Applications: What can I do with MEG?

Outline

- Resting State
- Dynamic Connectivity
- Pharmacologic Imaging
- Visual Processing
- Face Processing
- Machine Learning
- Neuromodulation

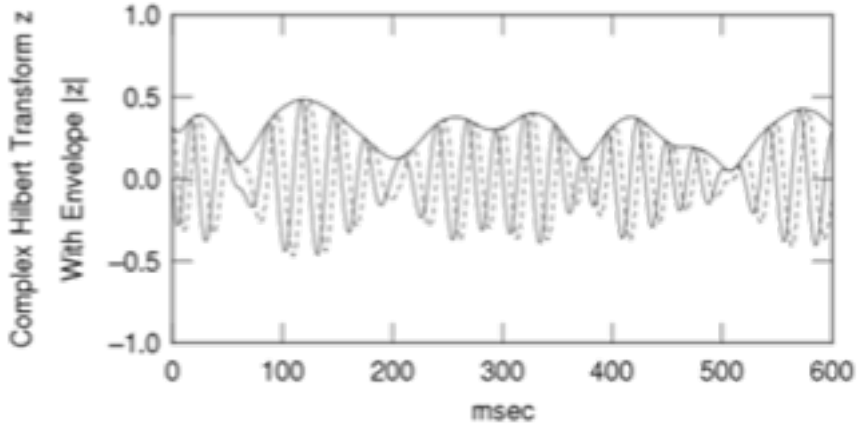
Resting State

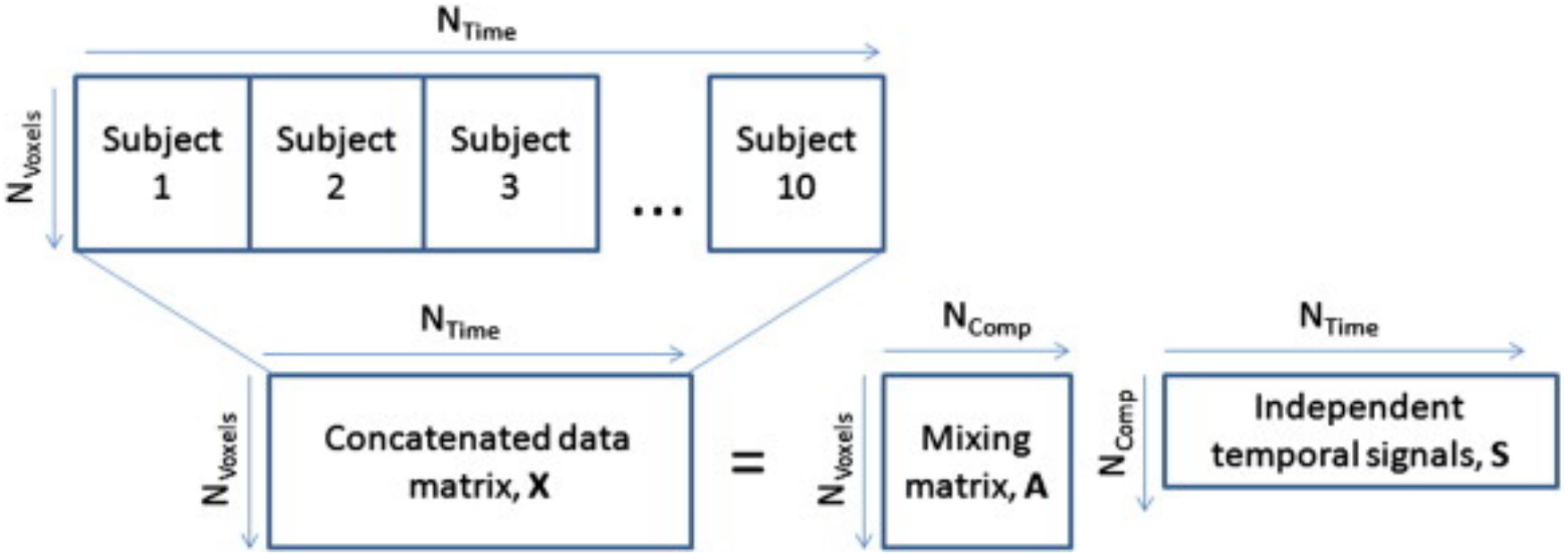
Investigating the electrophysiological basis of resting state networks using magnetoencephalography

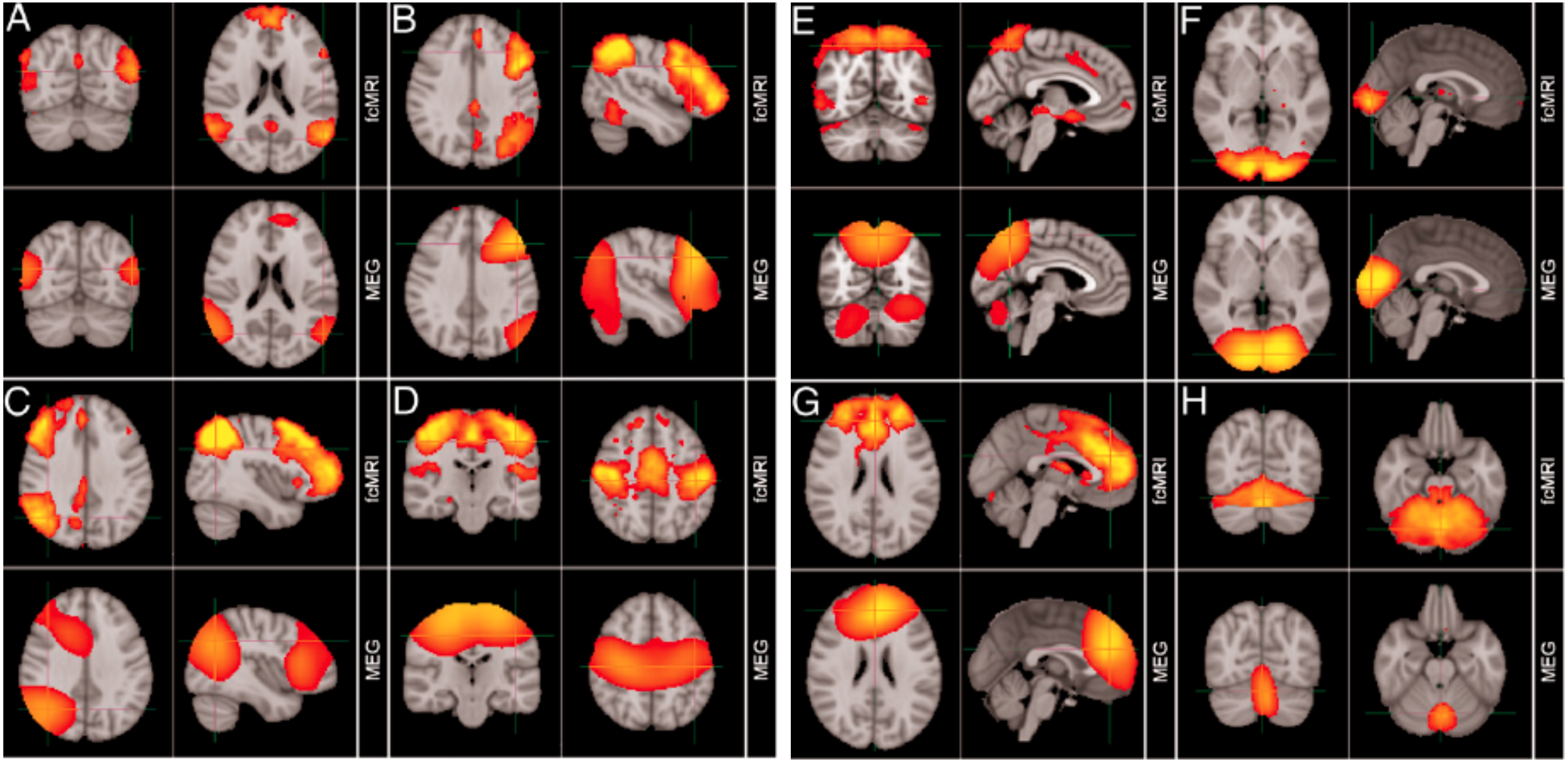
Matthew J. Brookes[a,1], Mark Woolrich[b], Henry Luckhoo[b], Darren Price[a], Joanne R. Hale[a], Mary C. Stephenson[a], Gareth R. Barnes[c], Stephen M. Smith[d], and Peter G. Morris[a]

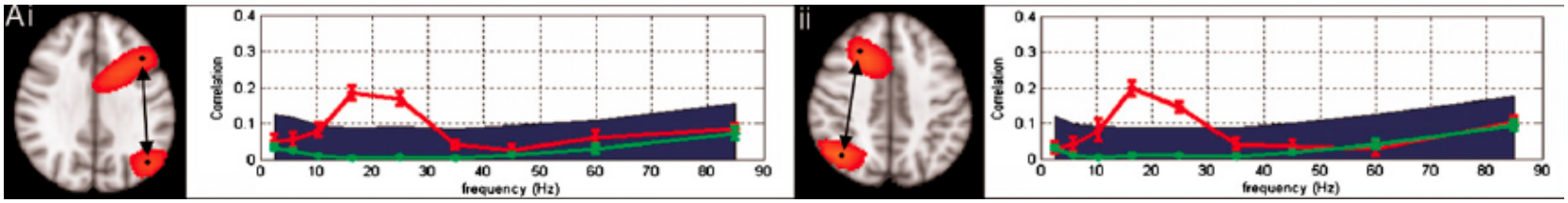
[a]Sir Peter Mansfield Magnetic Resonance Centre, School of Physics and Astronomy, University of Nottingham, University Park, Nottingham NG72RD, United Kingdom; [b]Oxford Centre for Human Brain Activity, University of Oxford, Warneford Hospital, Oxford OX37JX, United Kingdom; [c]Wellcome Trust Centre for Neuroimaging, University College London, London WC1N3BG, United Kingdom; and [d]Oxford Centre for Functional MRI of the Brain, University of Oxford, John Radcliffe Hospital, Oxford OX39DU, United Kingdom

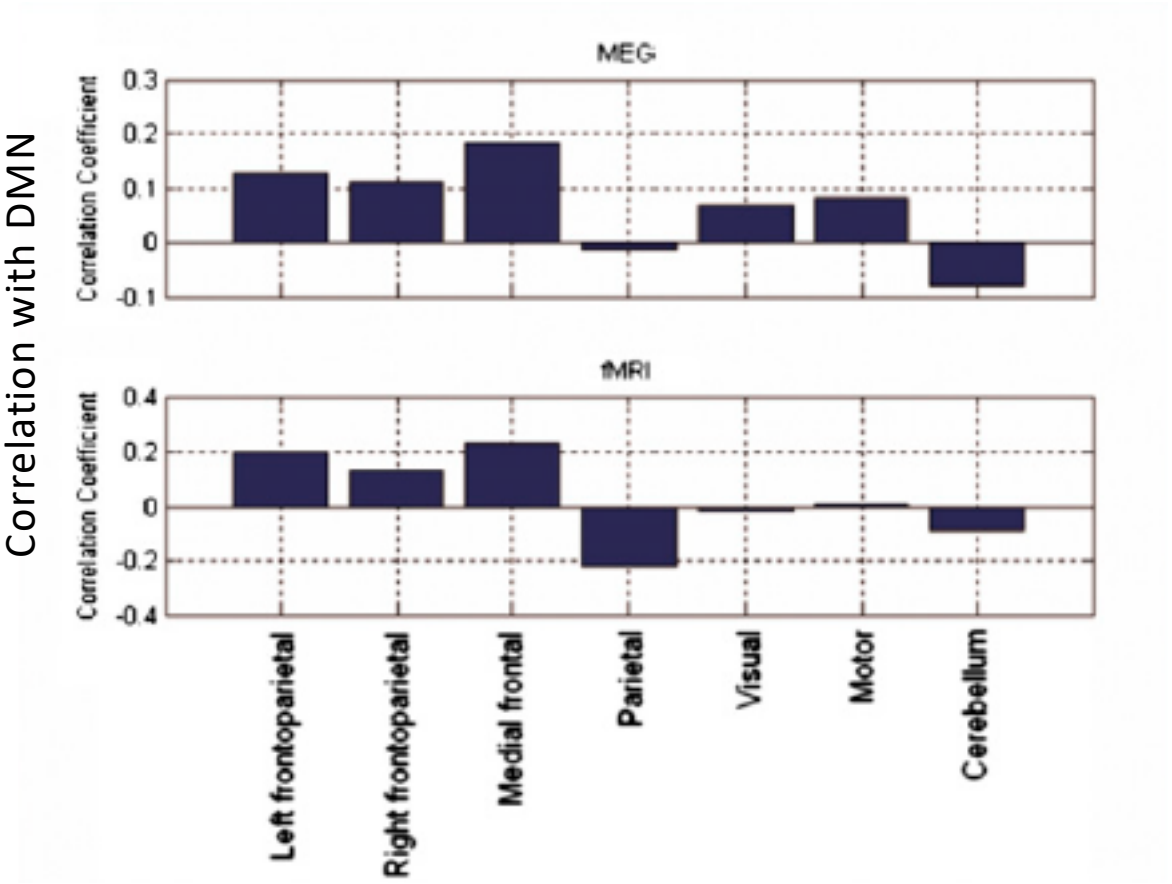
PNAS | October 4, 2011 | vol. 108 | no. 40 | 16783–16788


Complex Hilbert Transform z
With Envelope |z|
1.0
0.5
0.0
−0.5
−1.0
0
100
200
300
400
500
600
msec


N Time
N Voxels
Subject 1
Subject 2
Subject 3
...
Subject 10
N Time
N Voxels
Concatenated data matrix, X
=
N Comp
N Voxels
Mixing matrix, A
N Time
N Comp
Independent temporal signals, S


A
B
C
D
E
F
G
H
fcMRI
MEG


Ai
Correlation
frequency (Hz)
ii
Correlation
frequency (Hz)

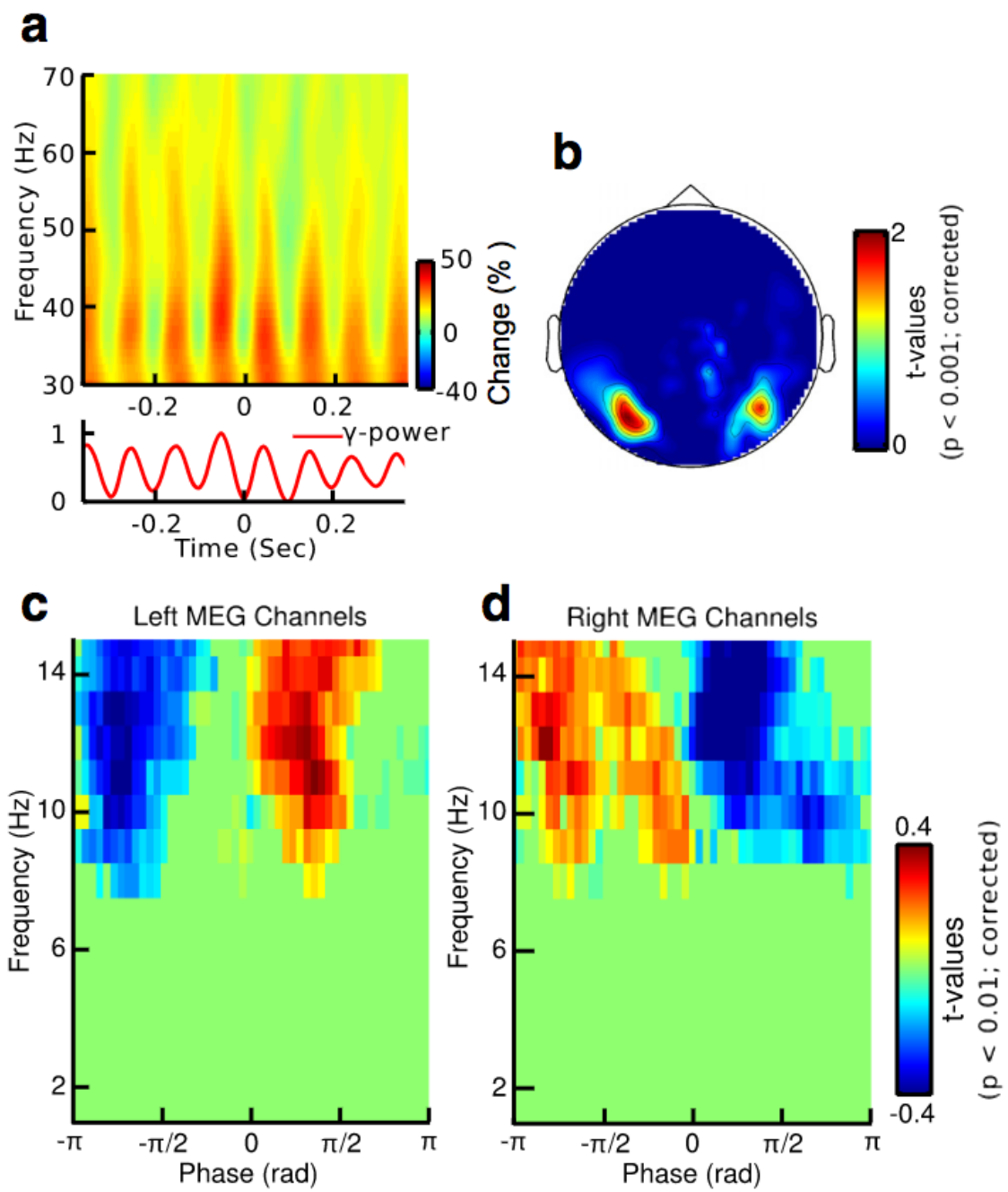

Correlation with DMN
MEG
Correlation Coefficient
fMRI
Correlation Coefficient
Left frontoparietal
Right frontoparietal
Medial frontal
Parietal
Visual
Motor
Cerebellum

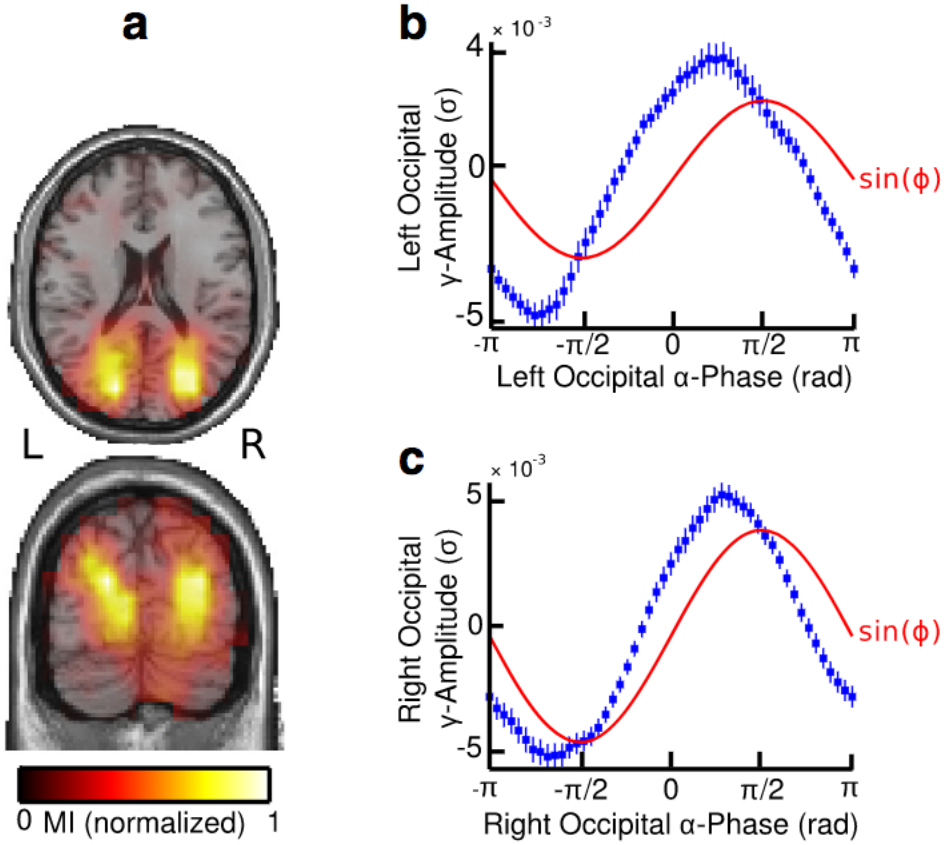
The Phase of Thalamic Alpha Activity Modulates Cortical Gamma-Band Activity: Evidence from Resting-State MEG Recordings

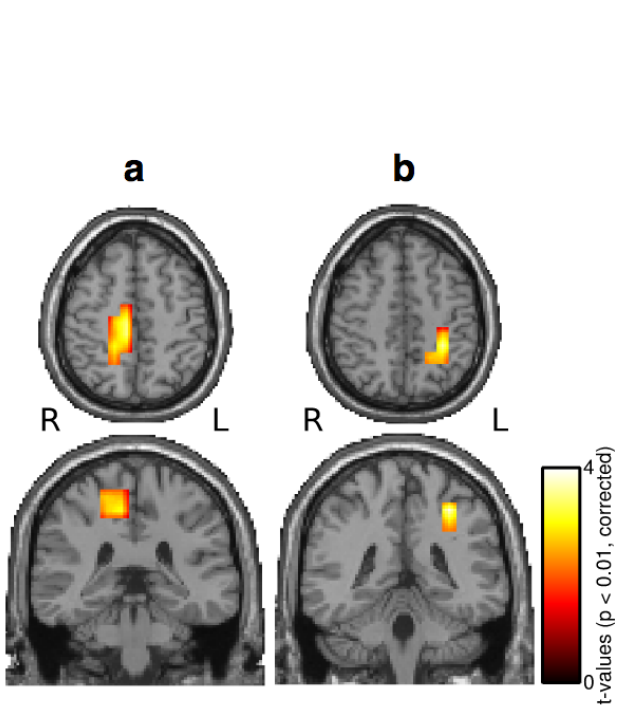
Frédéric Roux,[1,2] **Michael Wibral,**[2] **Wolf Singer,**[3,4,5] **Jaan Aru,**[3,5] **and Peter J. Uhlhaas**[3,4,6]

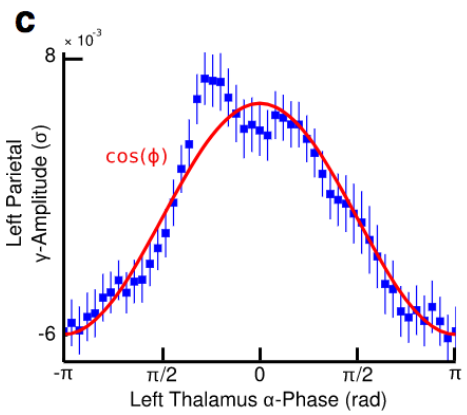
[1]Basque Center on Cognition, Brain, and Language (BCBL), 2009 Donostia/San Sebastian, Spain, [2]MEG Unit, Brain Imaging Center, Goethe University, 60528 Frankfurt am Main, Germany, [3]Max-Planck Institute for Brain Research, Department of Neurophysiology, 60438 Frankfurt am Main, Germany, [4]Ernst Strüngmann Institute, 60528 Frankfurt am Main, Germany, [5]Frankfurt Institute for Advanced Sciences, 60438 Frankfurt am Main, Germany, and [6]Institute of Neuroscience and Psychology, Glasgow University, Glasgow, G12 8QB Scotland

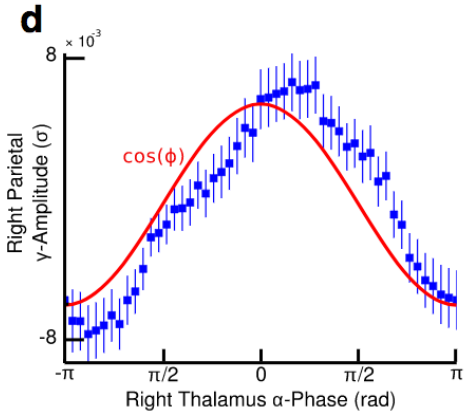
The Journal of Neuroscience, November 6, 2013 • 33(45):17827–17835 • **17827**

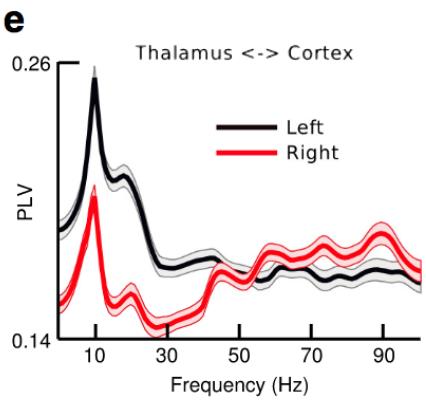

a
70
60
50
40
30
Frequency (Hz)
-0.2
0
0.2
50
0
-40
Change (%)
1
0
γ-power
-0.2
0
0.2
Time (Sec)
b
2
0
t-values
(p < 0.001; corrected)
c
Left MEG Channels
14
10
6
2
Frequency (Hz)
-π
-π/2
0
π/2
π
Phase (rad)
d
Right MEG Channels
14
10
6
2
Frequency (Hz)
-π
-π/2
0
π/2
π
Phase (rad)
0.4
-0.4
t-values
(p < 0.01; corrected)

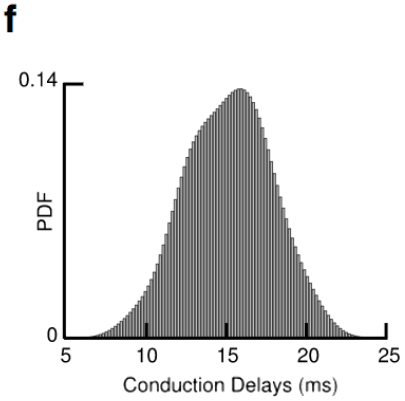

a
L
R
0 MI (normalized) 1
b
× 10-3
4
0
-5
Left Occipital γ-Amplitude (σ)
-π
-π/2
0
π/2
π
Left Occipital α-Phase (rad)
sin(ϕ)
c
× 10-3
5
0
-5
Right Occipital γ-Amplitude (σ)
-π
-π/2
0
π/2
π
Right Occipital α-Phase (rad)
sin(ϕ)

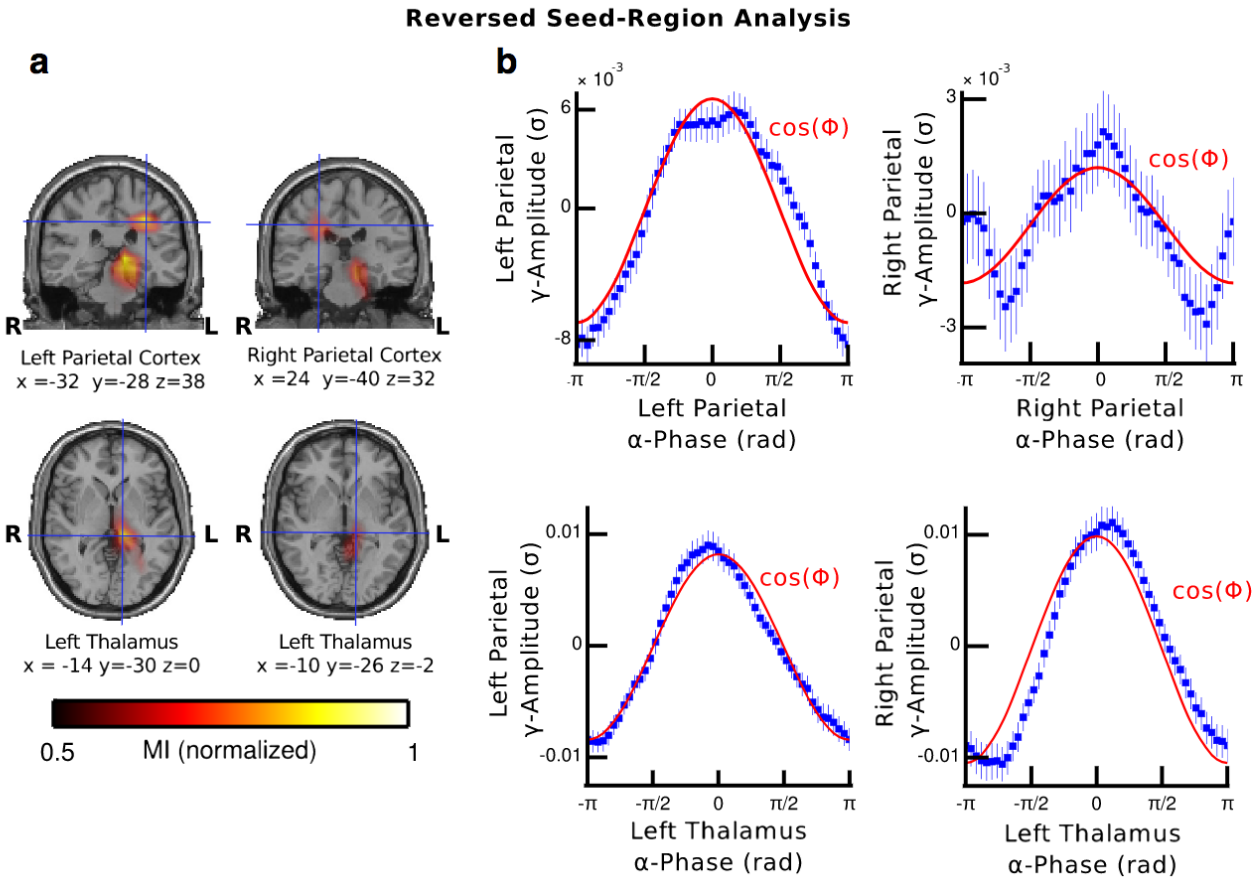

a
b
R
L
R
L
4
0
t-values (p < 0.01, corrected)


c
× 10⁻³
8
-6
Left Parietal
γ-Amplitude (σ)
cos(ϕ)
-π
π/2
0
π/2
π
Left Thalamus α-Phase (rad)


d
× 10⁻³
8
-8
Right Parietal
γ-Amplitude (σ)
cos(ϕ)
-π
π/2
0
π/2
π
Right Thalamus α-Phase (rad)


e
Thalamus <-> Cortex
0.26
0.14
PLV
Left
Right
10
30
50
70
90
Frequency (Hz)


f
0.14
0
PDF
5
10
15
20
25
Conduction Delays (ms)

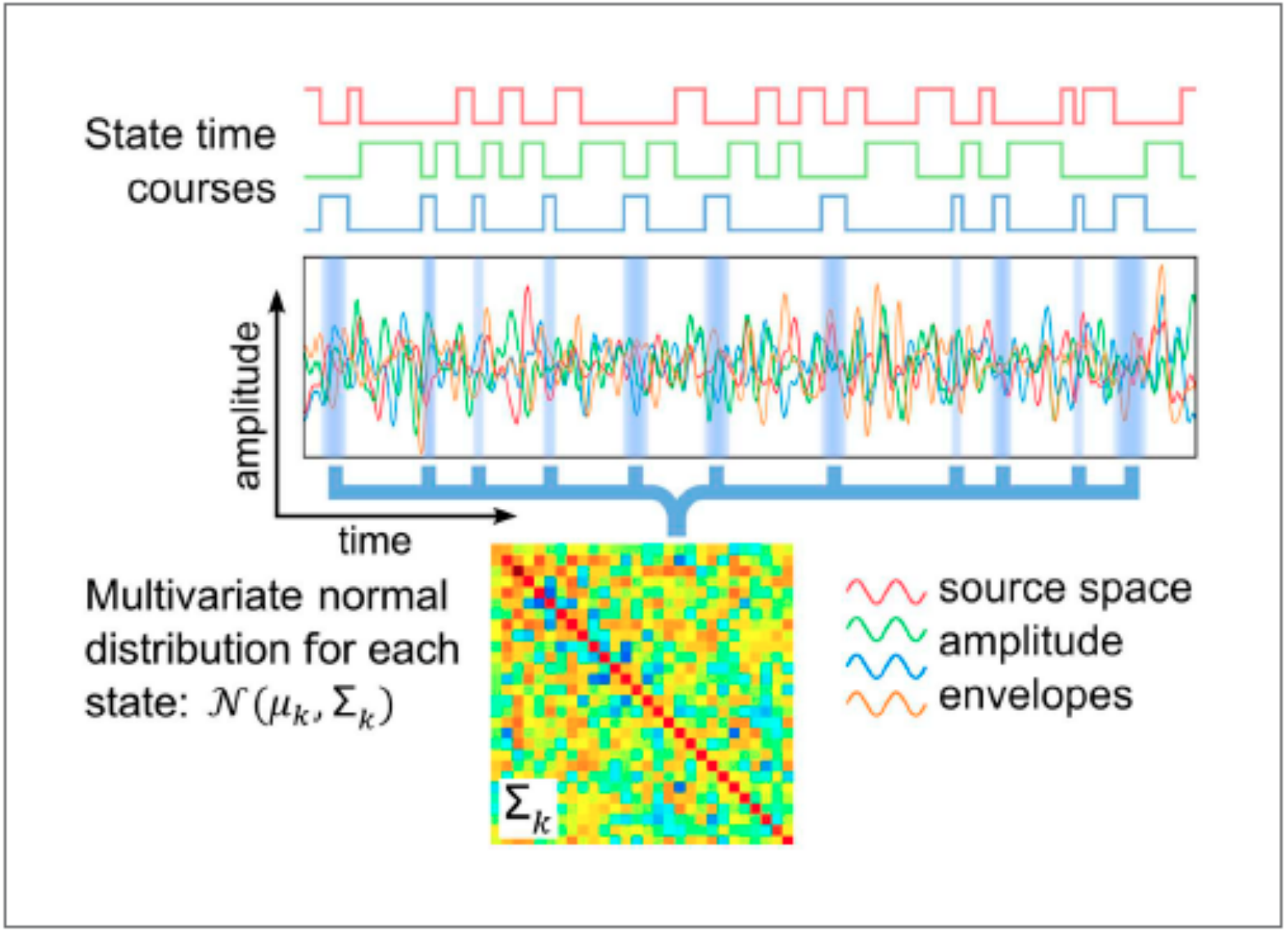

Reversed Seed-Region Analysis
a
b
R
L
Left Parietal Cortex
x =-32 y=-28 z=38
Right Parietal Cortex
x =24 y=-40 z=32
Left Thalamus
x = -14 y=-30 z=0
Left Thalamus
x =-10 y=-26 z=-2
0.5
MI (normalized)
1
× 10-3
Left Parietal γ-Amplitude (σ)
Right Parietal γ-Amplitude (σ)
cos(Φ)
-π
-π/2
0
π/2
π
Left Parietal α-Phase (rad)
Right Parietal α-Phase (rad)
Left Thalamus α-Phase (rad)

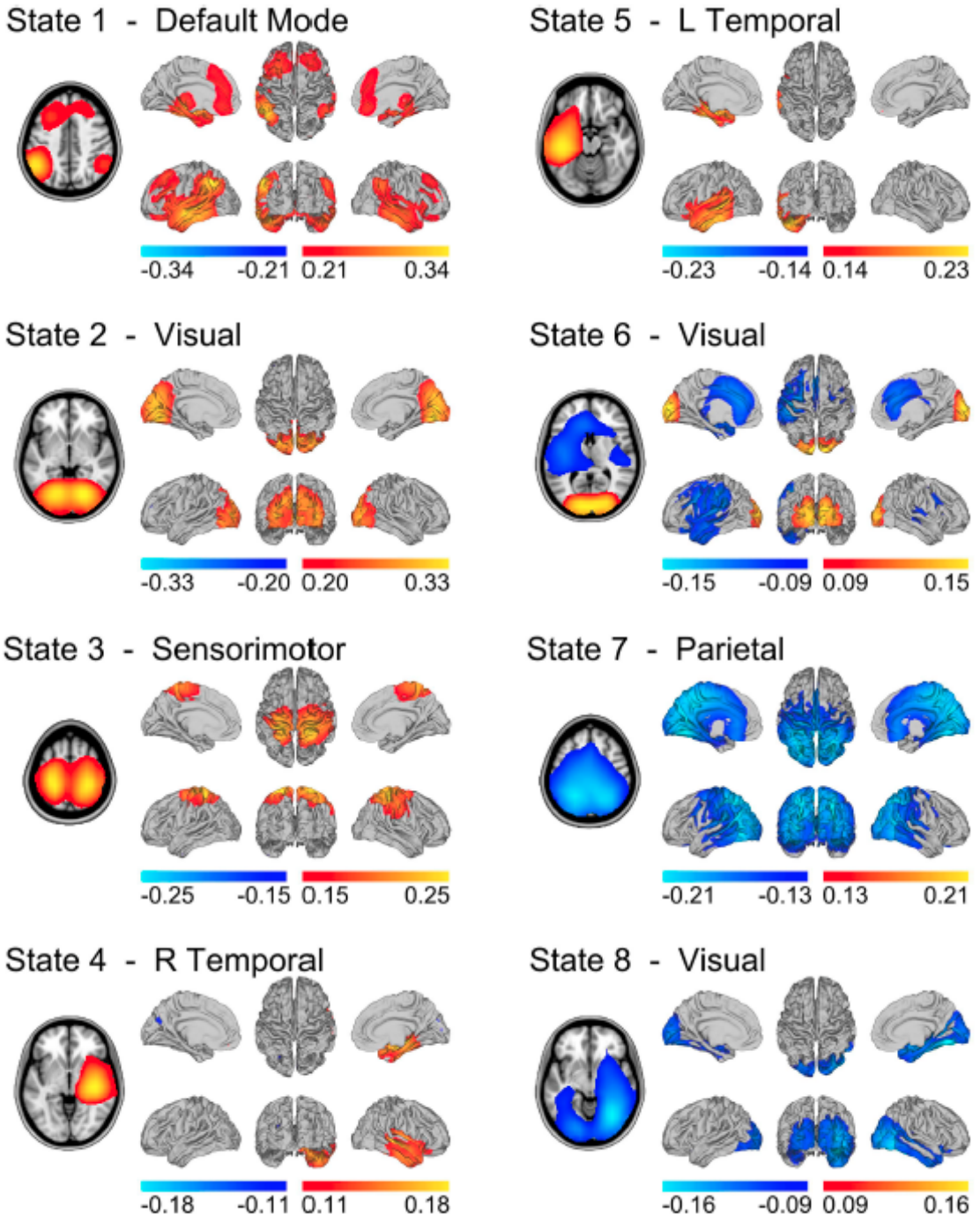
Dynamic Connectivity

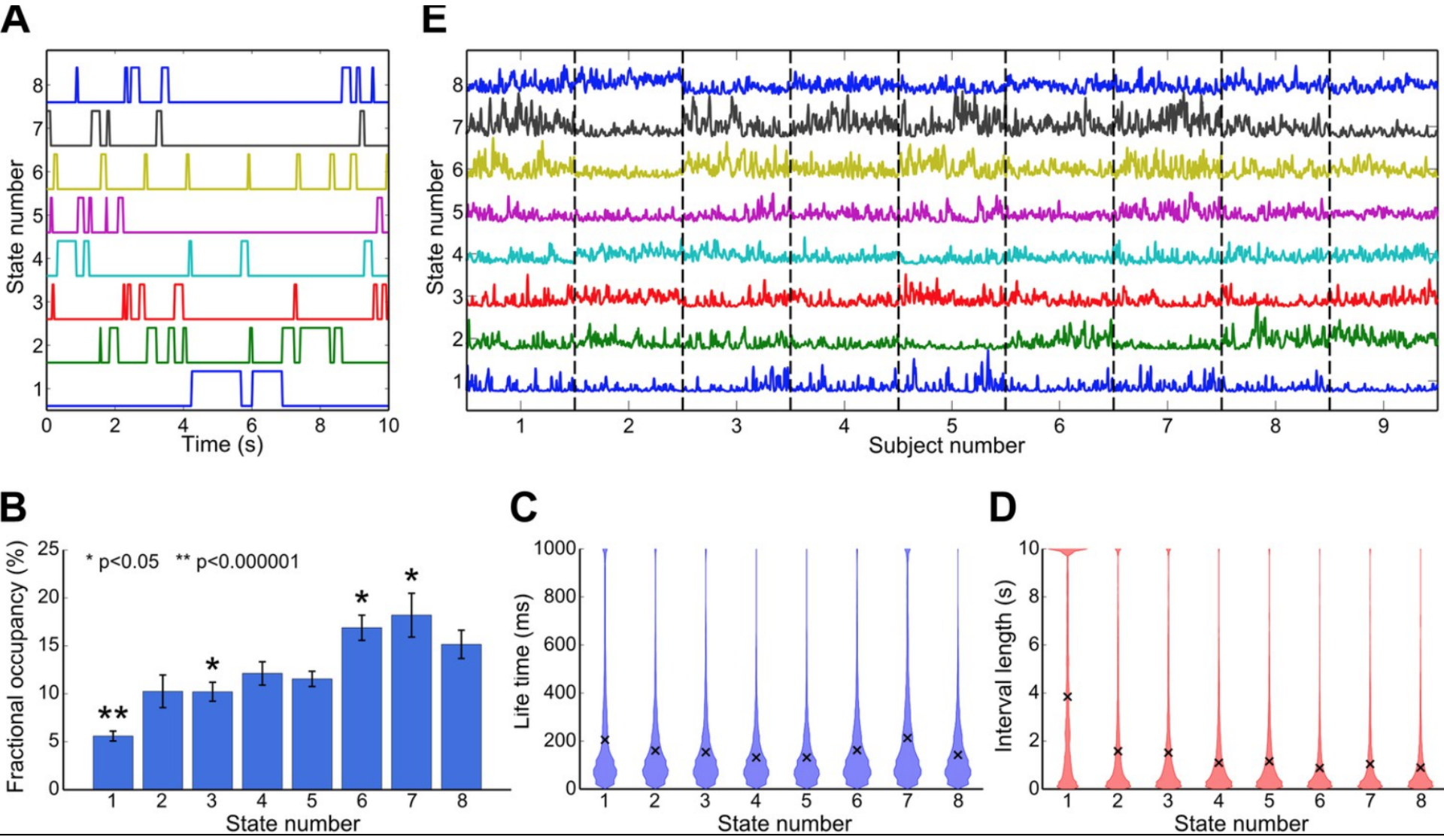
Fast transient networks in spontaneous human brain activity

Adam P Baker[1,8]*, Matthew J Brookes[2], Iead A Rezek[3†], Stephen M Smith[4], Timothy Behrens[5,6], Penny J Probert Smith[7], Mark Woolrich[4,1]*

Baker *et al.* eLife 2014;3:e01867. DOI: 10.7554/eLife.01867


State time courses
amplitude
time
Multivariate normal distribution for each state: $\mathcal{N}(\mu_k, \Sigma_k)$
Σ_k
source space
amplitude
envelopes


State 1 - Default Mode
-0.34 -0.21 0.21 0.34
State 5 - L Temporal
-0.23 -0.14 0.14 0.23
State 2 - Visual
-0.33 -0.20 0.20 0.33
State 6 - Visual
-0.15 -0.09 0.09 0.15
State 3 - Sensorimotor
-0.25 -0.15 0.15 0.25
State 7 - Parietal
-0.21 -0.13 0.13 0.21
State 4 - R Temporal
-0.18 -0.11 0.11 0.18
State 8 - Visual
-0.16 -0.09 0.09 0.16

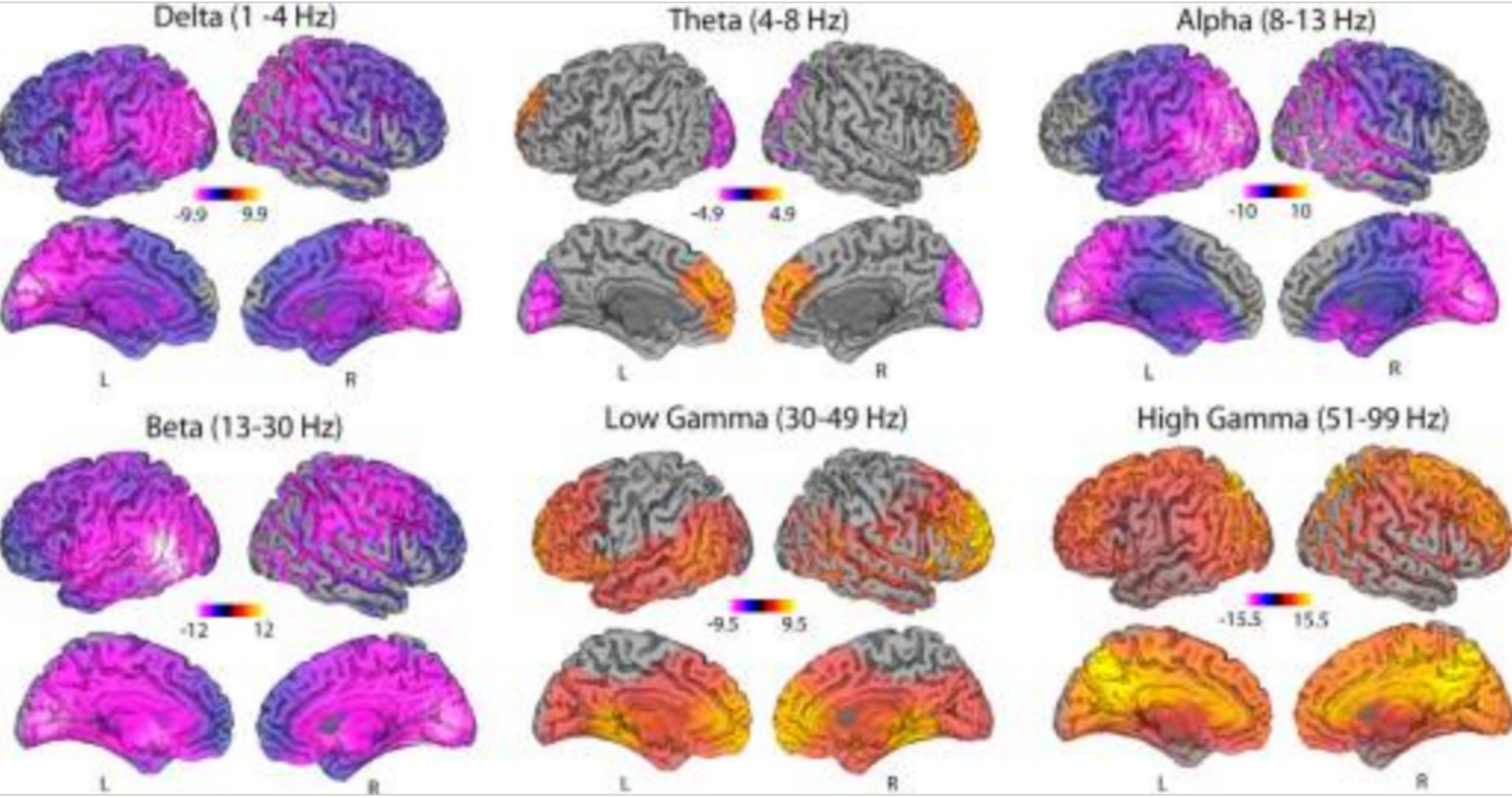

A
State number
Time (s)
E
State number
Subject number
B
Fractional occupancy (%)
* p<0.05 ** p<0.000001
State number
C
Life time (ms)
State number
D
Interval length (s)
State number

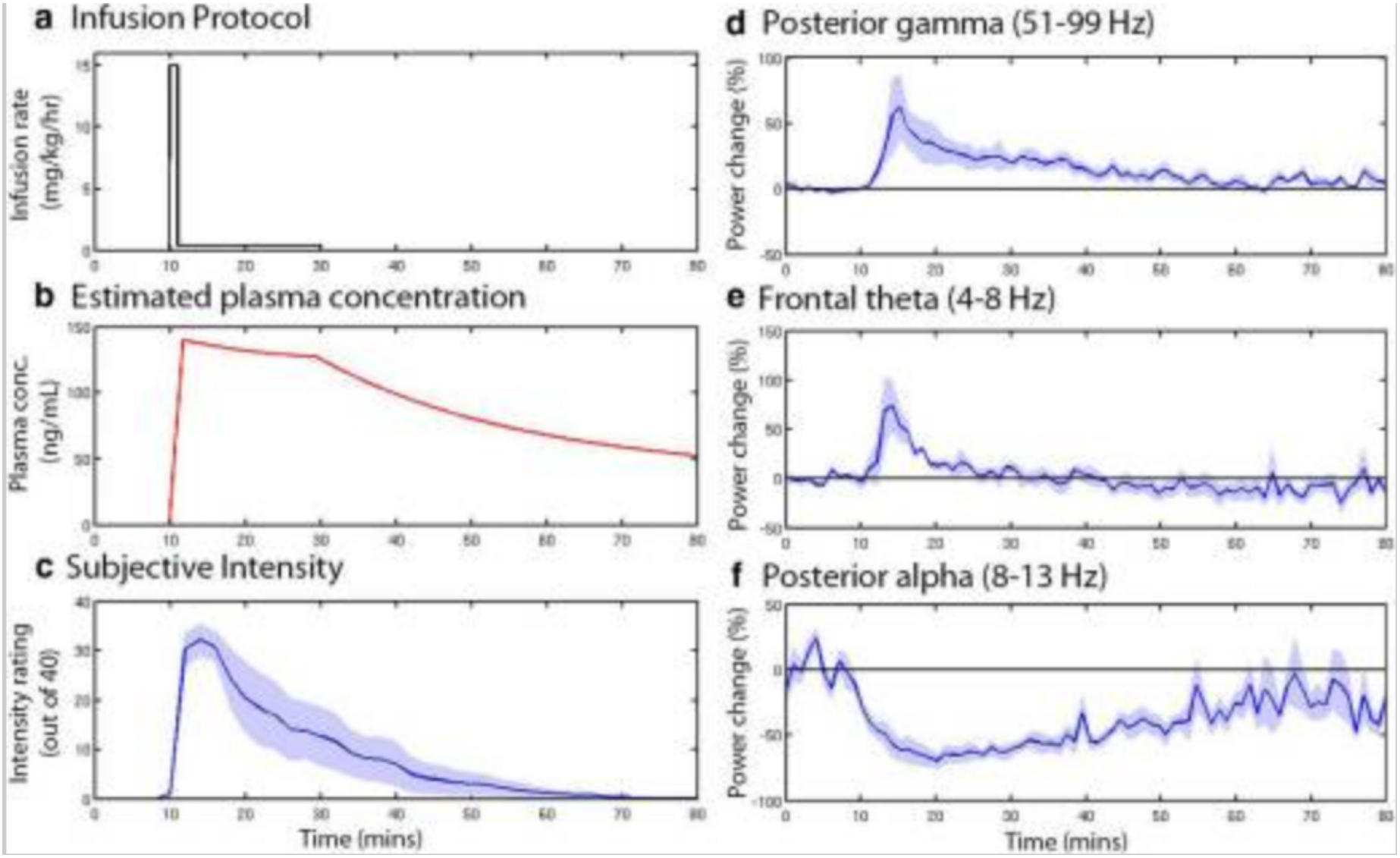
Pharmacologic Imaging

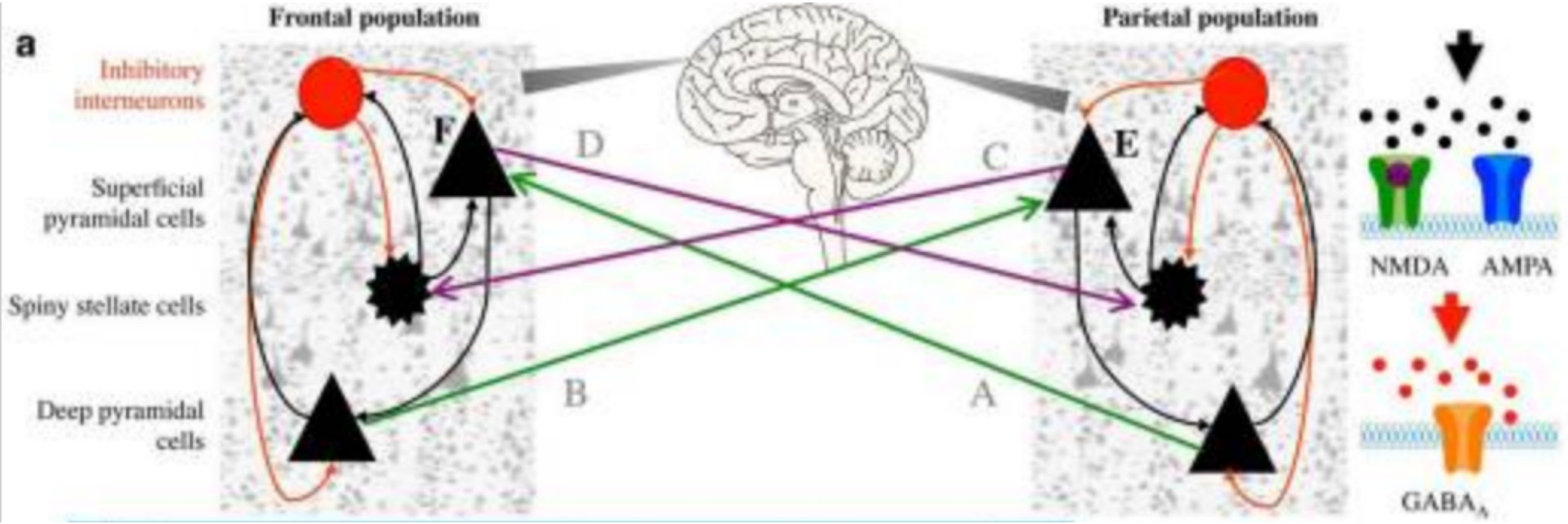
Evidence that Subanesthetic Doses of Ketamine Cause Sustained Disruptions of NMDA and AMPA-Mediated Frontoparietal Connectivity in Humans

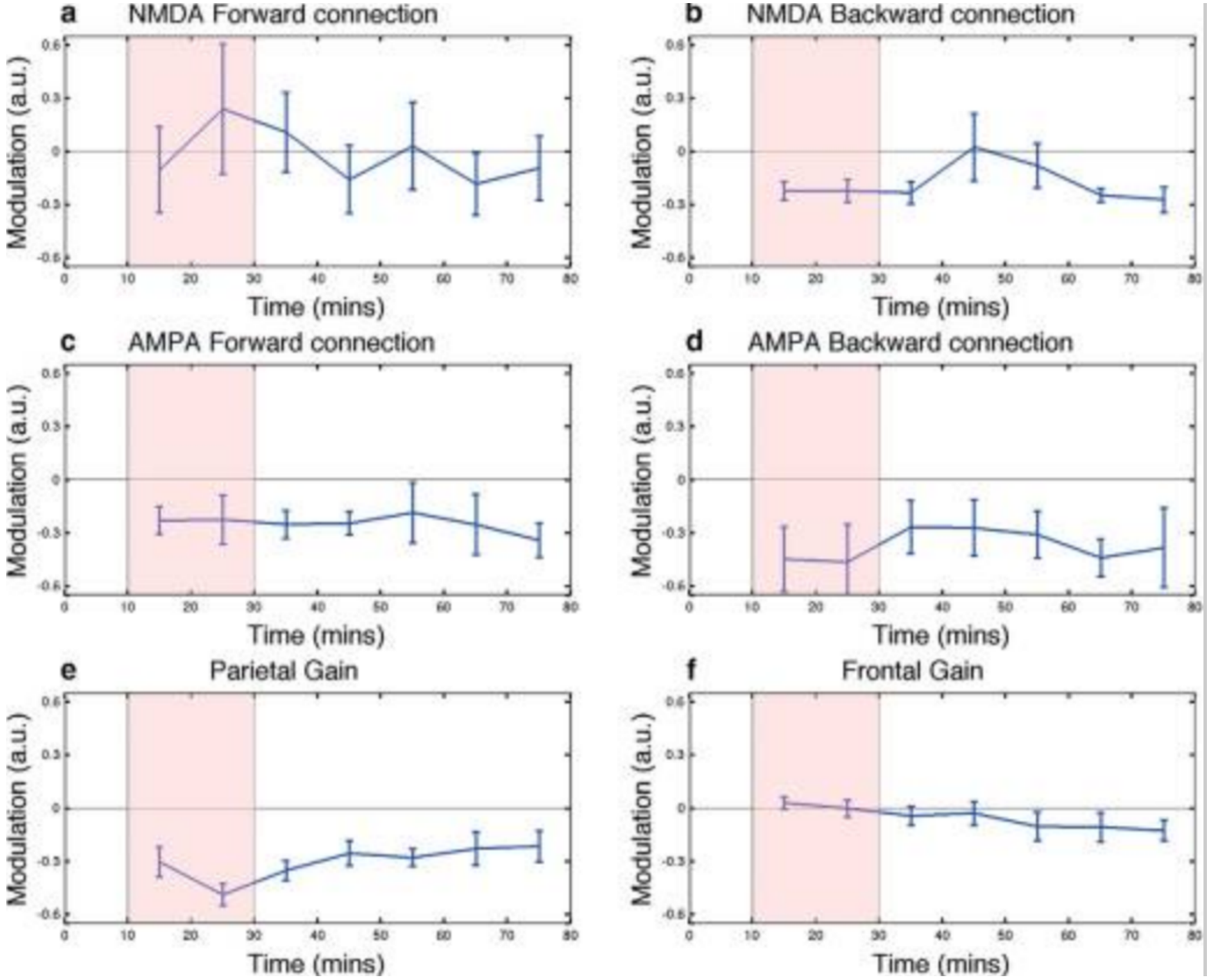
Suresh D. Muthukumaraswamy,[1] Alexander D. Shaw,[2] Laura E. Jackson,[3] Judith Hall,[3] Rosalyn Moran,[4] and Neeraj Saxena[3,5]

[1]Schools of Pharmacy and Psychology, The University of Auckland, Auckland 1142, New Zealand, [2]Cardiff University Brain Research Imaging Centre, Cardiff University, Cardiff CF103AT, United Kingdom, [3]Department of Anaesthetics, Intensive Care and Pain Medicine, Cwm Taf University Health Board, Llantrisant CF72 8XR, United Kingdom, [4]Virginia Tech Carilion Research Institute, Bradley Department of Electrical and Computer Engineering, Roanoke, Virginia 24016, and [5]Department of Anaesthetics, Intensive Care and Pain Medicine, School of Medicine, Cardiff University, Cardiff CF144XW, United Kingdom


Delta (1 -4 Hz)
-9.9
9.9
L
R
Theta (4-8 Hz)
-4.9
4.9
L
R
Alpha (8-13 Hz)
-10
10
L
R
Beta (13-30 Hz)
-12
12
L
R
Low Gamma (30-49 Hz)
-9.5
9.5
L
R
High Gamma (51-99 Hz)
-15.5
15.5
L
R


a Infusion Protocol
Infusion rate (mg/kg/hr)
b Estimated plasma concentration
Plasma conc. (ng/mL)
c Subjective Intensity
Intensity rating (out of 40)
Time (mins)
d Posterior gamma (51-99 Hz)
Power change (%)
e Frontal theta (4-8 Hz)
Power change (%)
f Posterior alpha (8-13 Hz)
Power change (%)
Time (mins)


a
Frontal population
Parietal population
Inhibitory interneurons
Superficial pyramidal cells
Spiny stellate cells
Deep pyramidal cells
F
E
D
C
B
A
NMDA
AMPA
GABA$_A$


a
NMDA Forward connection
b
NMDA Backward connection
c
AMPA Forward connection
d
AMPA Backward connection
e
Parietal Gain
f
Frontal Gain
Modulation (a.u.)
Time (mins)

Vision and Perception

ELSEVIER

NeuroImage

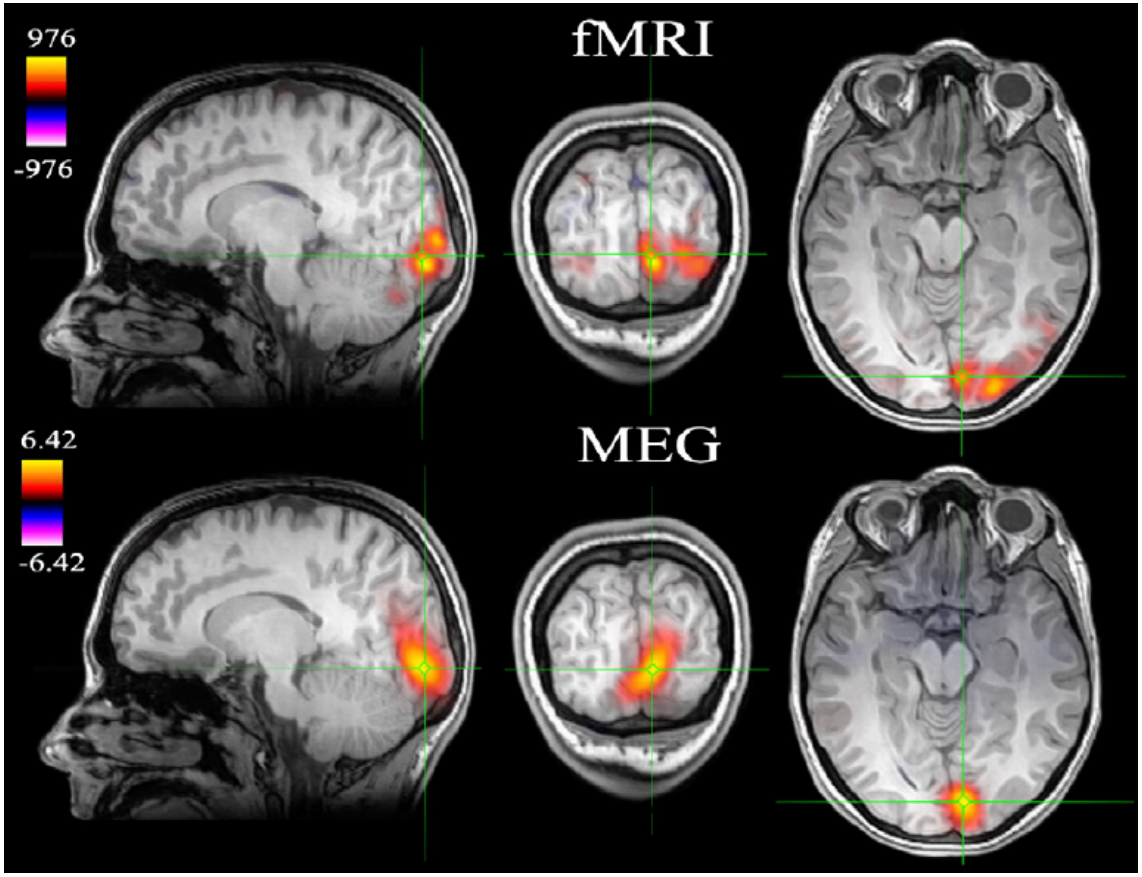
www.elsevier.com/locate/ynimg
NeuroImage 40 (2008) 1552–1560

Spatiotemporal frequency tuning of BOLD and gamma band MEG responses compared in primary visual cortex

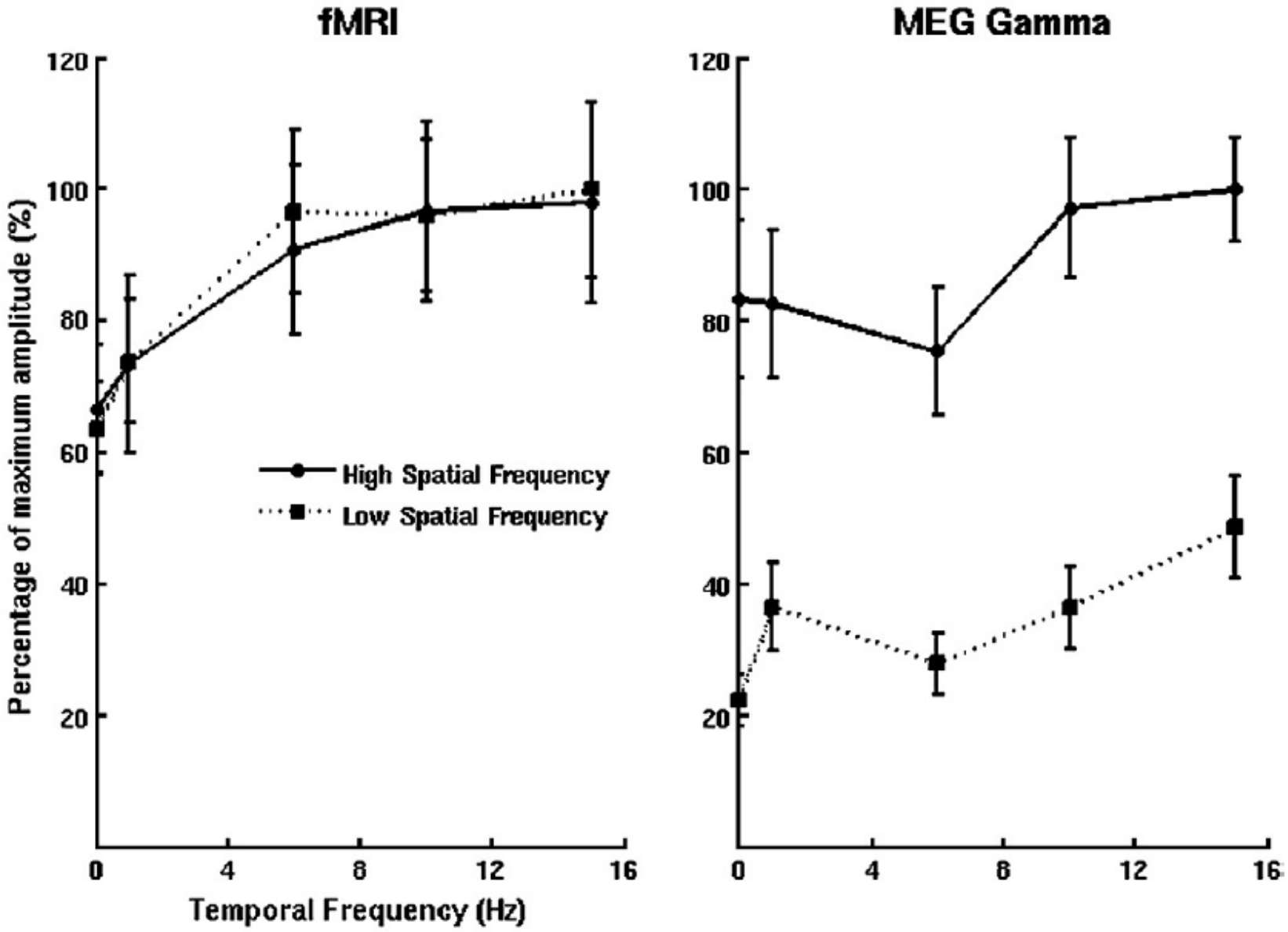
Suresh D. Muthukumaraswamy* and Krish D. Singh

CUBRIC (Cardiff University Brain Research Imaging Centre), School of Psychology, Cardiff University, Park Place, Cardiff CF103AT, UK

Reversing square wave gratings at two spatial frequencies (0.5 and 3 cycles per degree) and 5 temporal reversal frequencies (0, 1, 6, 10, 15 Hz).



Example data from the high spatial frequency stimulus reversing at 6Hz; MEG image is of gamma (40-60Hz)


fMRI
MEG Gamma
Percentage of maximum amplitude (%)
120
100
80
60
40
20
0
4
8
12
16
Temporal Frequency (Hz)
High Spatial Frequency
Low Spatial Frequency

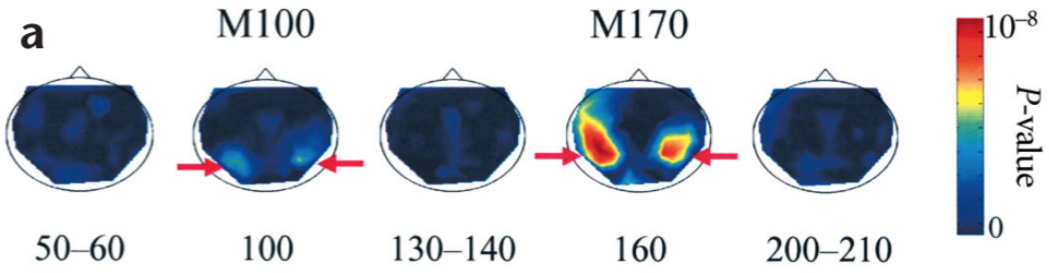
Face Perception

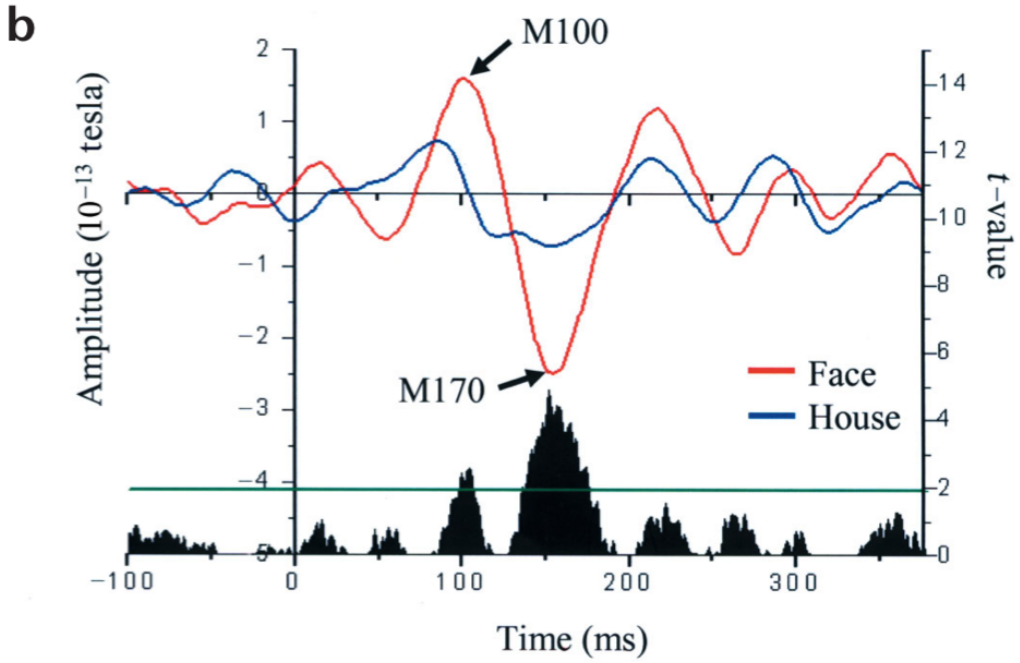
Stages of processing in face perception: an MEG study

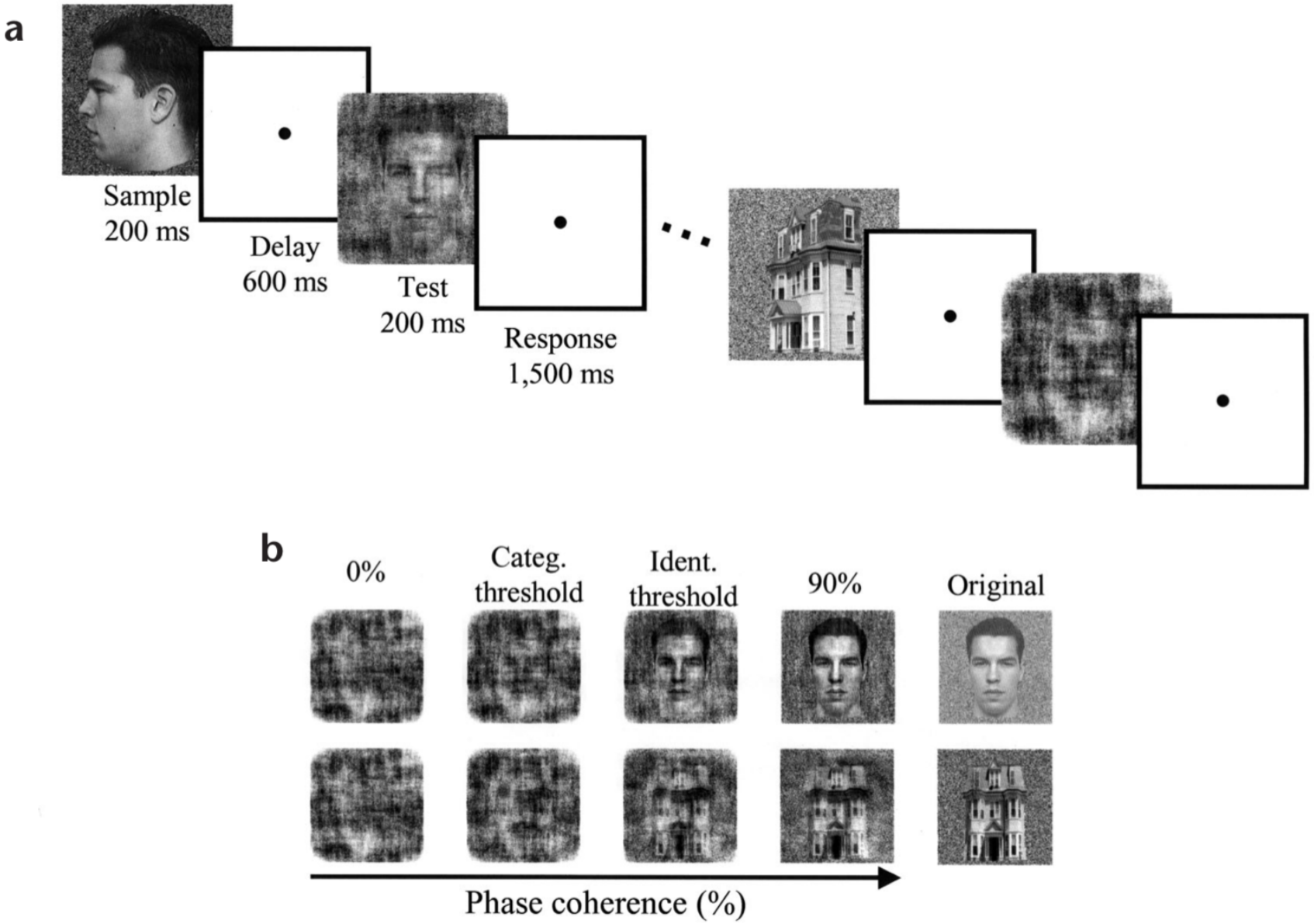
Jia Liu[1], Alison Harris[1] and Nancy Kanwisher[1,2,3]

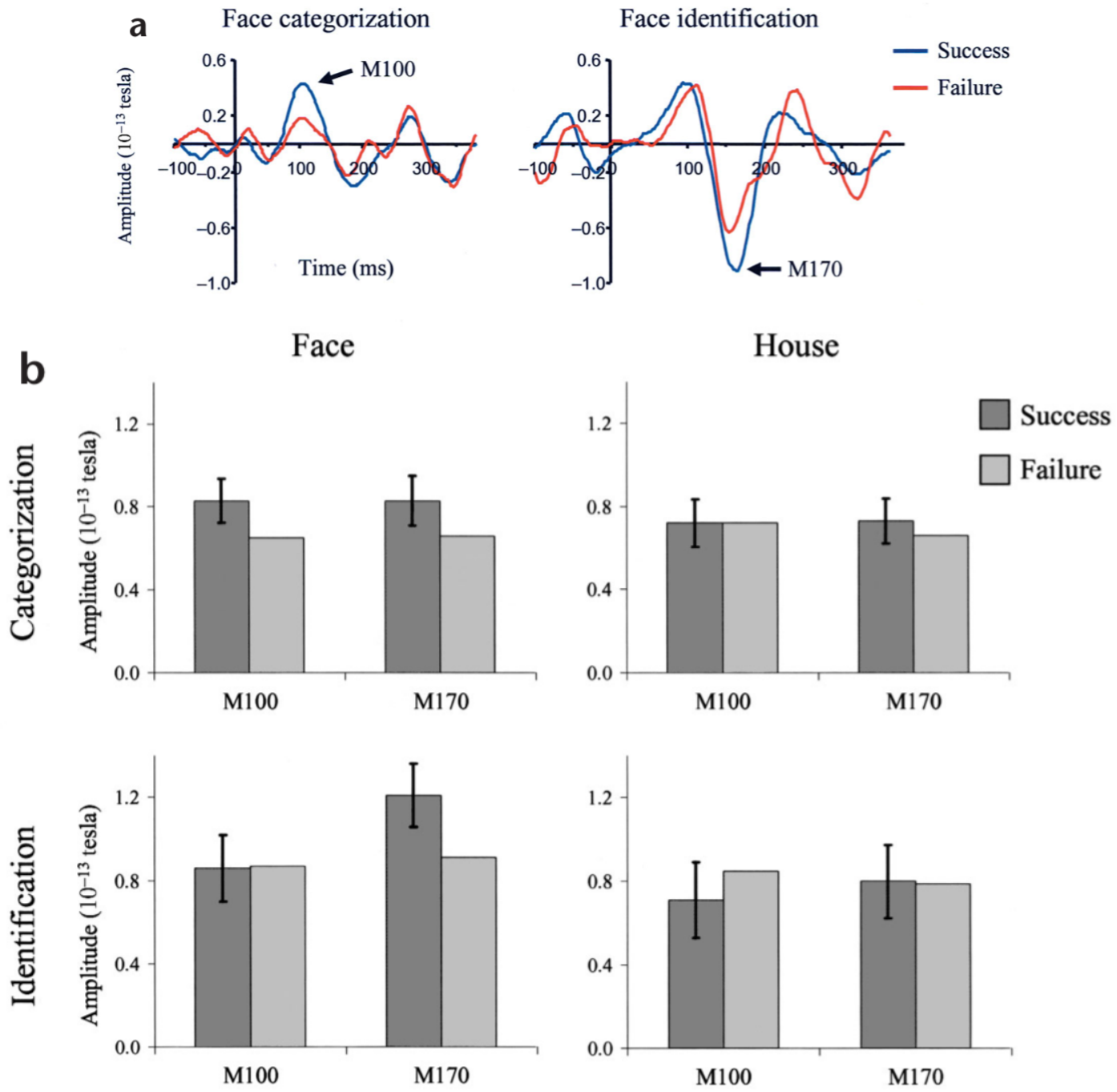
nature *neuroscience* • volume 5 no 9 • september 2002

Passive viewing of faces and houses






a
Sample
200 ms
Delay
600 ms
Test
200 ms
Response
1,500 ms
b
0%
Categ.
threshold
Ident.
threshold
90%
Original
Phase coherence (%)


a
Face categorization
Face identification
Success
Failure
M100
M170
Amplitude (10^{-13} tesla)
Time (ms)
b
Face
House
Categorization
Identification
Success
Failure
M100
M170

Machine Learning

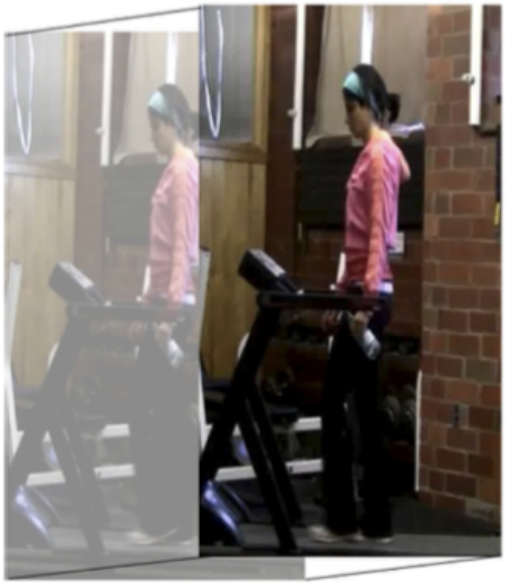
A fast, invariant representation for human action in the visual system

Leyla Isik,* Andrea Tacchetti,* and Tomaso Poggio
Center for Brains, Minds, and Machines, Massachusetts Institute of Technology, Cambridge, Massachusetts

Submitted 30 August 2017; accepted in final form 1 November 2017

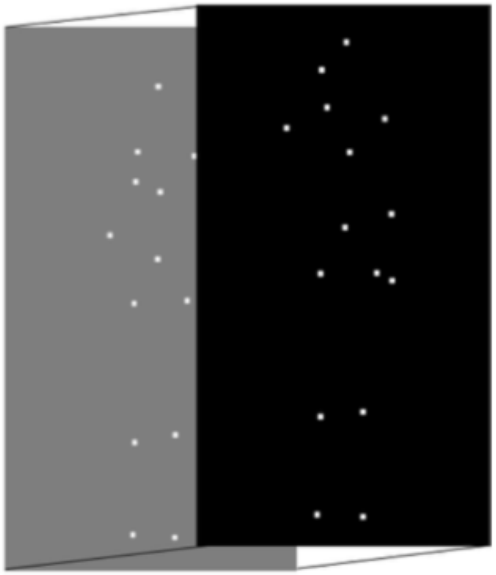
J Neurophysiol 119: 631–640, 2018.

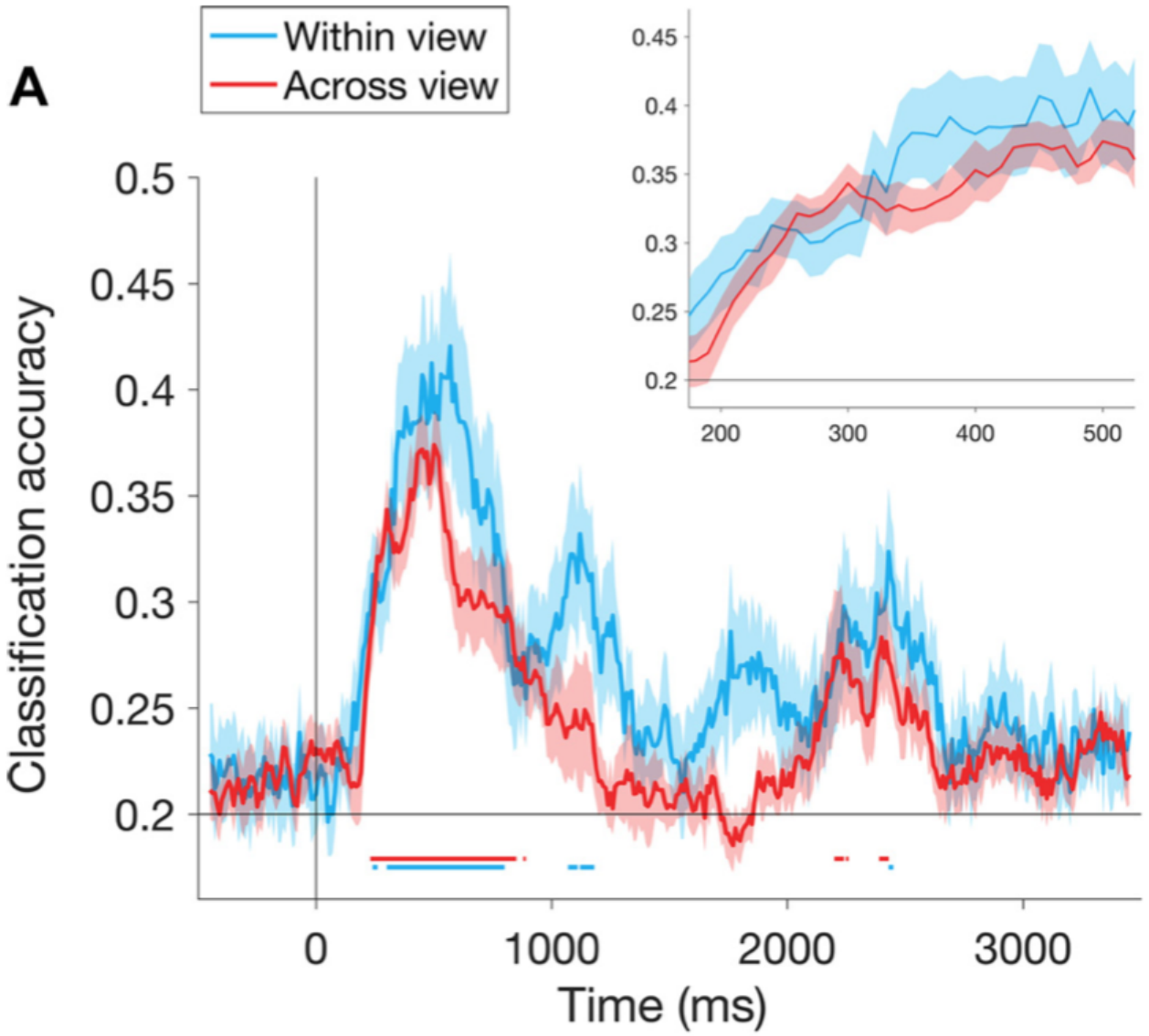
A Video



B Frame (form)

C Point light (motion)



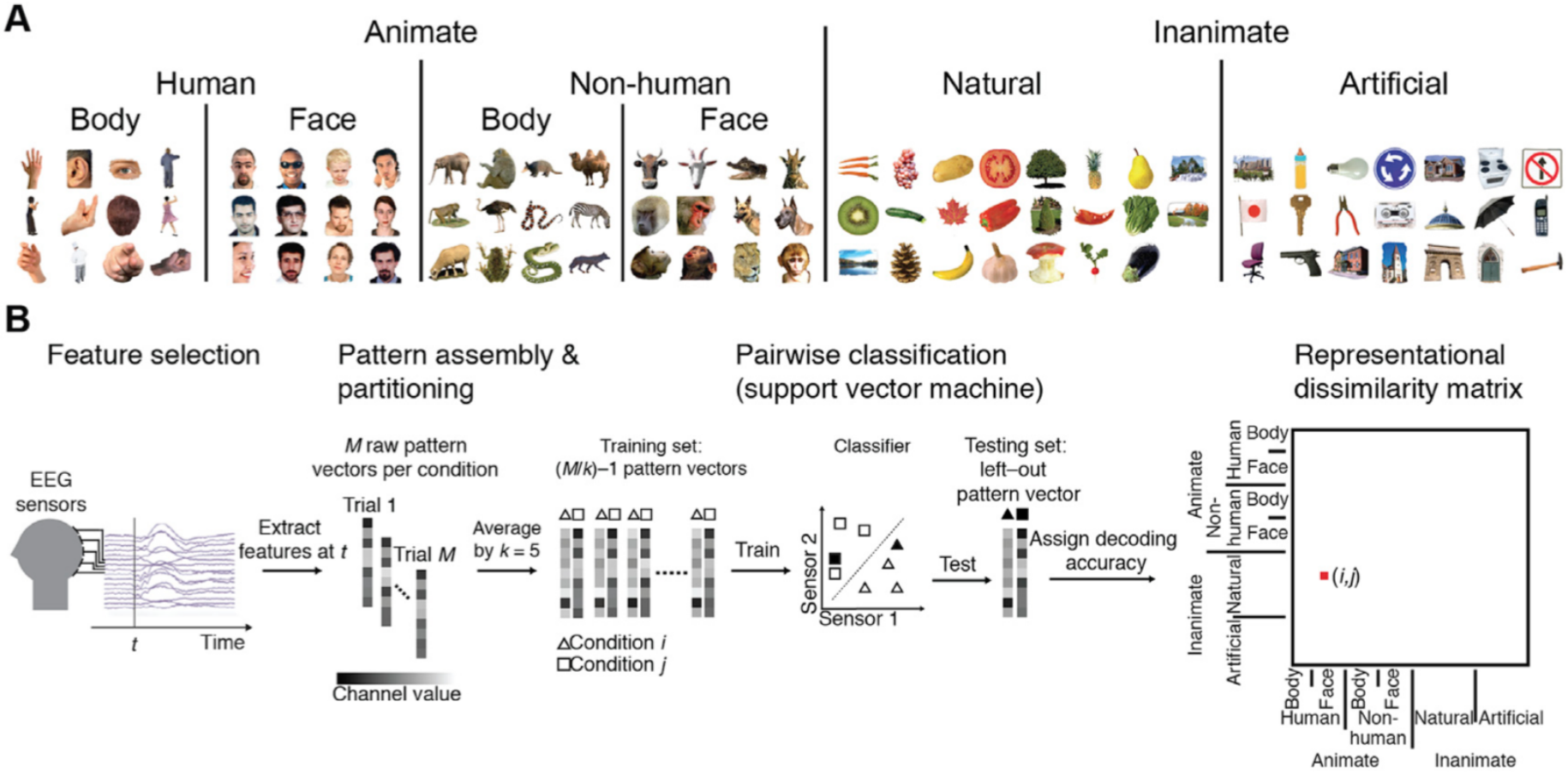

A
Within view
Across view
Classification accuracy
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0
1000
2000
3000
Time (ms)
0.45
0.4
0.35
0.3
0.25
0.2
200
300
400
500

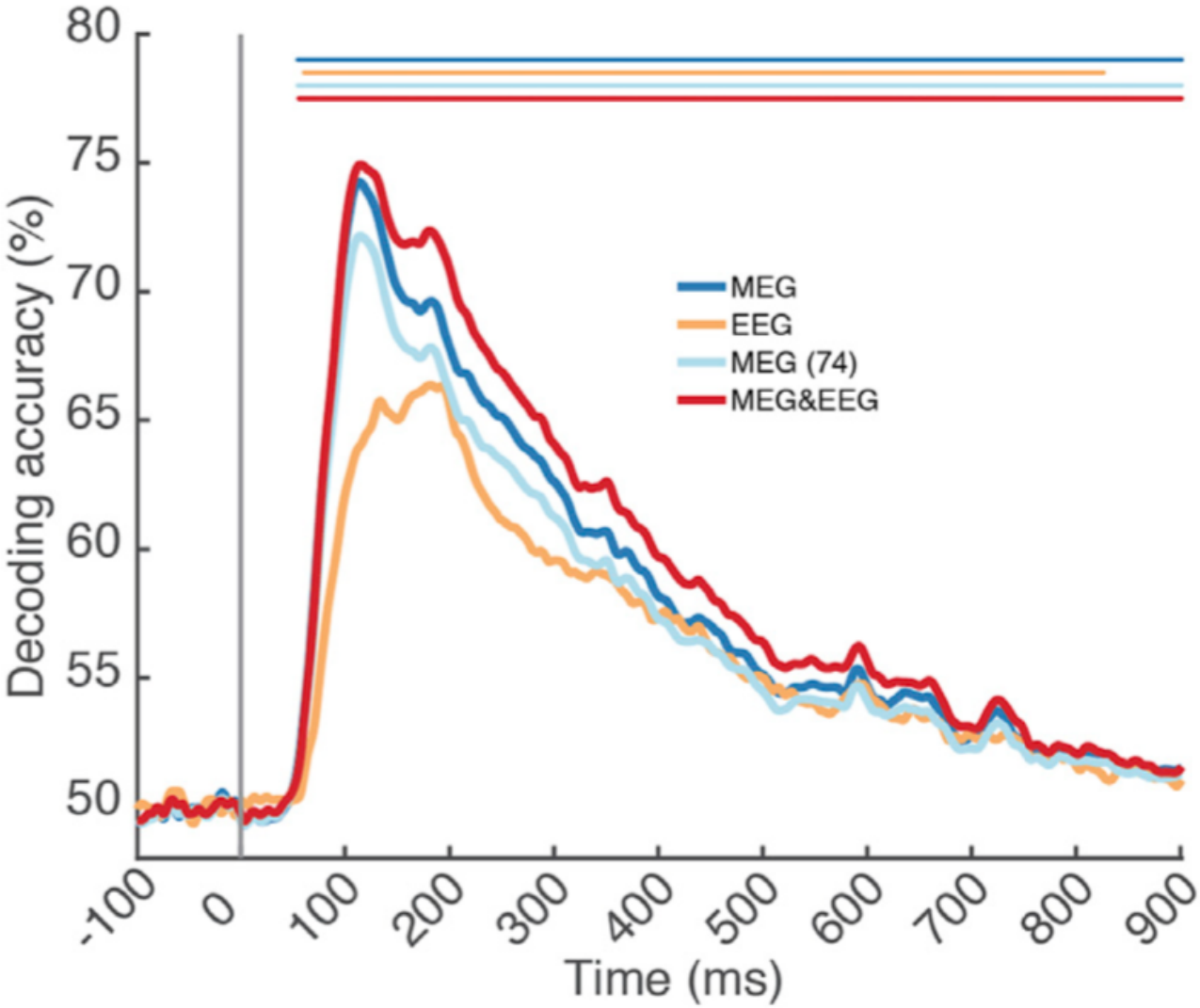
Multivariate pattern analysis of MEG and EEG: A comparison of representational structure in time and space

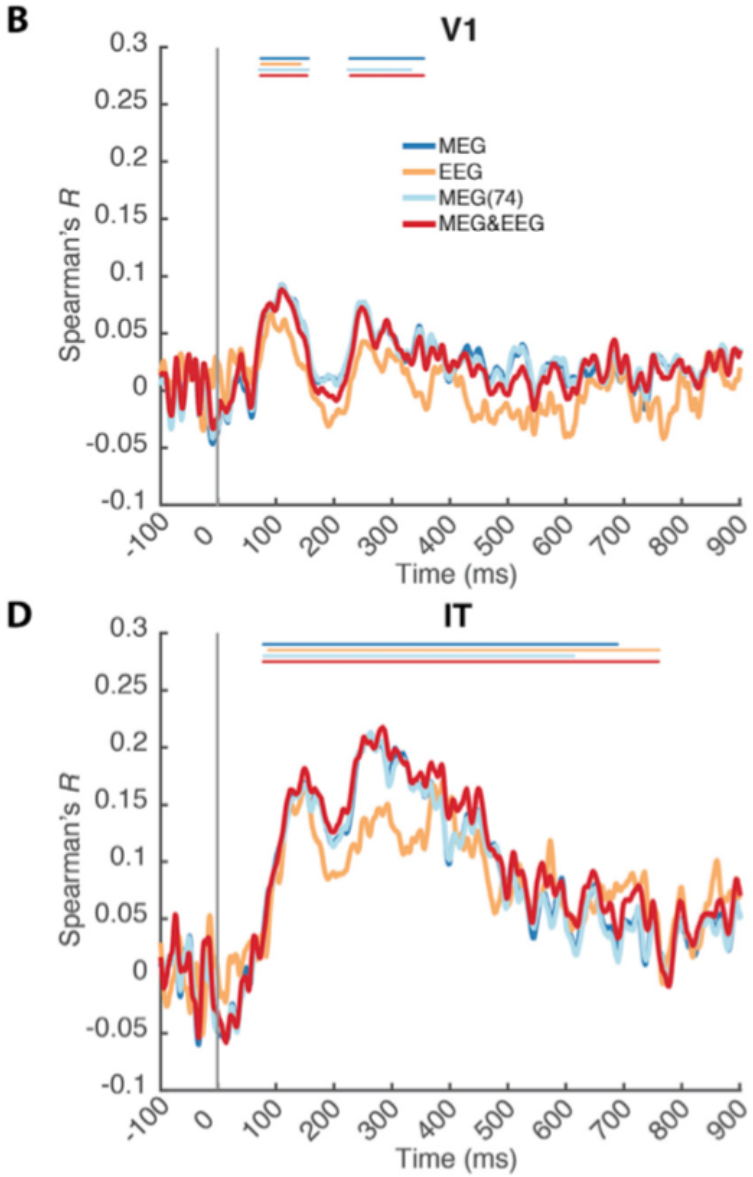
Radoslaw Martin Cichy [a,*], Dimitrios Pantazis [b]

[a] *Department of Education and Psychology, Free University Berlin, Berlin, Germany*
[b] *McGovern Institute for Brain Research, Massachusetts Institute of Technology, Cambridge, MA, USA*

NeuroImage 158 (2017) 441–454


A
Animate
Inanimate
Human
Non-human
Body
Face
Body
Face
Natural
Artificial
B
Feature selection
Pattern assembly & partitioning
Pairwise classification (support vector machine)
Representational dissimilarity matrix
EEG sensors
t
Time
Extract features at t
M raw pattern vectors per condition
Trial 1
Trial M
Channel value
Average by k = 5
Training set: (M/k)–1 pattern vectors
Condition i
Condition j
Train
Classifier
Sensor 2
Sensor 1
Test
Testing set: left–out pattern vector
Assign decoding accuracy
Animate
Inanimate
Human
Non-human
Natural
Artificial
Body
Face
(i,j)


80
75
70
65
60
55
50
Decoding accuracy (%)
-100
0
100
200
300
400
500
600
700
800
900
Time (ms)
MEG
EEG
MEG (74)
MEG&EEG


B
V1
MEG
EEG
MEG(74)
MEG&EEG
Spearman's R
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-100
0
100
200
300
400
500
600
700
800
900
Time (ms)
D
IT
Spearman's R
Time (ms)

Neuromodulation

tDCS Modulates Visual Gamma Oscillations and Basal Alpha Activity in Occipital Cortices: Evidence from MEG

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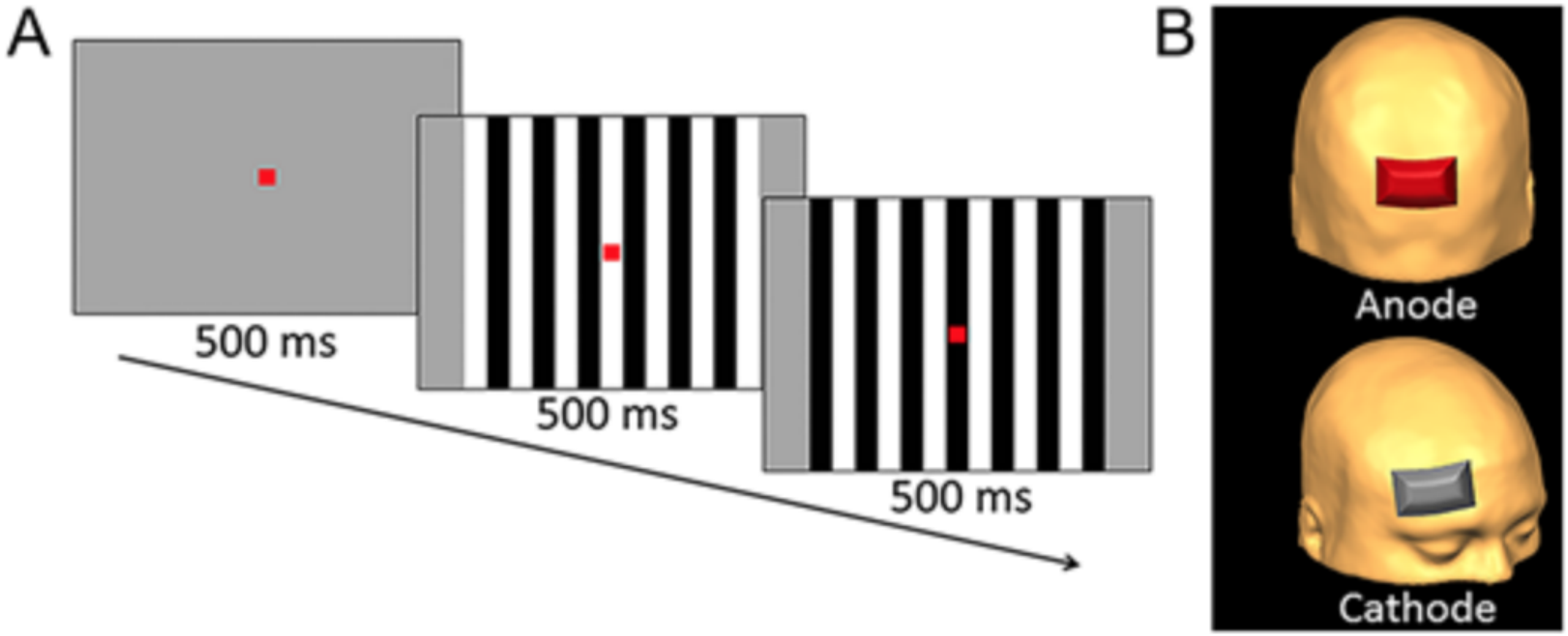
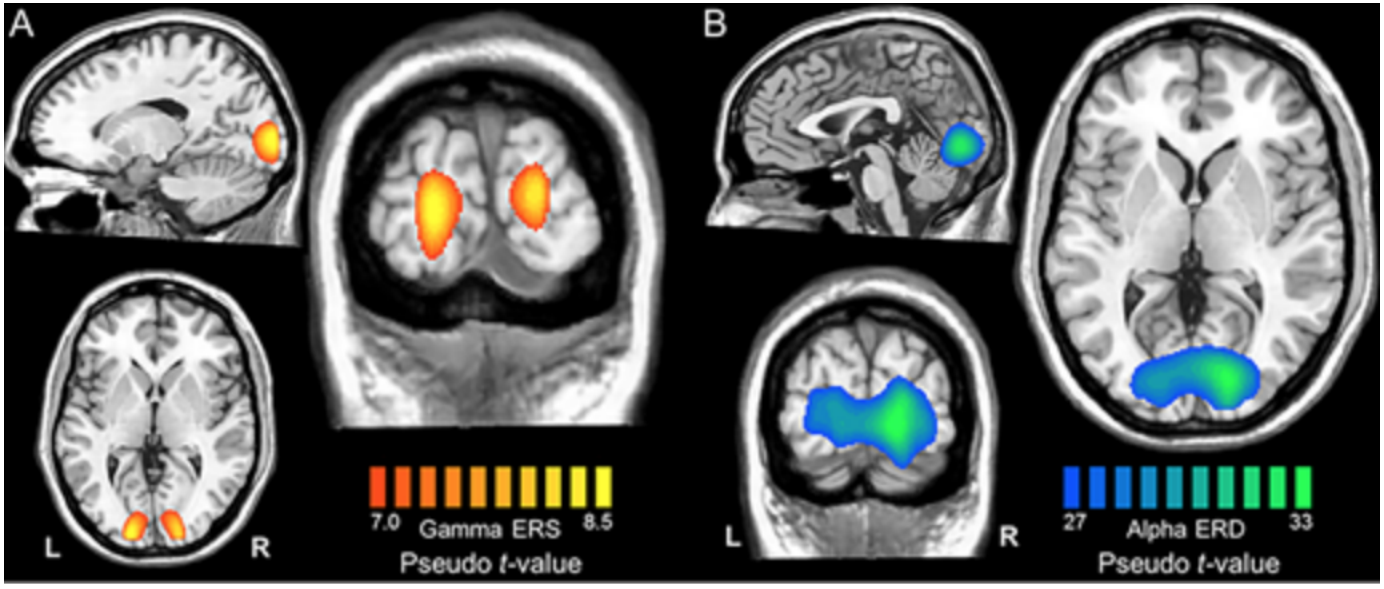
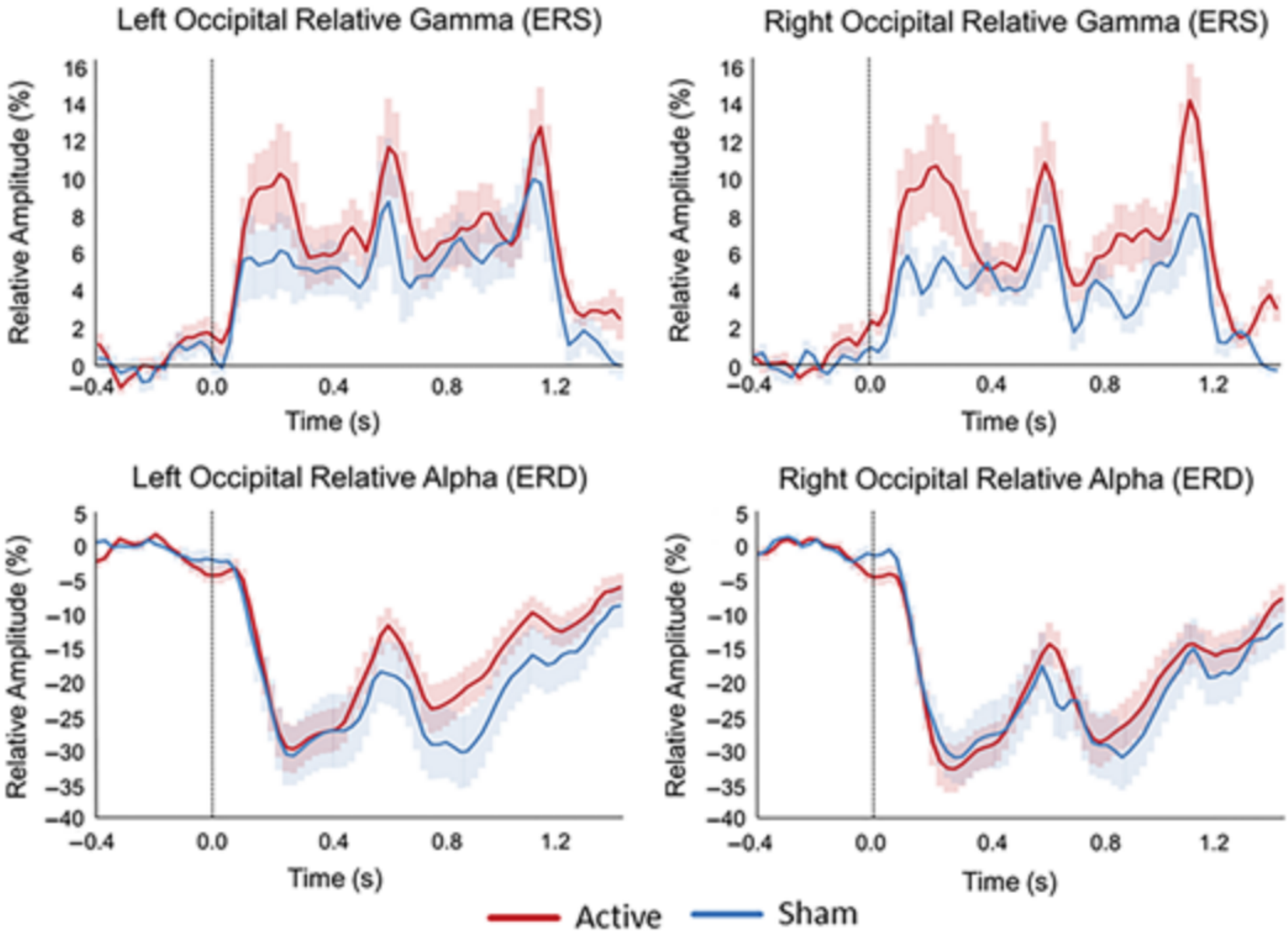
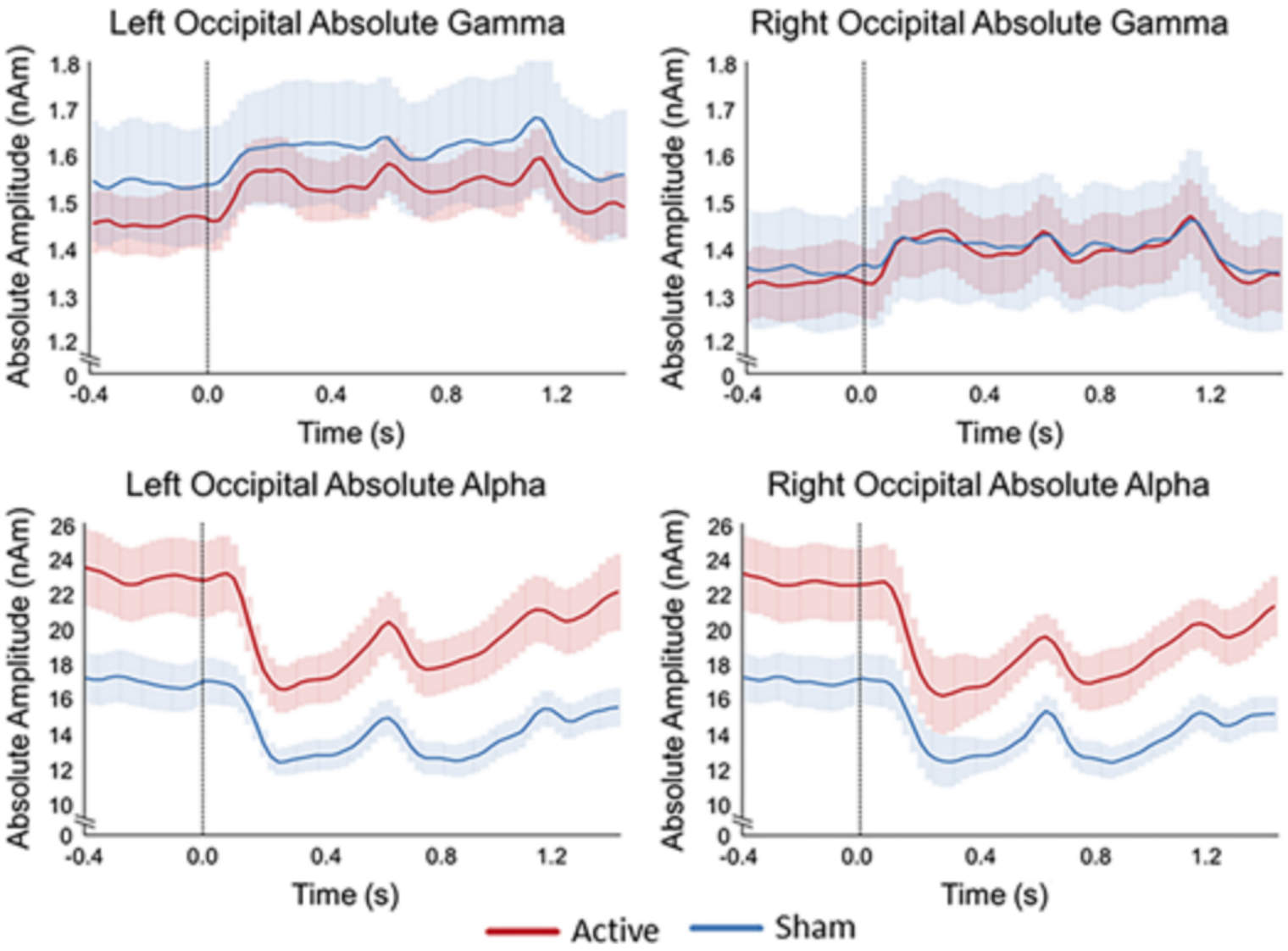
Cerebral Cortex, May 2018;28: 1597–1609


A
500 ms
500 ms
500 ms
B
Anode
Cathode


A
Occipital Spectrogram
Frequency (Hz)
80
70
60
50
40
30
20
10
-0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
Time (s)
%
20
15
10
5
0
−5
−10
−15
−20
−25
−30
B
A
L
R
P
A
L
R
P
A
L
R
7.0 Gamma ERS 8.5
Pseudo t-value
B
L
R
27 Alpha ERD 33
Pseudo t-value


Left Occipital Relative Gamma (ERS)
Right Occipital Relative Gamma (ERS)
Left Occipital Relative Alpha (ERD)
Right Occipital Relative Alpha (ERD)
Relative Amplitude (%)
Time (s)
16
14
12
10
8
6
4
2
0
−0.4
0.0
0.4
0.8
1.2
5
0
−5
−10
−15
−20
−25
−30
−35
−40
Active
Sham


Left Occipital Absolute Gamma
Absolute Amplitude (nAm)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
0
-0.4
0.0
0.4
0.8
1.2
Time (s)
Right Occipital Absolute Gamma
Absolute Amplitude (nAm)
1.8
1.7
1.6
1.5
1.4
1.3
1.2
0
-0.4
0.0
0.4
0.8
1.2
Time (s)
Left Occipital Absolute Alpha
Absolute Amplitude (nAm)
26
24
22
20
18
16
14
12
10
0
-0.4
0.0
0.4
0.8
1.2
Time (s)
Right Occipital Absolute Alpha
Absolute Amplitude (nAm)
26
24
22
20
18
16
14
12
10
0
-0.4
0.0
0.4
0.8
1.2
Time (s)
Active
Sham

Conclusions

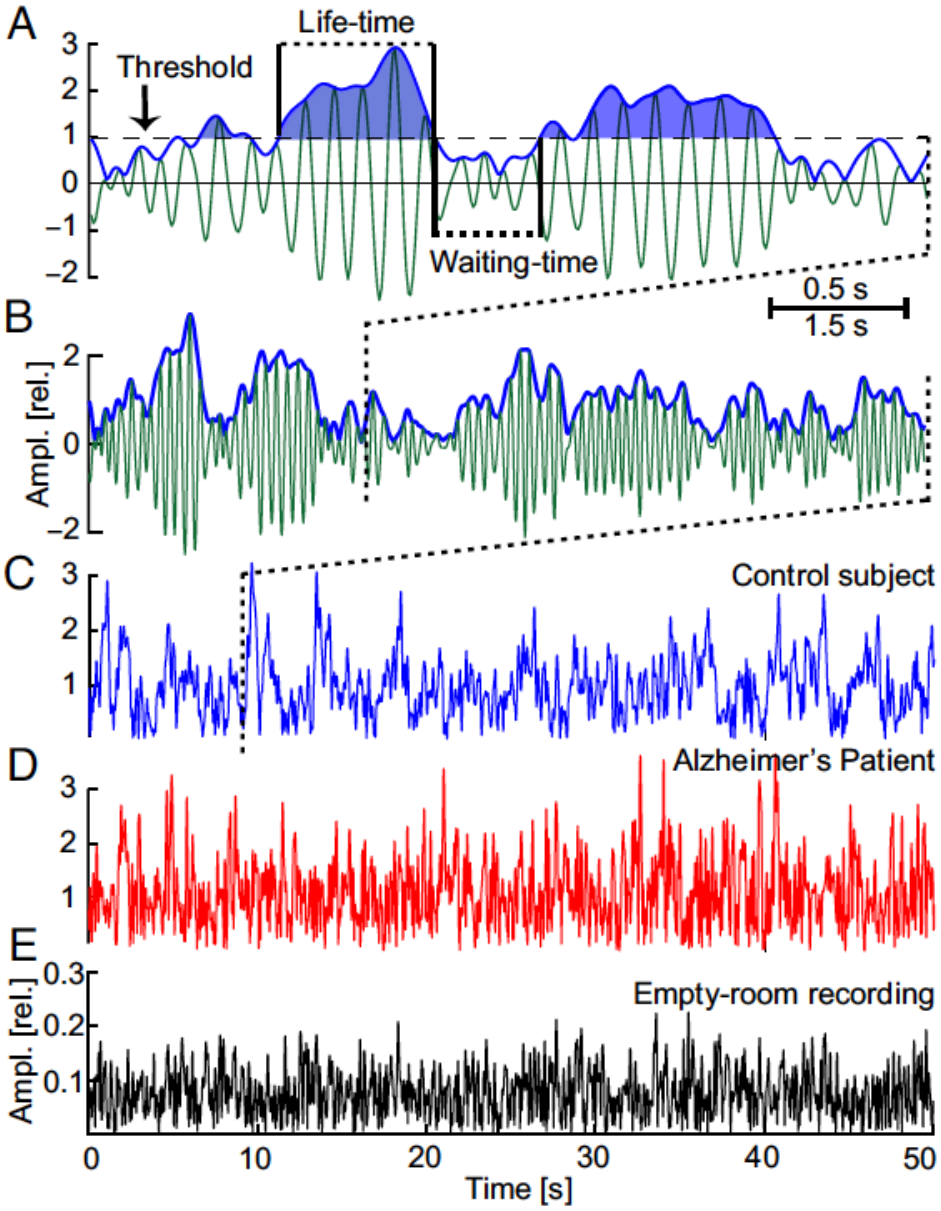
- MEG can be used to observe processes invisible to other techniques
  - fMRI is not as fast
  - fMRI can’t tell us about frequency
  - EEG may not be as sensitive
- MEG can be used to study a wide array of cognitive processes and neurophysiological phenomenon

Bonus Extras

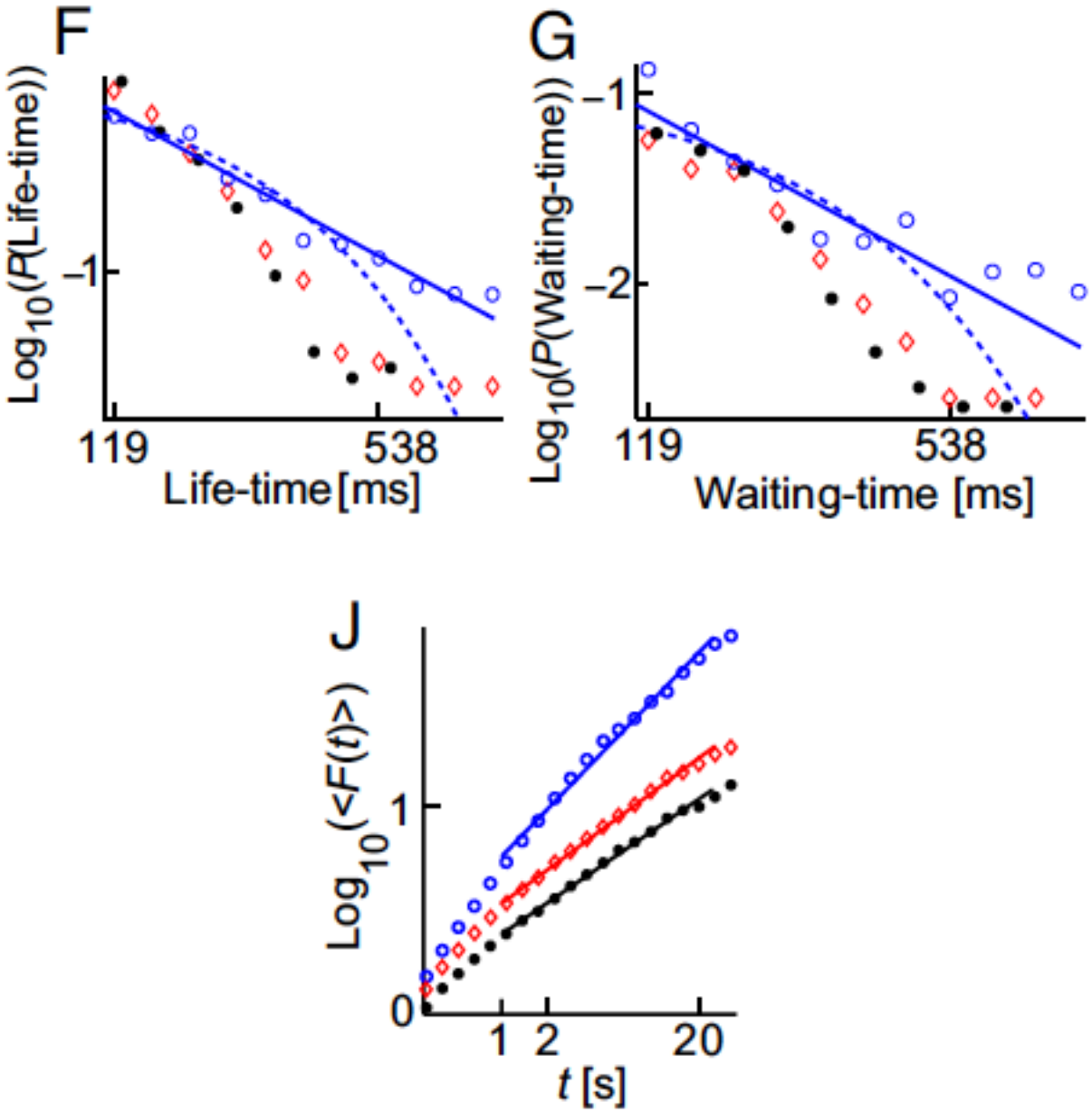
Altered temporal correlations in parietal alpha and prefrontal theta oscillations in early-stage Alzheimer disease

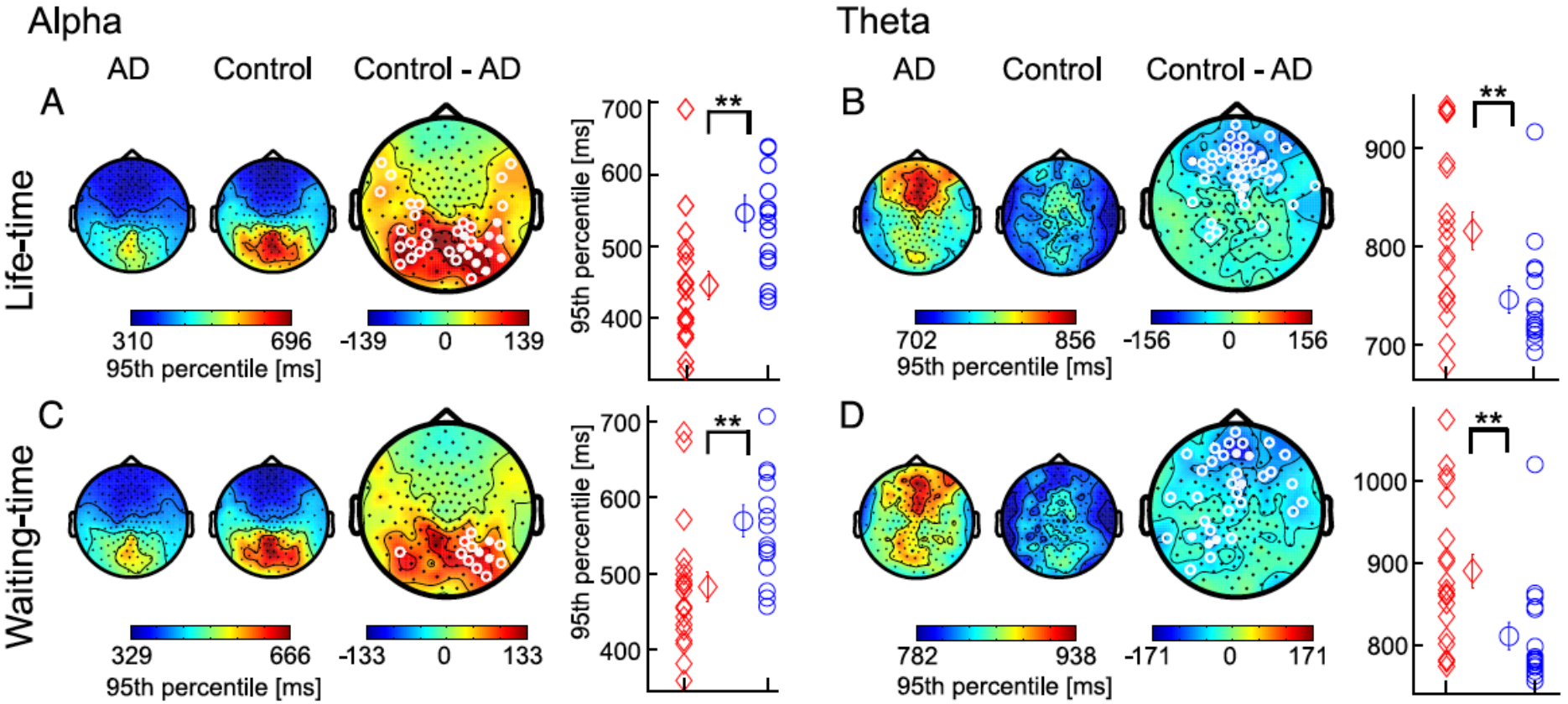
Teresa Montez[a,b,1], Simon-Shlomo Poil[c,1], Bethany F. Jones[b], Ilonka Manshanden[b], Jeroen P. A. Verbunt[b,d], Bob W. van Dijk[b,d], Arjen B. Brussaard[c], Arjen van Ooyen[c], Cornelis J. Stam[b], Philip Scheltens[e], and Klaus Linkenkaer-Hansen[c,2]

1614–1619 | PNAS | February 3, 2009 | vol. 106 | no. 5


A
Life-time
Threshold
Waiting-time
3
2
1
0
−1
−2
0.5 s
1.5 s
B
Ampl. [rel.]
2
0
−2
C
Control subject
3
2
1
D
Alzheimer's Patient
3
2
1
E
Empty-room recording
Ampl. [rel.]
0.3
0.2
0.1
0
10
20
30
40
50
Time [s]

Alpha Oscillations




Alpha
Theta
AD
Control
Control - AD
A
B
C
D
Life-time
Waiting-time
310
696
-139
0
139
95th percentile [ms]
702
856
-156
156
329
666
-133
133
782
938
-171
171
95th percentile [ms]
**

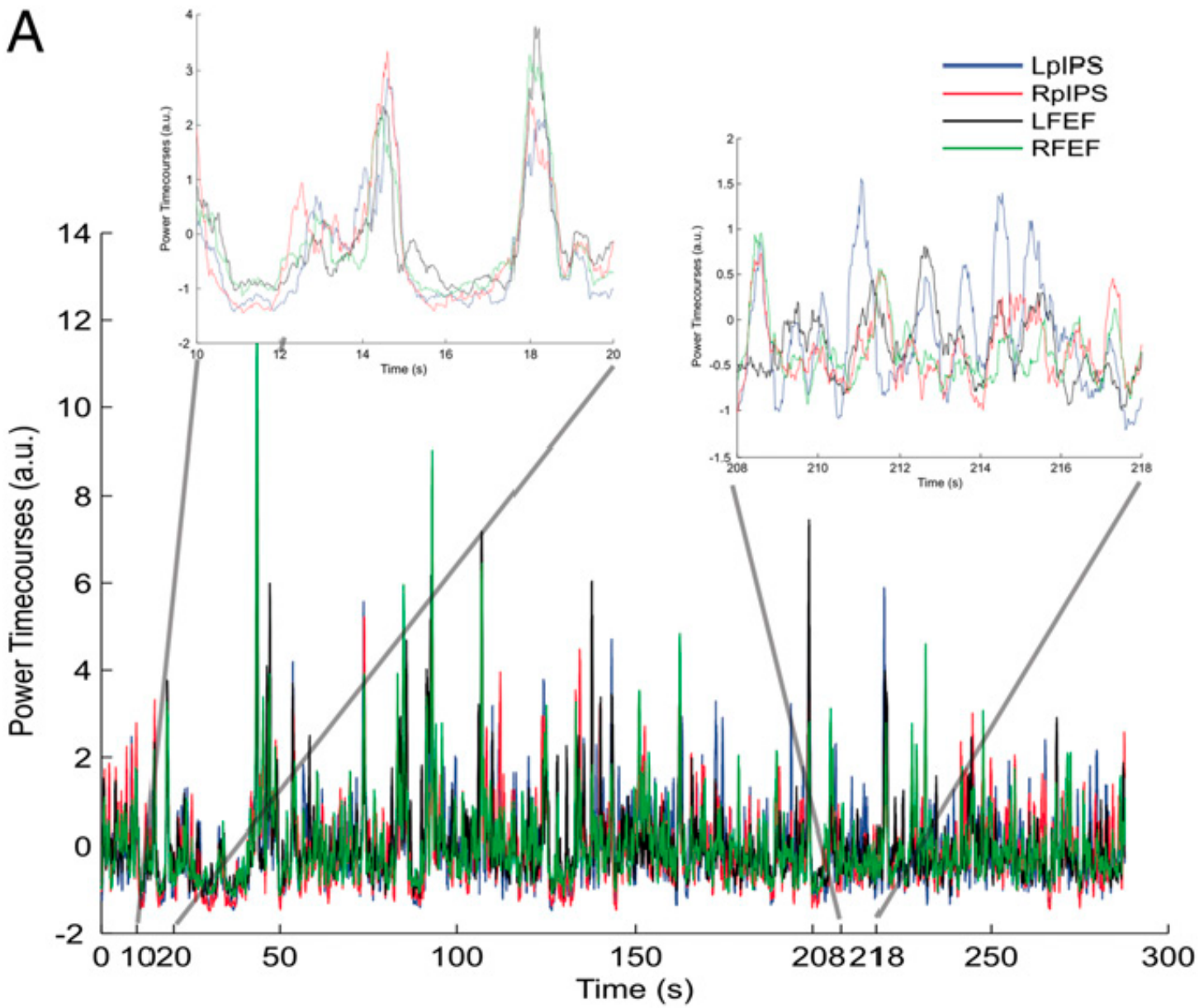
Dynamic Connectivity

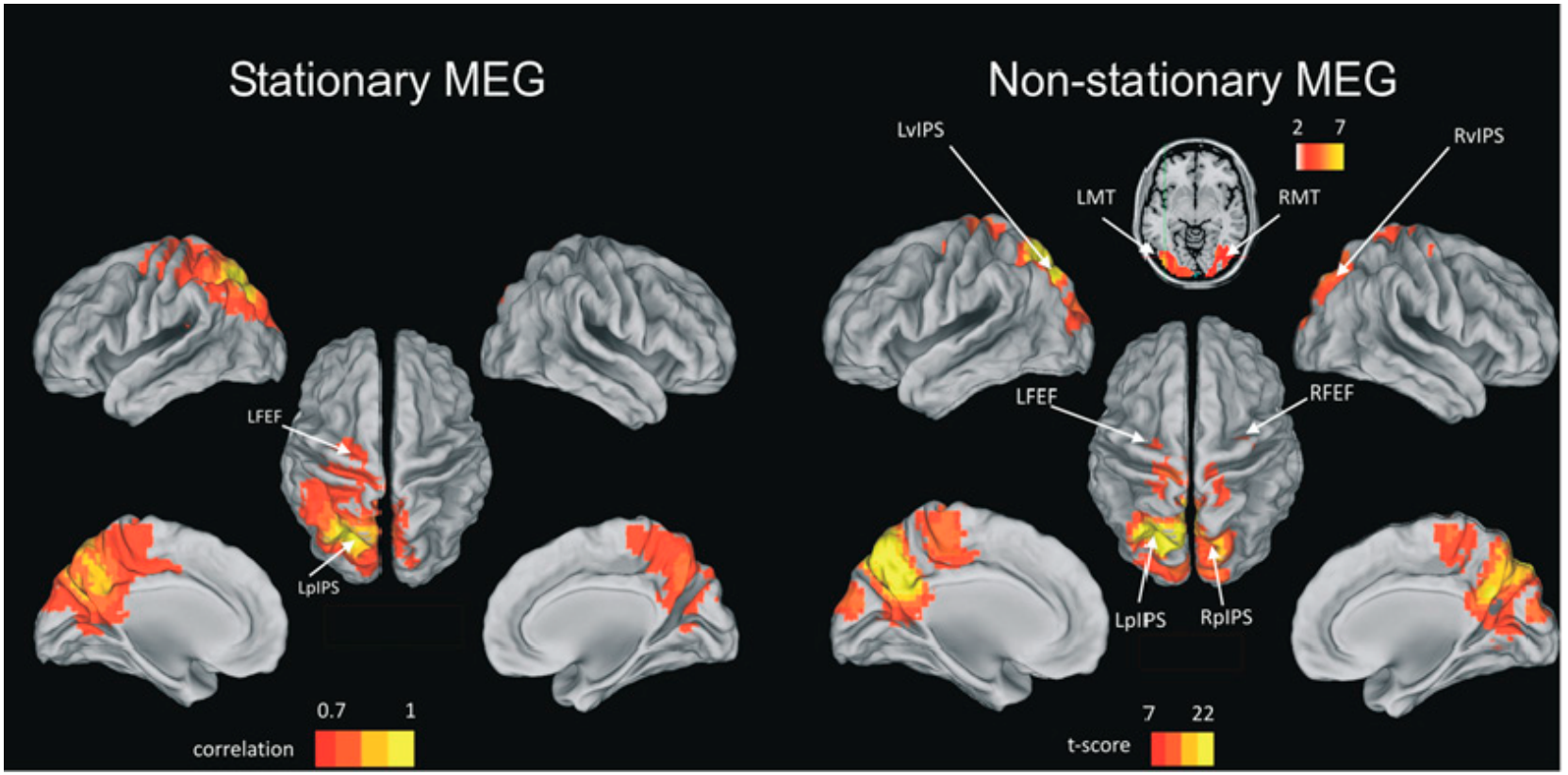
Temporal dynamics of spontaneous MEG activity in brain networks

Francesco de Pasquale[a,b,1], Stefania Della Penna[a,b], Abraham Z. Snyder[c,d], Christopher Lewis[a,b], Dante Mantini[a,b,2], Laura Marzetti[a,b], Paolo Belardinelli[a,b], Luca Ciancetta[a,b], Vittorio Pizzella[a,b], Gian Luca Romani[a,b], and Maurizio Corbetta[a,b,c,d]

[a]Institute for Advanced Biomedical Technologies, G. D'Annunzio University Foundation, G. D'Annunzio University, 66100 Chieti, Italy; [b]Department of Clinical Sciences and Bio-imaging, G. D'Annunzio University, 66100 Chieti, Italy; [c]Department of Neurology, Washington University, St. Louis, MO 63110; and [d]Department of Radiology, Washington University, St. Louis, MO 63110

6040–6045 | PNAS | March 30, 2010 | vol. 107 | no. 13


A
LpIPS
RpIPS
LFEF
RFEF
Power Timecourses (a.u.)
Time (s)
0 10 20 50 100 150 208 218 250 300
14 12 10 8 6 4 2 0 -2
Power Timecourses (a.u.)
Time (s)
10 12 14 16 18 20
Power Timecourses (a.u.)
Time (s)
208 210 212 214 216 218

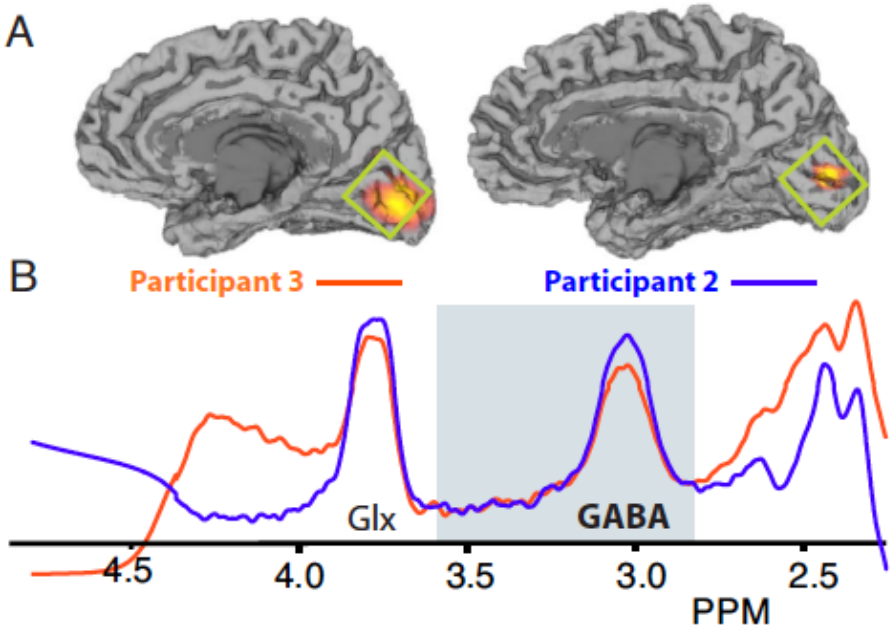

Stationary MEG
LFEF
LpIPS
0.7
1
correlation
Non-stationary MEG
LvIPS
RvIPS
LMT
RMT
2
7
LFEF
RFEF
LpIPS
RpIPS
7
22
t-score

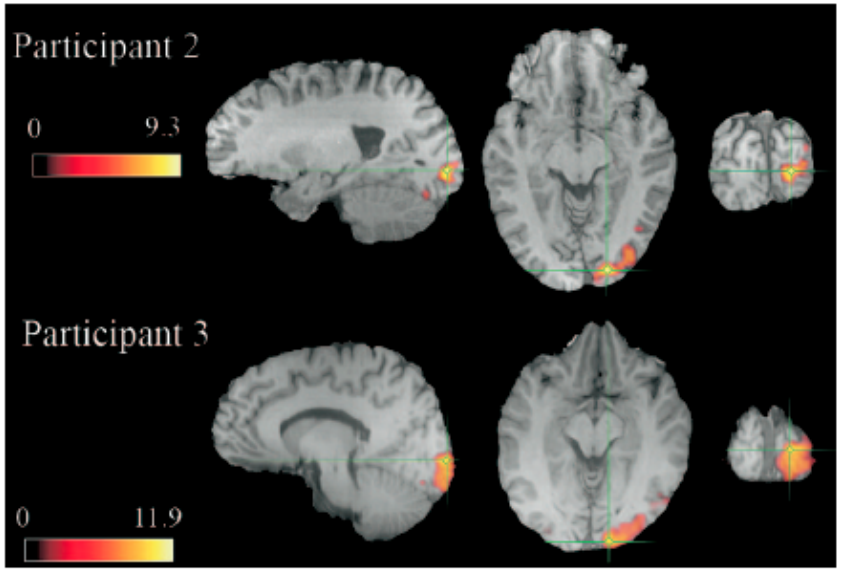
Resting GABA concentration predicts peak gamma frequency and fMRI amplitude in response to visual stimulation in humans

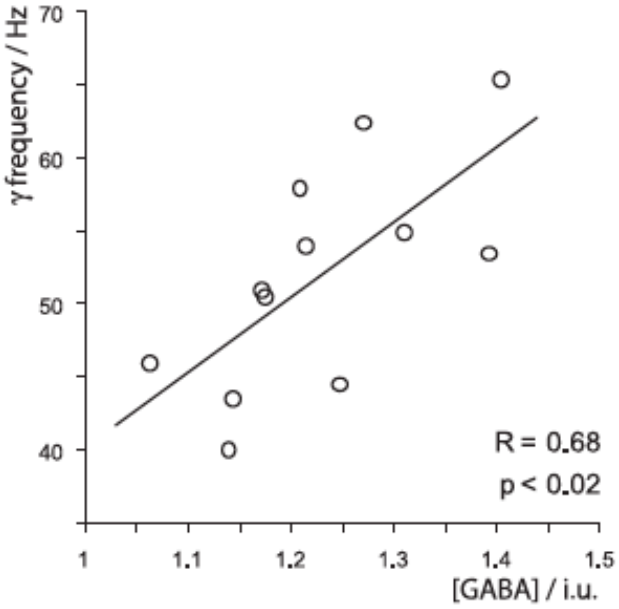
Suresh D. Muthukumaraswamy[a,1], Richard A.E. Edden[a,b,1], Derek K. Jones[a], Jennifer B. Swettenham[a], and Krish D. Singh[a,2]

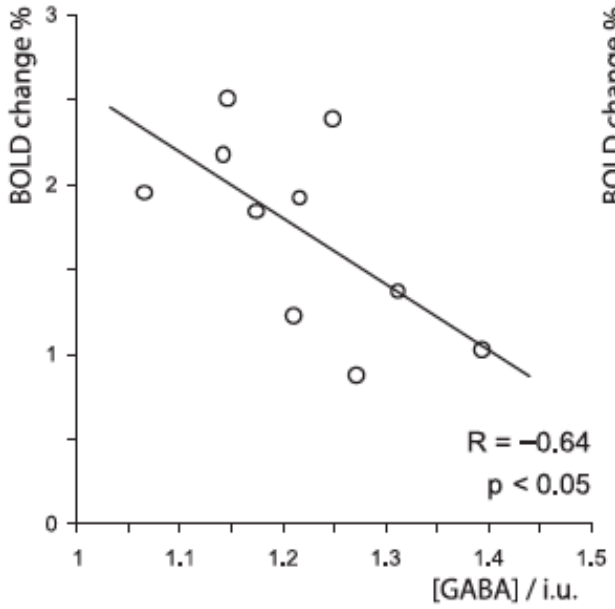
8356–8361 | PNAS | May 19, 2009 | vol. 106 | no. 20

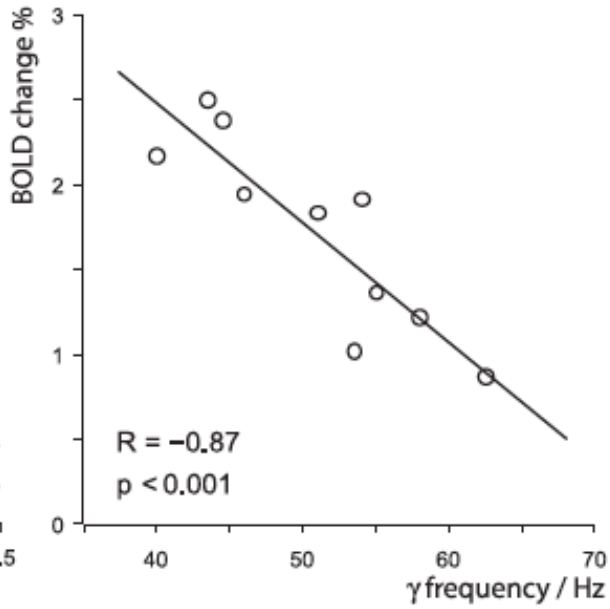
Static, high-contrast 3 cycles per degree grating
MEG, fMRI, and MRS






γ frequency / Hz
70
60
50
40
1
1.1
1.2
1.3
1.4
1.5
[GABA] / i.u.
R = 0.68
p < 0.02


BOLD change %
3
2
1
0
1
1.1
1.2
1.3
1.4
1.5
[GABA] / i.u.
R = −0.64
p < 0.05


BOLD change %
3
2
1
0
40
50
60
70
γ frequency / Hz
R = −0.87
p < 0.001