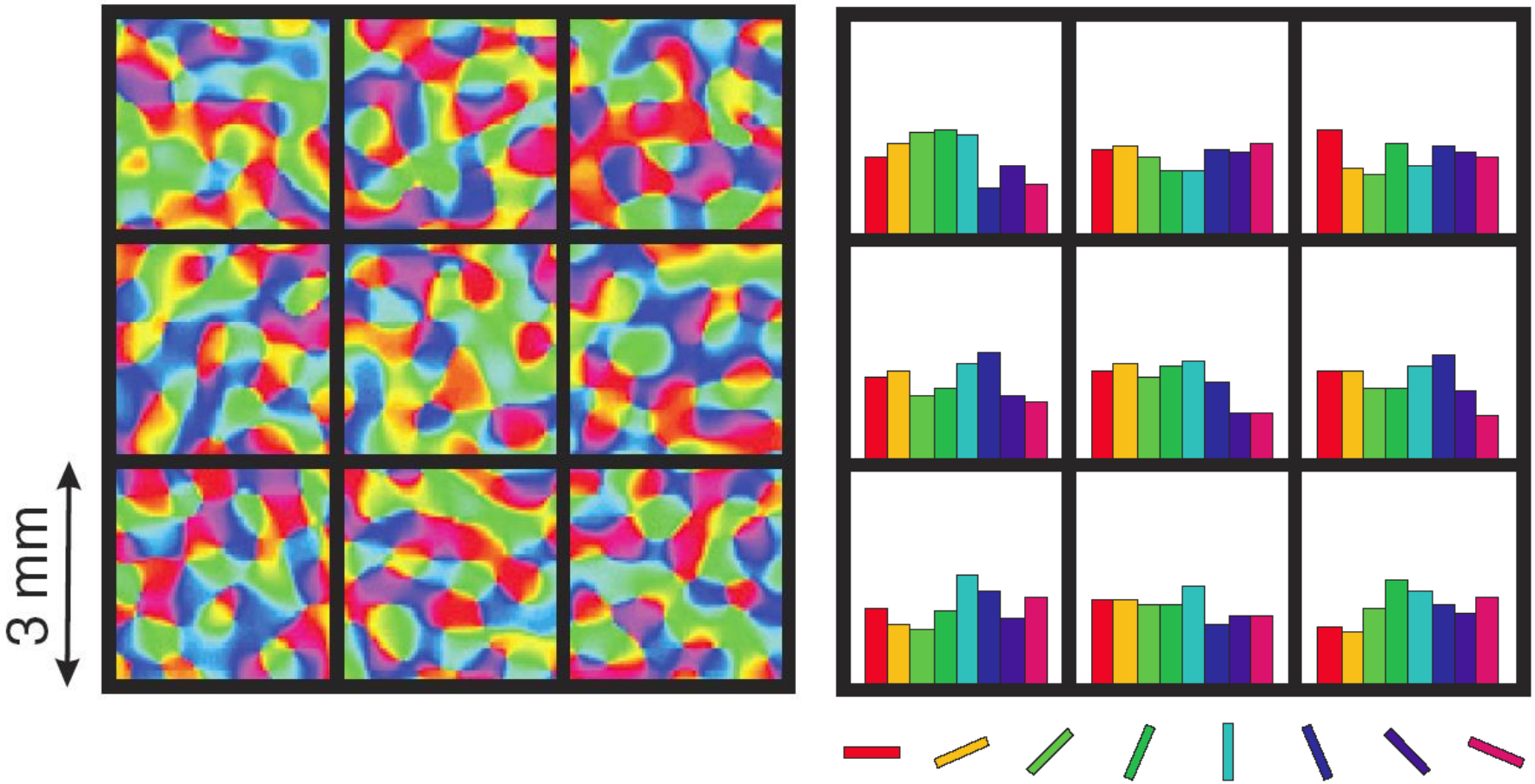
Neural Correlates of Visual Working Memory: fMRI Amplitude Predicts Task Performance

Luiz Pessoa,[1] Eva Gutierrez, Peter A. Bandettini, and Leslie G. Ungerleider
Laboratory of Brain and Cognition
National Institute of Mental Health
National Institutes of Health
Bethesda, Maryland 20892





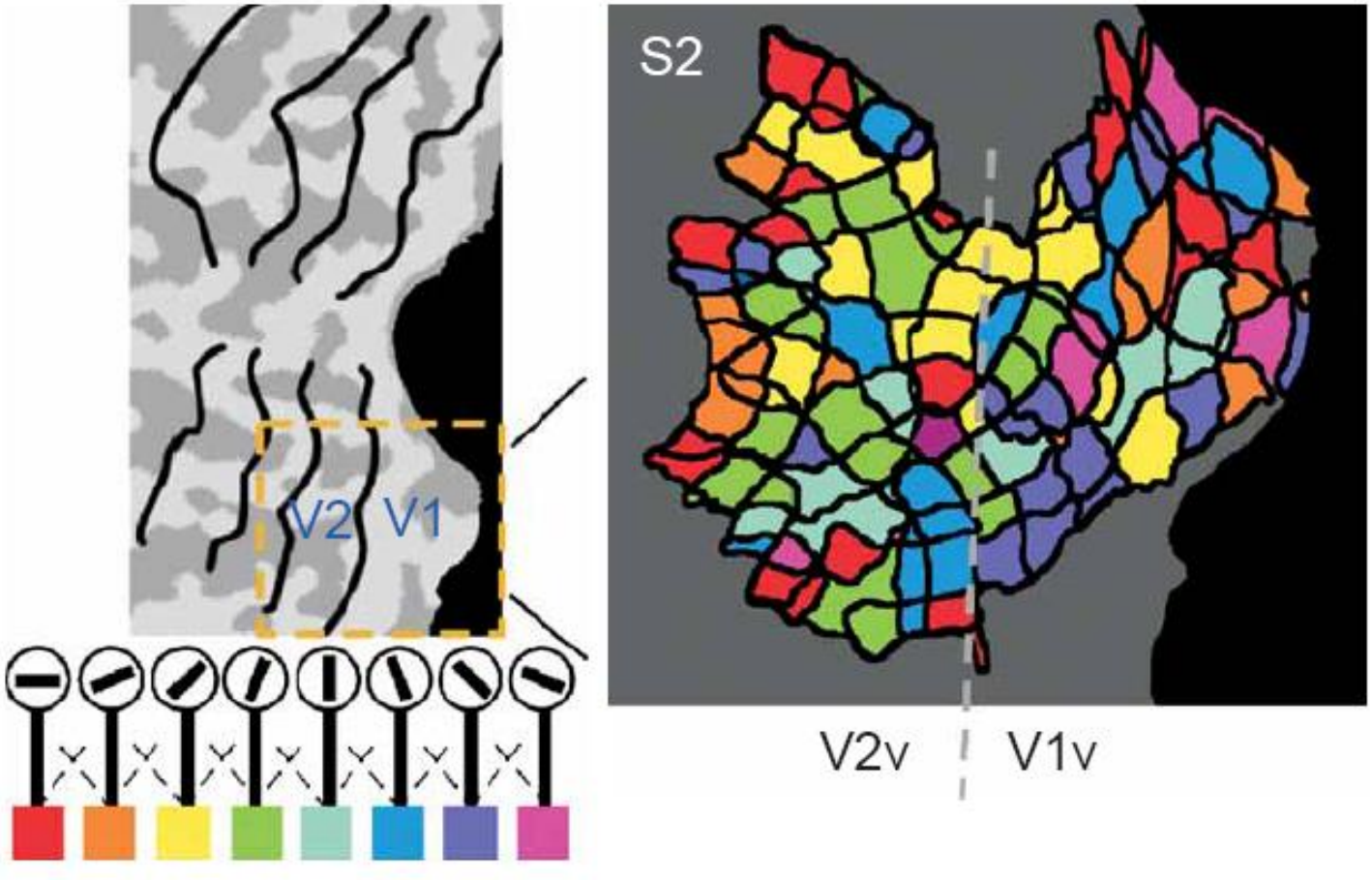
Methodology



Boynton (2005), News & Views on Kamitani & Tong (2005) and Haynes & Rees (2005)

Methodology

Lower spatial frequency clumping

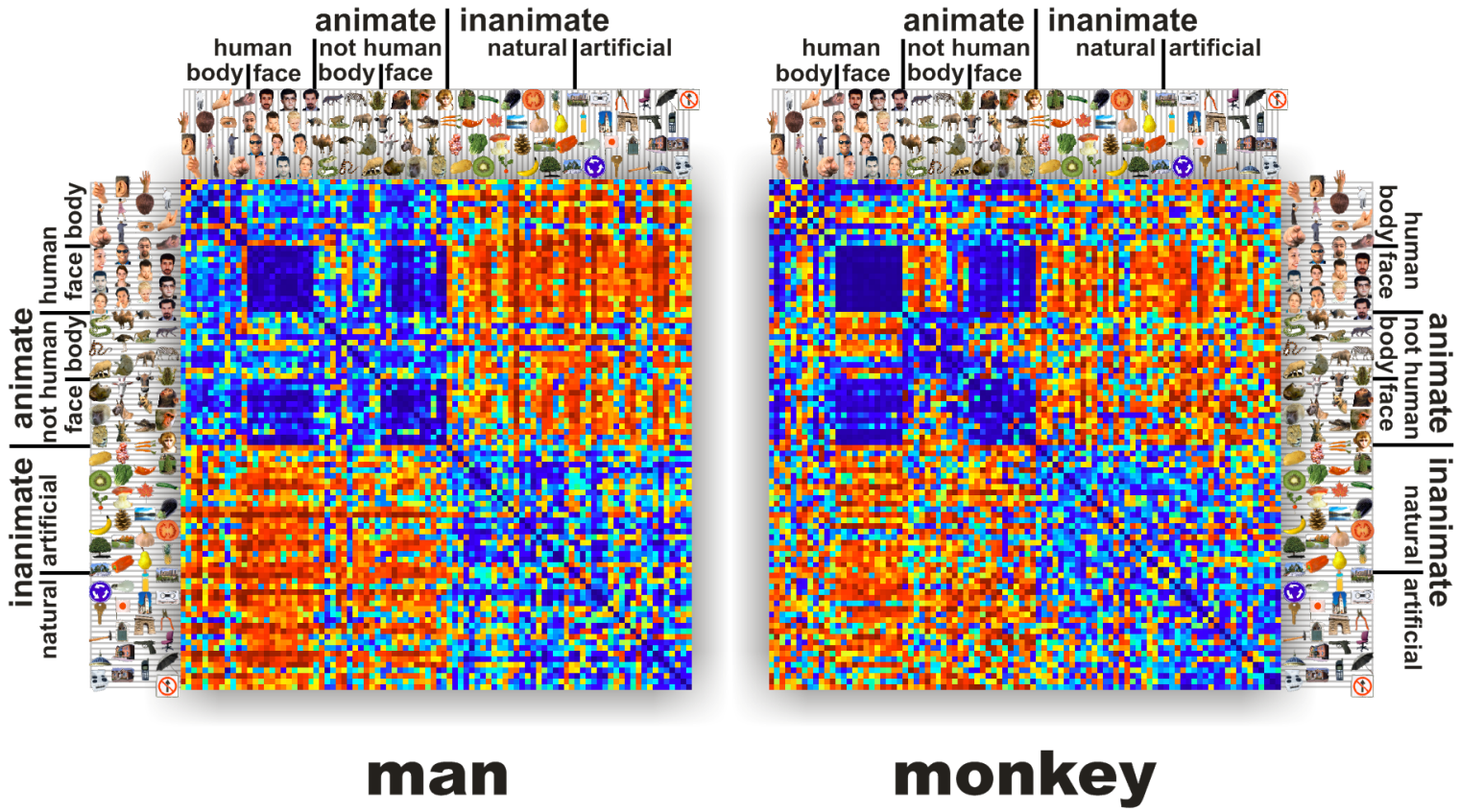


Kamitani & Tong (2005)

Matching categorical object representations in IT cortex of man & monkey

Kriegeskorte N, Mur M, Ruff D, Kiani R, Bodurka J, Bandettini P

dissimilarity matrices



Pattern Classification

(353 TH-AM) Unsupervised fMRI Analysis
David R. Hardoon , Janaina Mourao-Miranda , Michael Brammer , John Shawe-Taylor

(153 W-AM) Matching categorical object representations in inferotemporal cortex of man and monkey
Nikolaus Kriegeskorte , Marieke Mur , Douglas Ruff , Roozbeh Kiani , et al.

(288 M-PM) Creating topological signatures from graph-based representations of fMRI measurements
A. Ravishankar Rao , Guillermo Cecchi , Rahul Garg

(344 W-PM) Extracting cognitive conditions from neuroimaging data with Support Vector Machines
Xi Cheng , Qian Luo , Meyer-Lindenberg Andreas

(347 W-AM) Iterative selection and mapping of discriminative features in fMRI pattern recognition with Support Vector Machines
Federico De Martino , Giancarlo Valente , Rainer Goebel , Elia Formisano

(355 W-AM) Spatiotemporal SVM applied to event-related fMRI
Janaina Mourao-Miranda , Christine Ecker , Michael Brammer

(5 T-AM) Encoding of sensory stimuli and task sets in prefrontal cortex
Stefan Bode , John-Dylan Haynes

(19 T-AM) Reading hidden intentions in the human brain
Chun Siong Soon , Marcel Brass , Richard Passingham , John-Dylan Haynes

(23 W-AM) Pattern classification reveals control regions for visual spatial attention in prefrontal cortex
Christian Kalberlah , John-Dylan Haynes

(352 W-PM) Utilizing the covariance relationships in complex natural stimulus descriptors in fMRI brain state analysis
Stephen LaConte , Xiaoping Hu

(155 TH-AM) Distributed neural representations of odor quality in human piriform cortex
James Howard , Jay Gottfried , Jane Plailly , Wen Li , et al.

(160 W-PM) Origin of 'decoding' signals in the visual cortex: gray matter or macroscopic blood vessels?
Amir Shmuel , Guenter Raddatz , Denis Chaimow , Nikos Logothetis , et al.

(193 T-AM) Selective activation around the left occipito-temporal sulcus for words relative to pictures: individual variability or false positives?
Nicholas D. Wright , Andrea Mechelli , Uta Noppeney , Dick J. Veltman , et al.

(347 W-AM) Iterative selection and mapping of discriminative features in fMRI pattern recognition with Support Vector Machines
Federico De Martino , Giancarlo Valente , Rainer Goebel , Elia Formisano

(364 W-PM) Comparison of methods for fMRI brain reading: a study on generalization and interpretability.
Giancarlo Valente , Federico De Martino , Walt Schneider , Rainer Goebel , et al.

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Interpretation

- Basic and Cognitive Neuroscience
- Behavior correlation/prediction
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Applications

Multi-Modal

(243 M-AM) Exploring the feasibility of simultaneous EEG/fMRI at 7T
Karen Mullinger , Matthew Brookes , Claire Stevenson , Matthew Clemence , et al.

(201 M-AM) On the relationship between oscillatory brain activity and event-related fields
Ali Mazaheri , Daria Osipova , Ole Jensen

(238 M-PM) Comparing Gamma oscillations and BOLD signal during a reading task: a combined fMRI and intracranial EEG study
Alexandra Juphard , Jean-Philippe Lachaux , Monica Baciu , Sylviane Valdois , et al.

(244 M-PM) Effects of Simultaneous EEG Recording on MRI Data Quality at 1.5, 3 and 7 Tesla
Karen Mullinger , Andreas Bungert , Ron Coxon , David Foxhall , et al.

(146 M-PM) Investigating Sensorimotor Stroke Recovery using Simultaneous Skin Conductance and Event-Related fMRI at 3 T
Bradley MacIntosh , Richard Mraz , Sandra Black , Richard Staines , et al.

(138 W-PM) Trial by trial BOLD correlates of working memory related alpha and theta power increases during simultaneous EEG/fMRI measurement
René Scheeringa , Marcel Bastiaansen , Karl Magnus Petersson , David Norris , et al.

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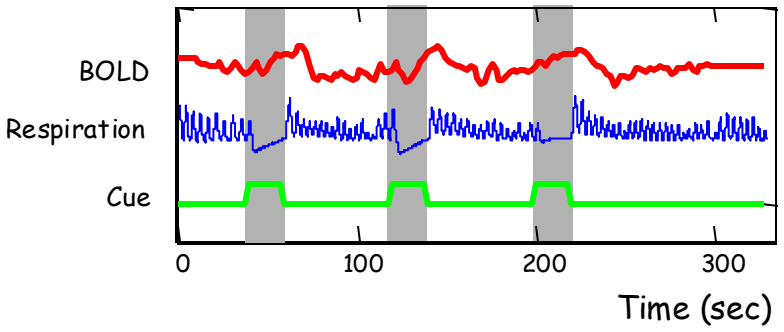
Applications

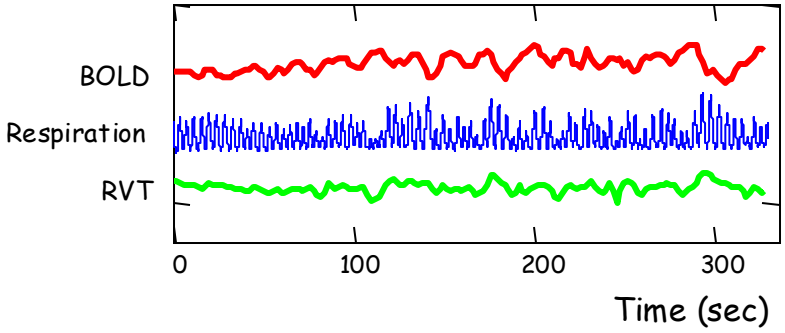
Methodology

Respiration induced signal changes

Breath-holding



Rest



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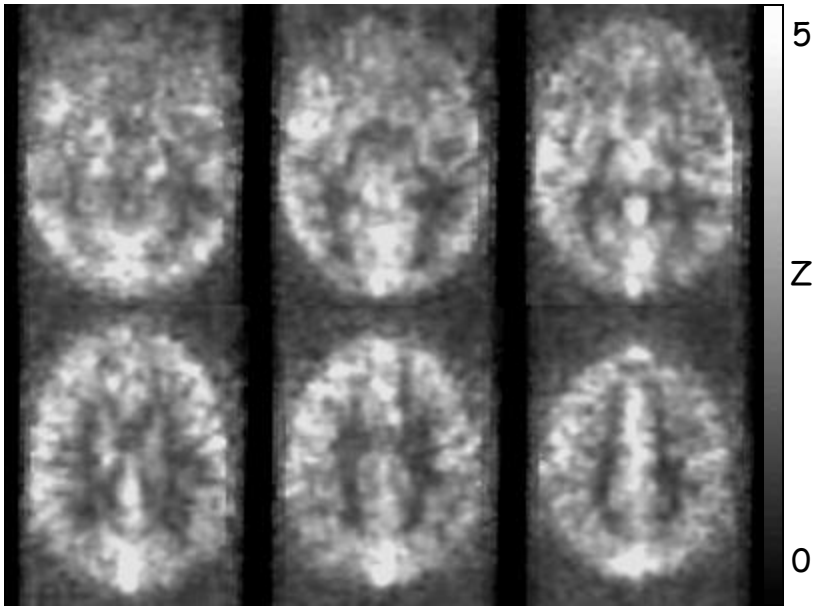
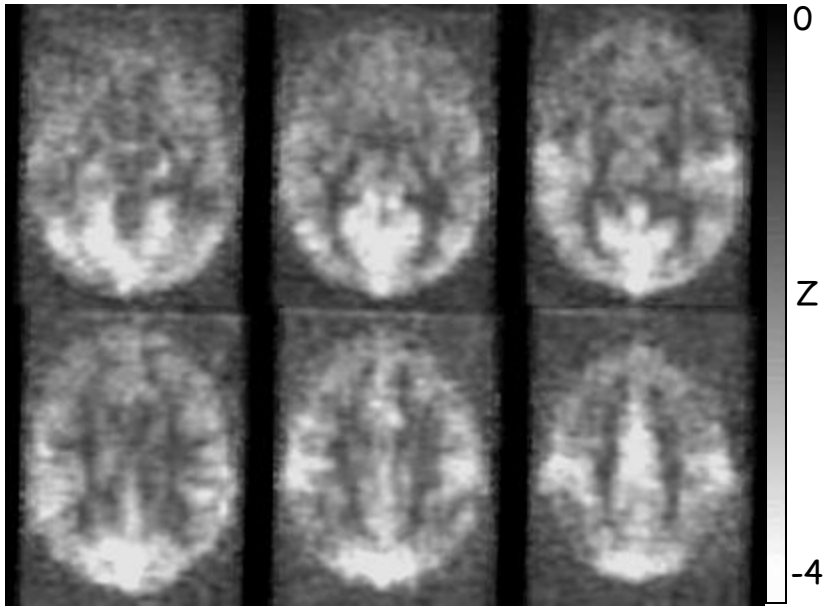
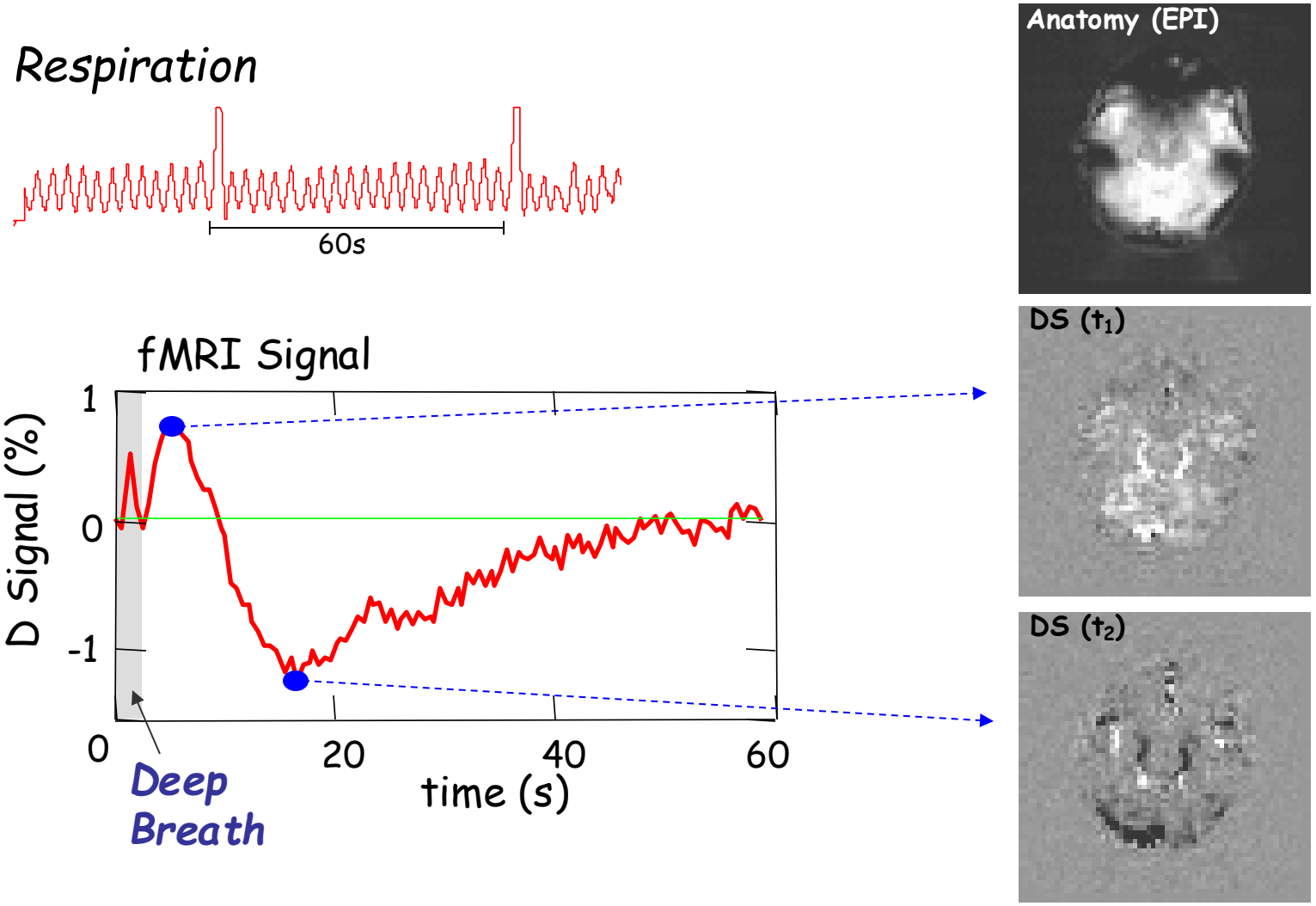




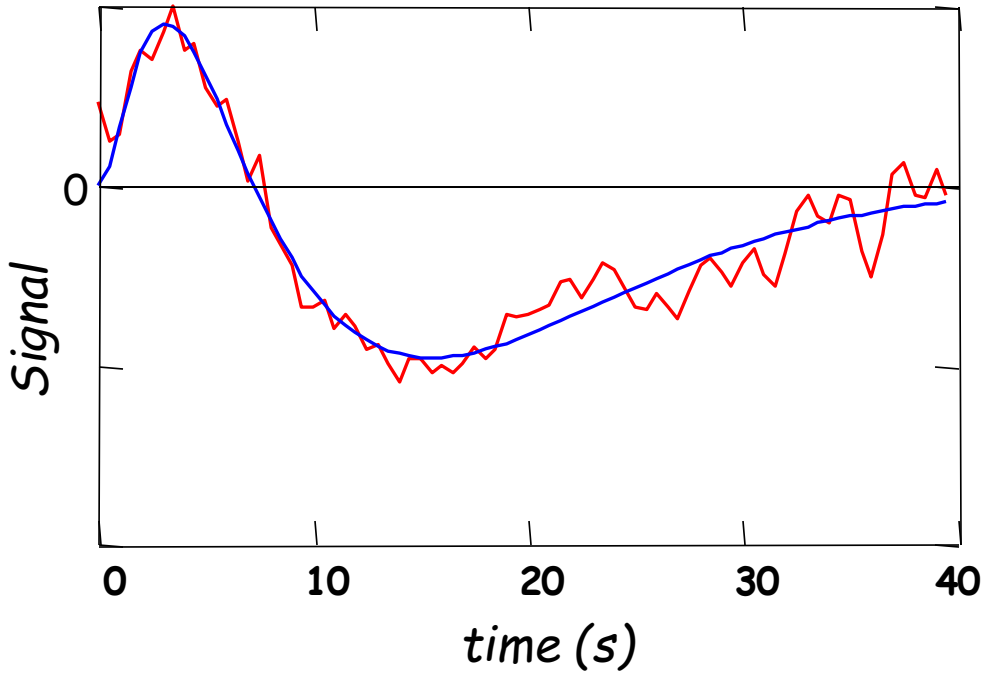
R. M. Birn, J. B. Diamond, M. A. Smith, P. A. Bandettini, Separating respiratory variation-related fluctuations from neuronal activity-related fluctuations in fMRI, NeuroImage 31, 1536-1548 (2006)

Respiration Response Function

fMRI response to a single Deep Breath



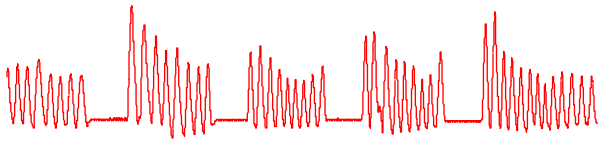
Respiration response function



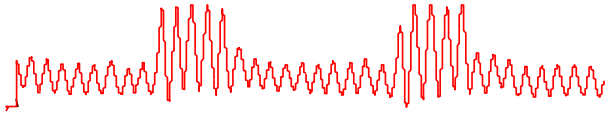
Average of 3 subjects

$$RRF(t) = 0.6\, t^{2.1} e^{-\frac{t}{1.6}} - 0.0023\, t^{3.54} e^{-\frac{t}{4.25}}$$

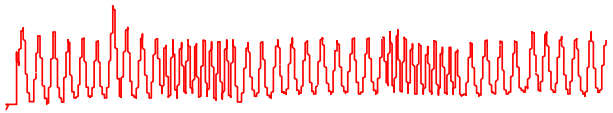
Calibration using other respiration changes



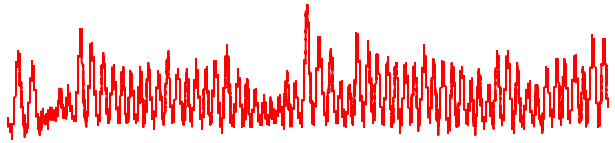
Breath-holding



Depth changes



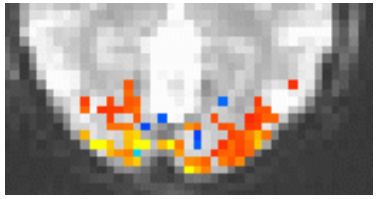
Rate changes



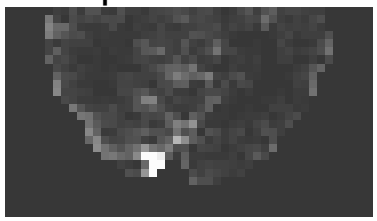
spontaneous fluctuations
in respiration during rest

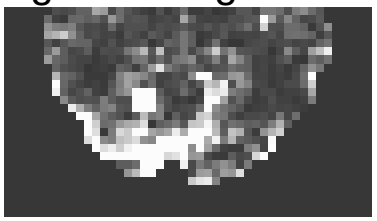
Respiration Response Function

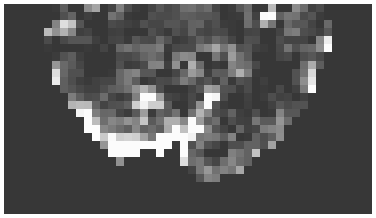
Visual Activation

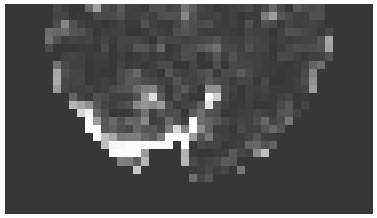


Respiration – induced signal changes









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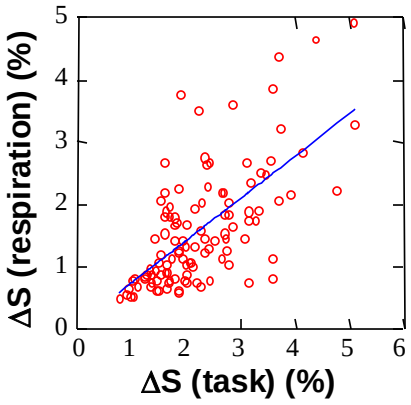

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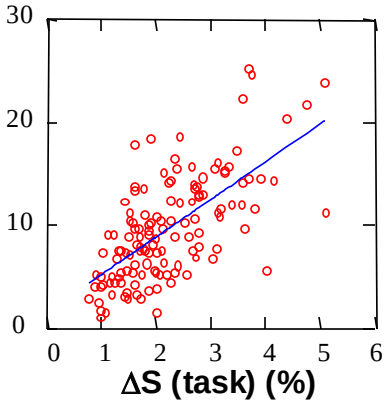
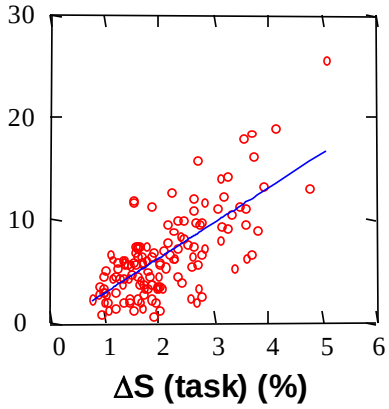


Depth changes



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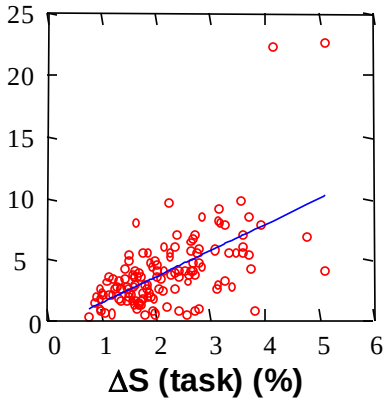

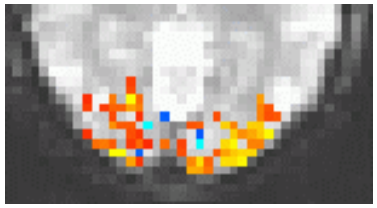

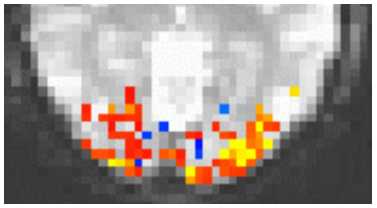

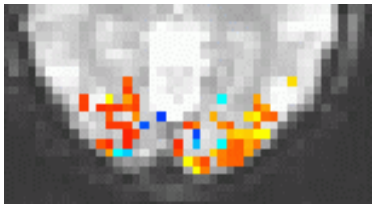

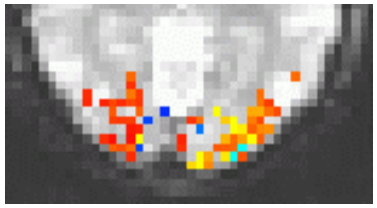

Improving Signal to Noise / Calibration in fMRI

(311 W-AM) Improved temporal SNR in amygdala fMRI signal with physiological noise correction and image segmentation
David Knight , Joseph Dunsmoor , Peter Bandettini

(321 TH-AM) Modeling spontaneous fluctuations in resting state networks in the standard GLM improves activation detection
AM Clare Kelly , Bharat Biswal , Lucina Uddin , F. Xavier Castellanos , et al.

(356 TH-PM) Separation of physiological noise sources for spatially-coherent fluctuations in BOLD signal using Probabilistic Independent Component Analysis
Timothy Laumann , Jason Stein , Jerzy Bodurka , Yunxia Tong , et al.

(297 W-AM) Calibration of BOLD fMRI signal changes using cued and spontaneous breathing variations
Rasmus M. Birn , Tyler B. Jones , Peter A. Bandettini

(301 W-AM) Reducing Correlated Noise in fMRI Data
Jacco A de Zwart , Peter van Gelderen , Masaki Fukunaga , Jeff H Duyn

(296 W-PM) The Respiration Response Function: modeling the temporal dynamics of respiration-volume induced signal changes
Rasmus M. Birn , Tyler B. Jones , Monica A. Smith , Peter A. Bandettini

(316 W-PM) Accurate Estimation of Physiologic Noise Using Temporal ICA-derived Spatial Measures
Erik Beall , Mark Lowe

Practical Issues

(321 W-AM) Artifact Repair for fMRI Data from High Motion Clinical Subjects
Paul Mazaika , Susan Whitfield-Gabrieli , Allan Reiss

(337 T-AM) A Study of Subject Motion and the Effects on the BOLD Signal
Ryan T. Simpson , Michael F. Glabus

(292 TH-PM) Methodological Problems and Success Rate of Pediatric fMRI at 3T
Roland Beisteiner , Agnes Pirker , Thomas Foki , Alexander Geissler , et al.

(328 TH-PM) fMRIpower: A Power Calculation Tool for 2-Stage fMRI Models
Jeanette Mumford , Russell Poldrack , Thomas Nichols

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Applications

Connectivity

(240 TH-PM) Selectively disturbed connectivity of resting state networks in patients with mild cognitive impairment
Christian Sorg , Valentin Riedl , Alexander Kurz , Claus Zimmer , et al.

(278 M-PM) Functional Connectivity of Anterior Cingulate Cortex: A Resting-State Mapping Approach
Daniel S. Margulies , A.M. Clare Kelly , Lucina Q. Uddin , F. Xavier Castellanos , et al.

(12 TH-PM) Different Connectivity Patterns in Populations with Different IQs
Ming Song , Yuan Zhou , Jun Li , Chunshui Yu , et al.

(168 M-PM) Functional Connectivity is Altered During Recovery Following Stroke
Ali-Mohammad Golestani , Andrew Demchuk , Mayank Goyal , Bradley Goodyear

(168 T-PM) Altered brain activity and effective connectivity in children with dyslexia during phonological processing
Fan Cao , Tali Bitan , Tai-Li Chou , Douglas Burman , et al.

(171 TH-AM) Functional connectivity associated with the comprehensibility of speech sounds
Kevin Hynnä , Hannu Tiitinen , Patrick May

(213 W-AM) Decreased Functional Connectivity of Motor Systems in Autism.
Daniel J Simmonds , Stewart H Mostofsky

(235 T-AM) Impaired functional connectivity within the frontal lobes in schizophrenia
Pierre Fonlupt , A. Caclin , I. Baeza , C. Junque , et al.

(241 T-AM) Effect of Nicotine on Resting-State Functional Connectivity in Schizophrenia
L. Elliot Hong , Hong Gu , Thomas Ross , Robert Hayes , et al
.
(245 W-AM) Functional connectivity can measure epilepsy networks.
Anthony Waites , David Abbott , Richard Masterton , Graeme Jackson

(247 TH-AM) Motor connectivity in Parkinson disease: differences from normal in M1, SMA and Cerebellum
Paula Arantes , João Sato , Claudia Leite , Edson Amaro Jr.

(255 M-AM) Detecting time-varying connectivity
Felix Carbonell , Keith Worsley , Nelson Trujillo , Roberto Carlos Sotero , et al.

(259 M-AM) Effect of scanner signal drift on evaluation of baseline connectivity
Hu Cheng , Samantha Brandfon

(94 W-PM) Functional Connectivity Reflects Structural Connectivity in a Human Memory Network
Michael Greicius , Kaustubh Supekar , Robert Dougherty

(297 M-AM) Mapping effective connectivity in a short-delay continuous performance task using Granger causality analysis
Yunxia Tong , Lucas Kempf , Caroline Zink , Courtnea Rainey , et al.

Technology

- Coil arrays
- High field strength
- High resolution
- Novel functional contrast

Methodology

- Novel processing methods/paradigms
- Multi-modal integration/comparison
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- Magnitude
- Dynamics
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Applications

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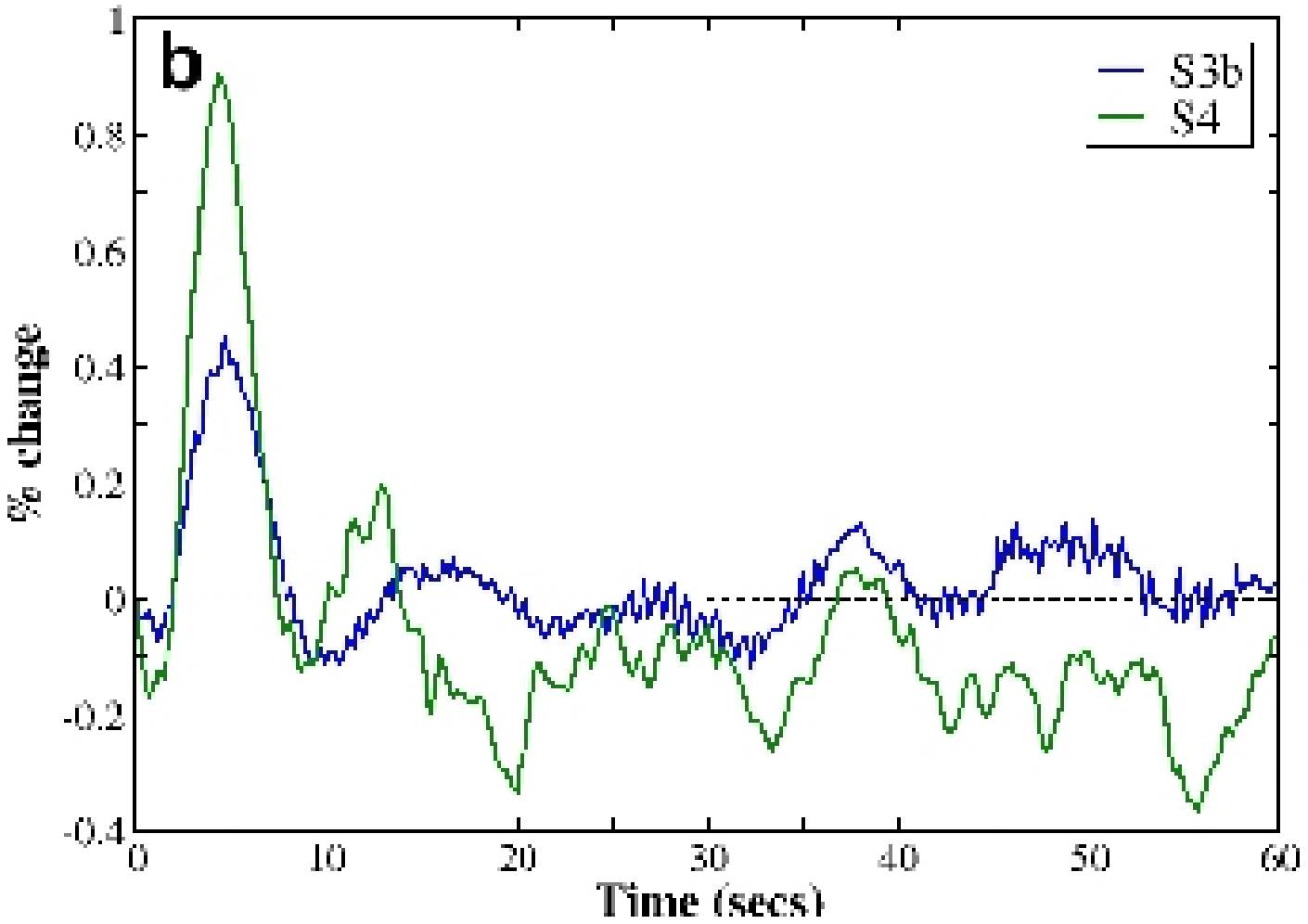
- Behavior correlation/prediction
- Pathology assessment



85 TH-AM

Evidence of the BOLD Post-Undershoot Rebound

Kevin Murphy, Jerzy Bodurka, Peter Bandettini

fMRI Dynamics

(128 M-PM) Multiscale BOLD dynamics during simulated driving
Ruey-Song Huang , Tzyy-Ping Jung , Jeng-Ren Duann , Scott Makeig , et al.

(285 TH-AM) Evidence of the BOLD Post-Undershoot Rebound
Kevin Murphy , Jerzy Bodurka , Peter Bandettini

(296 W-PM) The Respiration Response Function: modeling the temporal dynamics of respiration-volume induced signal changes
Rasmus M. Birn , Tyler B. Jones , Monica A. Smith , Peter A. Bandettini

(191 W-AM) Can fMRI detect temporal differences in processing somatosensory information ?
Patrizia Baraldi , Angela Agnes Manginelli , Davide Anchisi , Marco Serafini , et al.

(396 M-PM) BOLD Signal Decreases Following Caffeine Challenge in Individuals Who Intake High Daily Doses of Caffeine.
Lucie L Yang , Ann M Peiffer , Merideth A Addicott , Robert A Kraft , et al.

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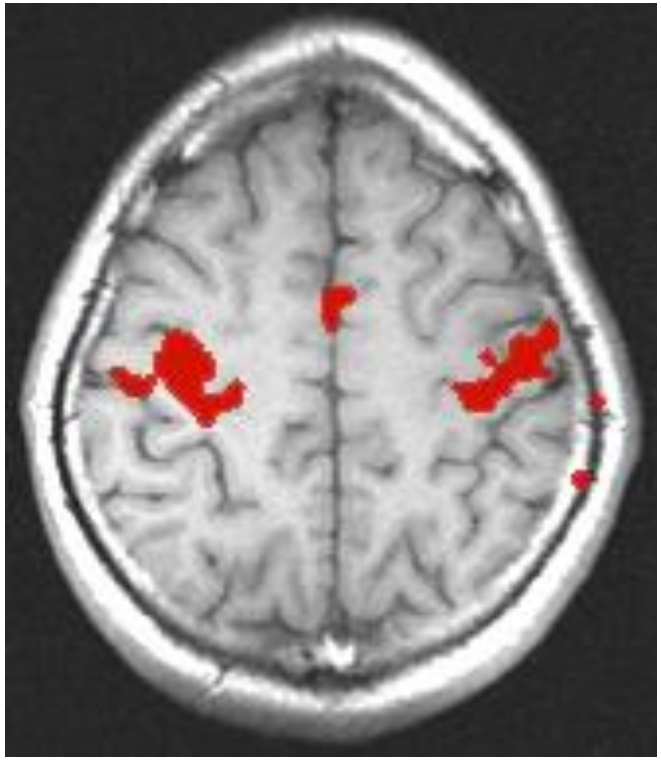
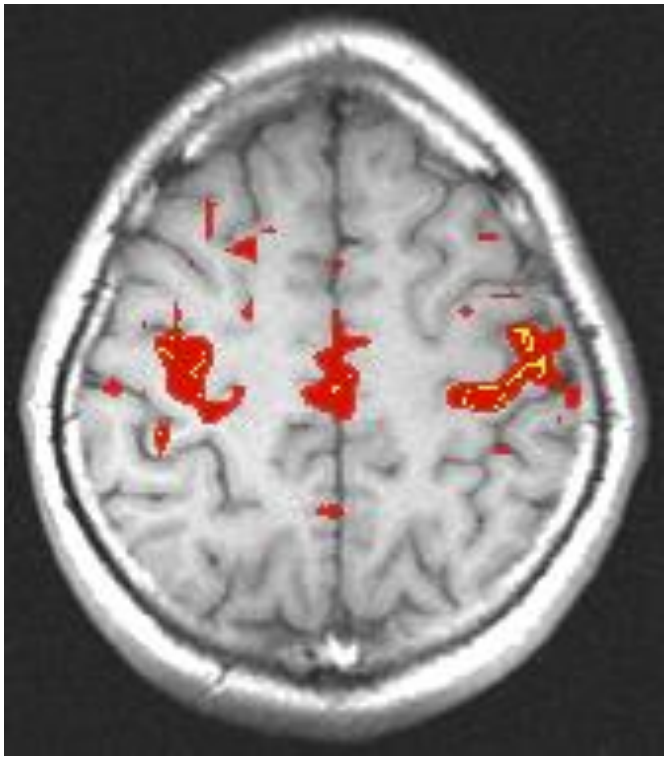
Resting State Correlations



Activation:
correlation with reference function



Rest:
seed voxel in motor cortex

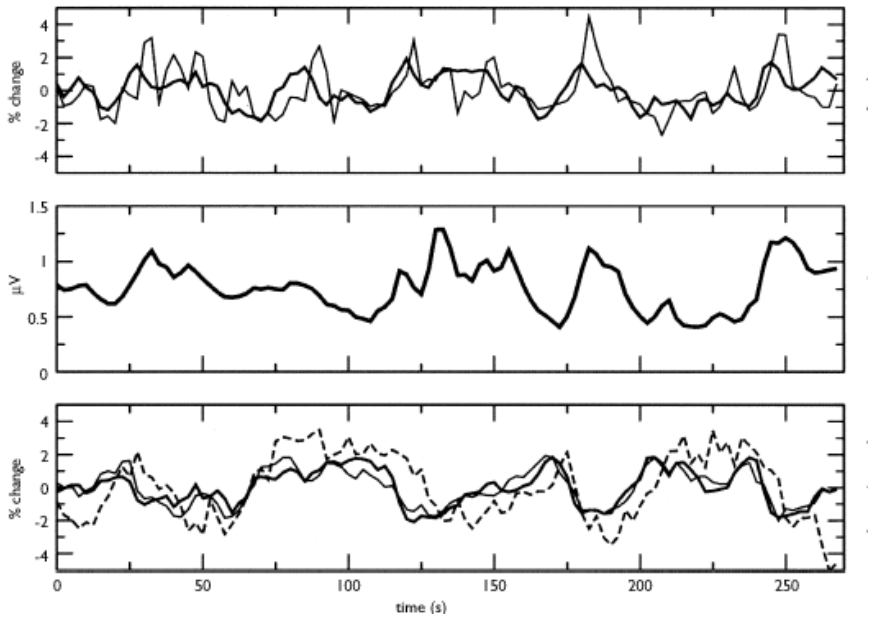
B. Biswal *et al.*, MRM, 34:537 (1995)

BOLD correlated with 10 Hz power during "Rest"

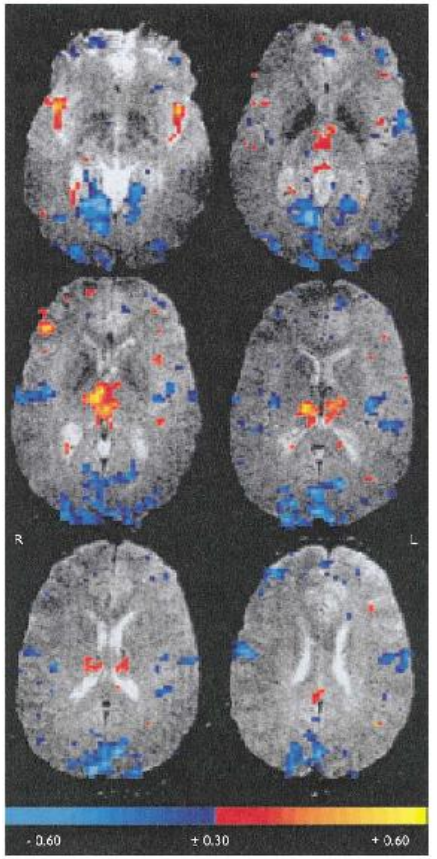
Positive

10 Hz power

Negative



Goldman, et al (2002), Neuroreport



Resting State Fluctuations

(277 M-AM) Brain rhythms and large scale networks in the resting human brain: an EEG/fMRI study
Dante Mantini , Mauro Gianni Perrucci , Cosimo Del Gratta , Gian Luca Romani , et al.

(390 M-PM) Spontaneous fluctuations in functional MRI signal reflect fluctuations in the underlying local neuronal activity
Amir Shmuel , Mark Augath , Axel Oeltermann , Nikos Logothetis

(19 M-AM) Functional connectivity during deep sleep: a simultaneous EEG-fMRI study
Silvina G. Horovitz , Masaki Fukunaga , Walter S. Carr , Dante Picchioni , et al.

(265 M-AM) BrainSCAPE: An Online Spontaneous Correlation Analysis Processing Environment for fMRI BOLD data
Michael D. Fox , Daniel S. Marcus , Abraham Z. Snyder , Marcus E. Raichle

(330 W-PM) Cardiac Rate Variations as a Source of Physiological Noise in the Resting-State fMRI BOLD Signal
Karin Shmueli , Peter van Gelderen , Jacco de Zwart , Silvina G. Horovitz , et al.

(3 M-AM) Baseline brain activity fluctuations predict somatosensory perception in humans
Mélanie Boly , Evelyne Balteau , Caroline Schnakers , Christian Degueldre , et al.

(282 M-PM) Spectral Content of the Ongoing BOLD Activity is Modulated by Resting State-Type
Mark McAvoy , Giovanni d'Avossa , Marcus E. Raichle , Linda Larson-Prior

(296 M-PM) A Preliminary Study of the Brain Functional Network of Thalamic Nuclei In the Resting State
Yi Zhang , Jie Tian , Xiaohong Pan , Wei Qin , et al.

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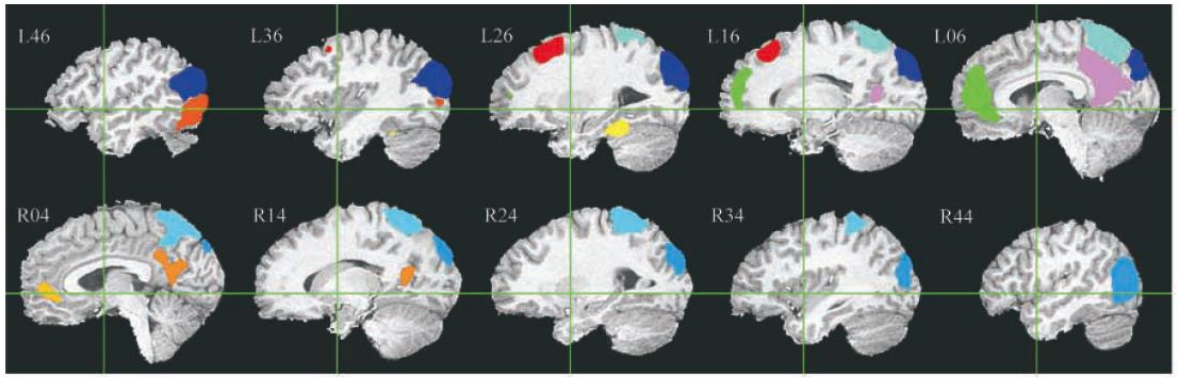
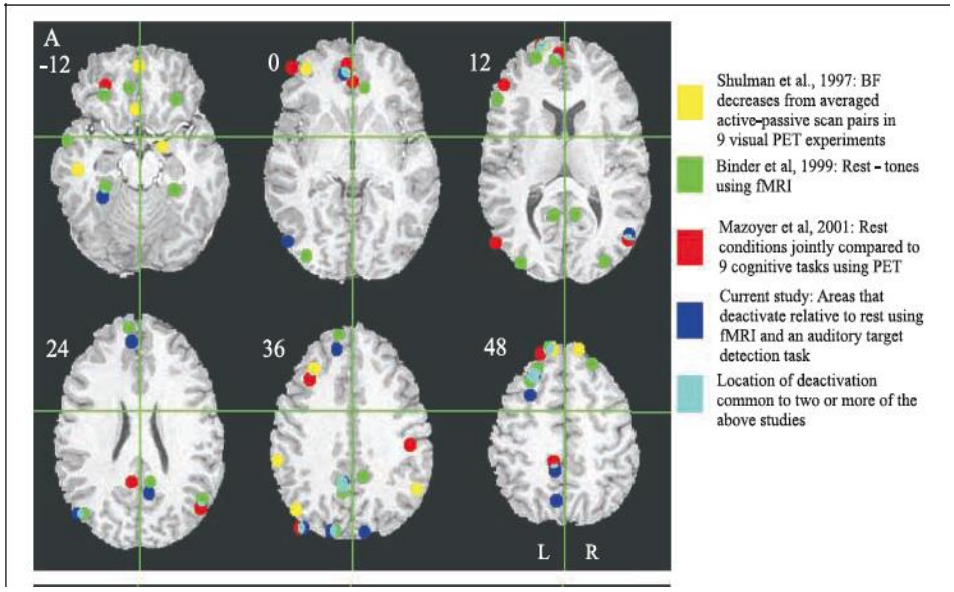
Regions showing decreases during cognitive tasks





McKiernan, et al (2003), Journ. of Cog. Neurosci. 15 (3), 394-408

Default Network

(295 M-AM) Asymmetry Patterns in the Resting Brain: An fMRI Analysis Study of the Default Mode Network
Lijun Bai , Jie Tian , Xiaohong Pan , Wei Qin , et al.

(61 W-AM) A self-focused judgment task reverses anterior medial frontal cortex deactivation to cognitive tasks
Ashley Chen , Robert Welsh , Israel Liberzon , Stephan Taylor

(47 TH-AM) Effects of normal Aging on Resting State Networks
Jessica S Damoiseaux , Christian F Beckmann , Stephen M Smith , Ernesto J Sanz Arigita , et al.

(49 TH-AM) Preservation of default mode functioning in healthy aging adults.
Christina Hugenschmidt , Ann Peiffer , Ramon Casanova , Joseph Maldjian , et al.

(1 W-AM) Partial Overlap of Stimulus-Driven Attention, Theory of Mind, Visuospatial Reasoning, and Default Networks as Determined by fMRI
Christopher Asplund , René Marois

(295 M-AM) Asymmetry Patterns in the Resting Brain: An fMRI Analysis Study of the Default Mode Network
Lijun Bai , Jie Tian , Xiaohong Pan , Wei Qin , et al.

(298 M-PM) Dissociating ventromedial prefrontal and posterior cingulate components of the default mode network
Lucina Q. Uddin , A.M. Clare Kelly , F. Xavier Castellanos , Michael P. Milham

(317 T-AM) Multi-center and multi-method to confirm the default mode of brain network by resting-state fMRI
Xiangyu Long , Xinian Zuo , Vesa Kiviniemi , Yihong Yang , et al.

(34 TH-PM) Modulation of default mode network by training of abacus mental calculation in children
Feiyan Chen , Hongjian He , Lixia Tian , Zhikang Wang , et al.

(36 TH-PM) Intrinsic Default-Mode and Executive Control Networks in Children: Relation to Individual Differences in Working Memory Capacity
Nirav Kamdar , Michael Greicius , Catherine Chang , Christian Beckmann , et al.

(178 TH-PM) Auditory adventures in wonderland: selective antagonism between 'intrinsic' / 'default mode' and language regions during story perception
Yuval Nir , Uri Hasson , Rafael Malach , David Heeger

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9:15-10:00 *What Should be Known on MRI Physics for fMRI and DTI Studies*:
Larry Wald, Massachusetts General Hospital, Harvard University, Charlestown, MA, USA

10:00-10:45 *Interpreting the BOLD Signal*
Rick Hoge, Massachusetts General Hospital, Harvard University, Charlestown, MA, USA

10:45-11:00 Break

11:00-11:45 *GLM, Within and Between Subjects Inference*
Alexis Roche, SHFJ/CEA, Orsay, France

11:45-12:30 *Bayesian Inference*
William Penny, Institute of Neurology, University College London, London, UK

12:30-13:30 Lunch

13:30-14:00 *Multivariate Techniques*
Christian Beckman, Oxford University, Oxford, United Kingdom

14:00-14:30 *Classifier Techniques*
John-Dylan Haynes, Max Planck Institute, Leipzig, Germany

14:30-14:45 Break

14:45-15:15 *Functional Connectivity Analyses and Fiber Tracking*
Ed Bullmore, University of Cambridge, Cambridge, UK

15:15-15:45 *DCM and Related*
Uta Noppeney, Institute of Neurology, University College London, London, UK

15:45-16:00 Break

16:00-16:45 *Computational Neuroanatomy*
L. Collins, Bruce Fischl

16:45-17:30 *fMRI and EEG*:
Helmut Laufs, Institute of Neurology, University College London, London, UK