Neuronal Current Imaging

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of Mental Health

NATIONAL INSTITUTES OF HEALTH

Primary People Involved

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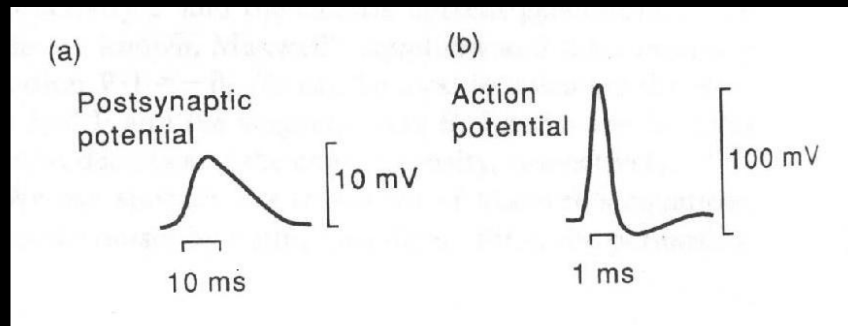
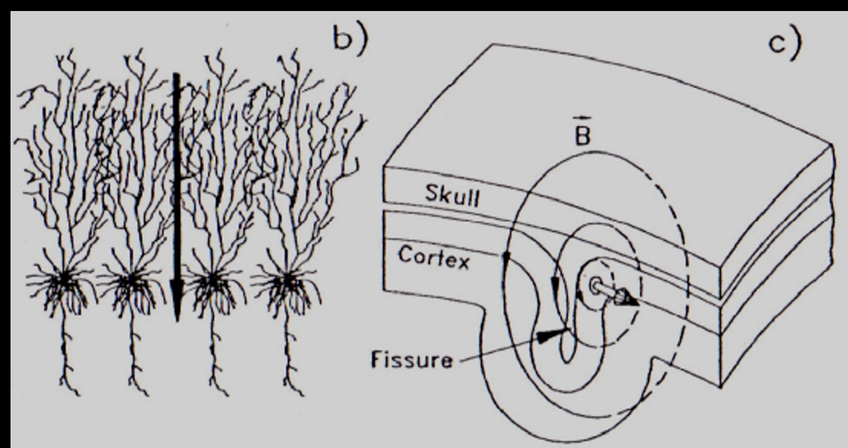
Natalia Petridou
Frank Ye
Rasmus Birn

The Basic Idea...





100 fT at on surface of skull

J.P. Wikswo Jr et al. *J Clin Neuronphy* 8(2): 170-188, 1991

Derivation of B field generated in an MRI voxel by a current dipole

Single dendritic tree having a diameter d, and length L behaves like a conductor with conductivity σ. Resistance is R=V/I, where $R=4L/(\pi d^2 \sigma)$. From Biot-Savart:

$$B = \frac{\mu_0}{4\pi}\frac{Q}{r^2} = \frac{\mu_0}{16}\frac{d^2 \sigma V}{r^2}$$

by substituting d = 4μm, $\sigma \approx 0.25\ \Omega^{-1}\ m^{-1}$, V = 10mV and

r = 4cm (measurement distance when using MEG) the resulting value is: **B≈0.002 fT**

Because $\mathbf{B_{MEG}}$**=100fT** is measured by MEG on the scalp, (0.002 fT x 50,000 = 100 fT), must coherently act to generate such field. These bundles of neurons produce, within a typical voxel, 1 mm x 1 mm x 1 mm, a field of order:

$$B_{MRI} = B_{MEG}\left(\frac{r_{MEG}}{r_{MRI}}\right)^2 = B_{MEG}\left(\frac{4\,cm}{0.1\,cm}\right)^2 = 1600\,B_{MEG}$$

$\mathbf{B_{MRI} \approx 0.2nT}$

J. Bodurka, P. A. Bandettini. *Toward direct mapping of neuronal activity: MRI detection of ultra weak transient magnetic field changes.* **Magn. Reson. Med. 47: 1052-1058, (2002).**

Some background...

G. C. Scott, M. L. Joy, R. L. Armstrong, R. M. Henkelman, *RF current density imaging homogeneous media.* **Magn. Reson. Med. 28: 186-201, (1992).**

M. Singh, *Sensitivity of MR phase shift to detect evoked neuromagnetic fields inside the head.* **IEEE Transactions on Nuclear Science. 41: 349-351, (1994).**

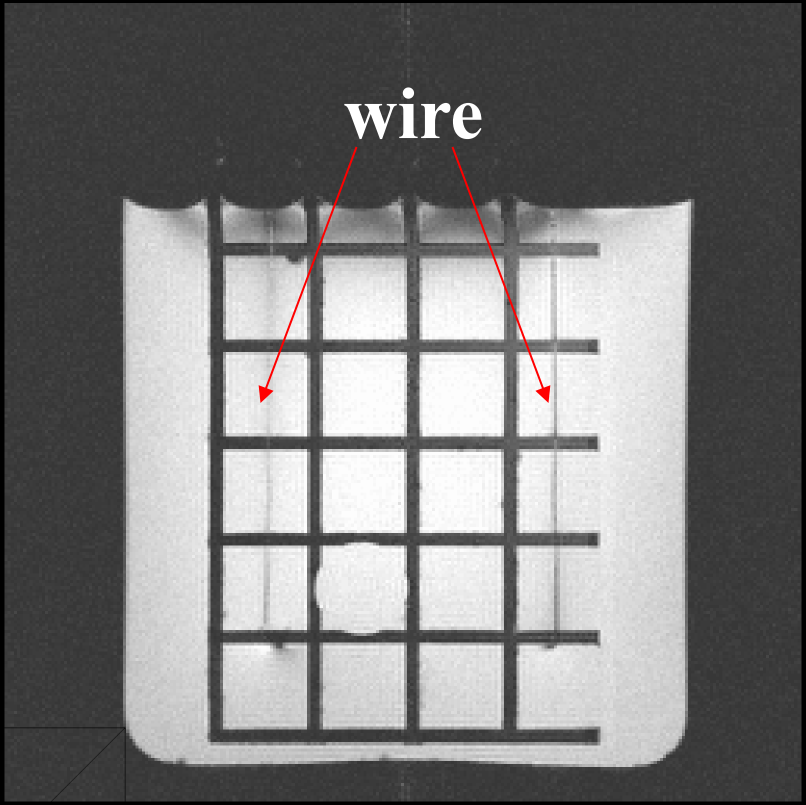
H. Kamei, J, Iramina, K. Yoshikawa, S. Ueno, *Neuronal current distribution imaging using MR.* **IEEE Trans. On Magnetics, 35: 4109-4111, (1999)**

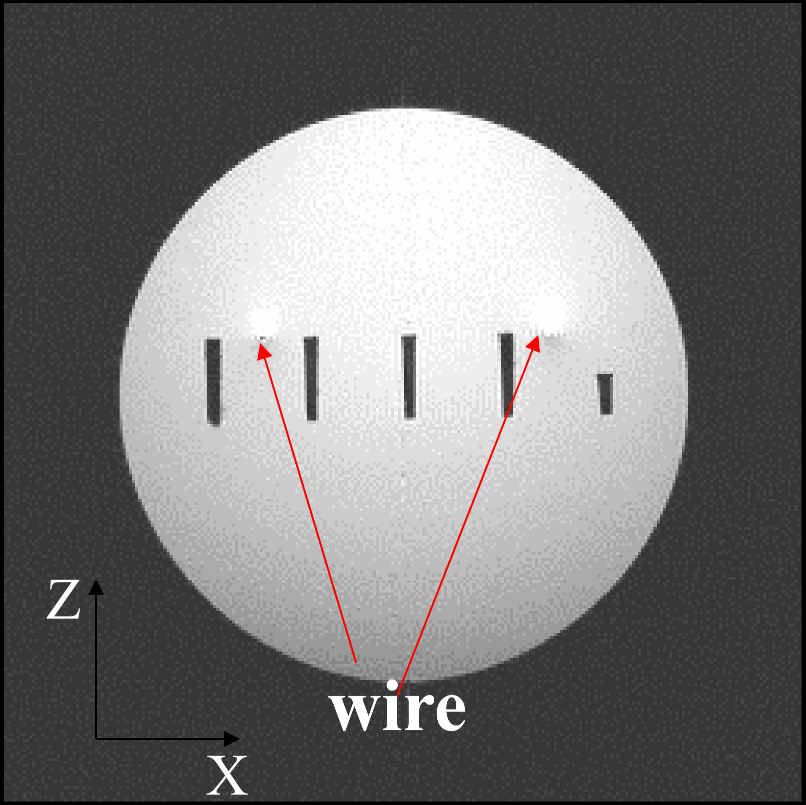
J. Bodurka, P. A. Bandettini. *Toward direct mapping of neuronal activity: MRI detection of ultra weak transient magnetic field changes.* **Magn. Reson. Med. 47: 1052-1058, (2002).**

D. Konn, P. Gowland, R. Bowtell, *MRI detection of weak magnetic fields due to an extended current dipole in a conducting sphere: a model for direct detection of neuronal currents in the brain.* **Magn. Reson. Med. 50: 40-49, (2003).**

J. Xiong, P. T. Fox, J.-H. Gao, *Direct MRI Mapping of neuronal activity.* **Human Brain Mapping, 20: 41-49, (2003)**

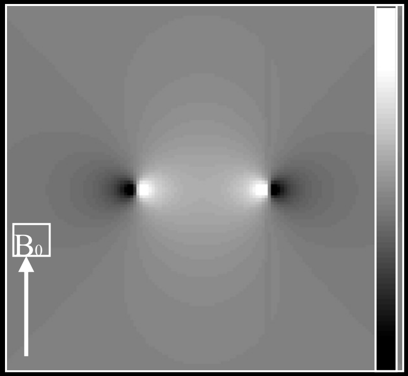
Current Phantom Experiment



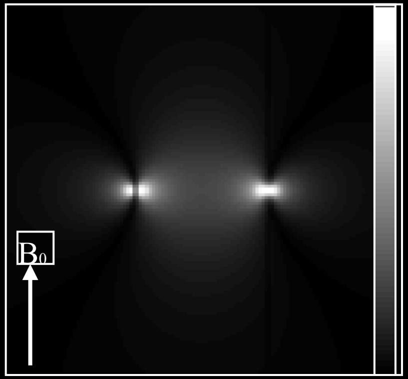


Simulation

calculated B_c || B_0

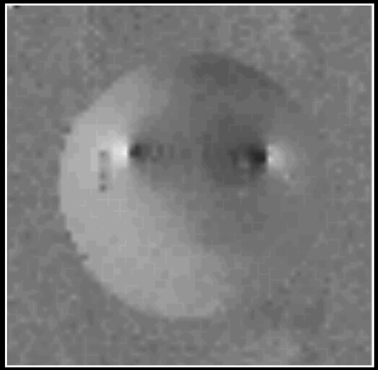


calculated $|\Delta B_c|$ || B_0

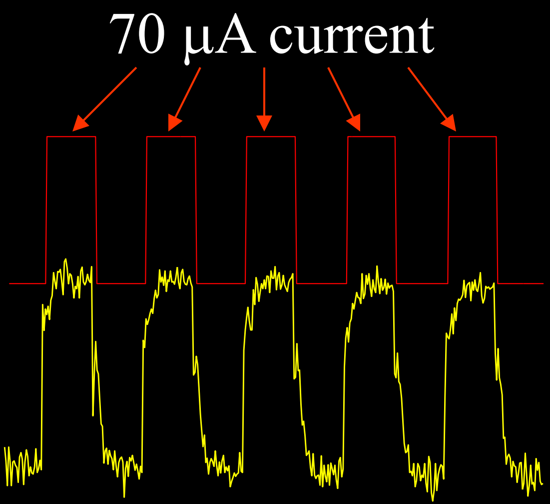


Measurement

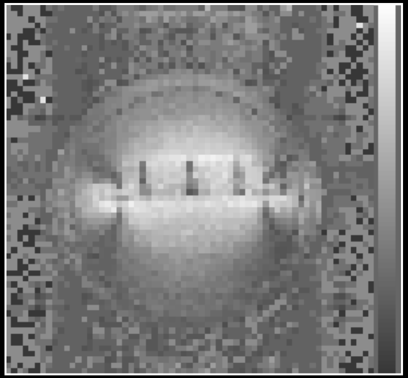
$\Delta\phi \cong 20^0$



Correlation image

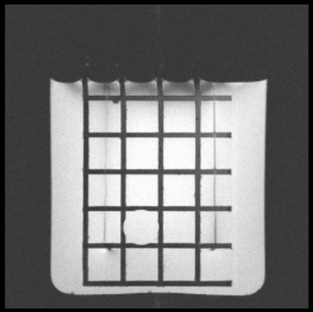


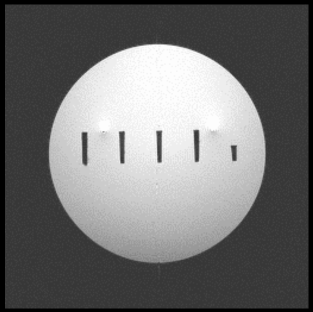
Single shot GE EPI

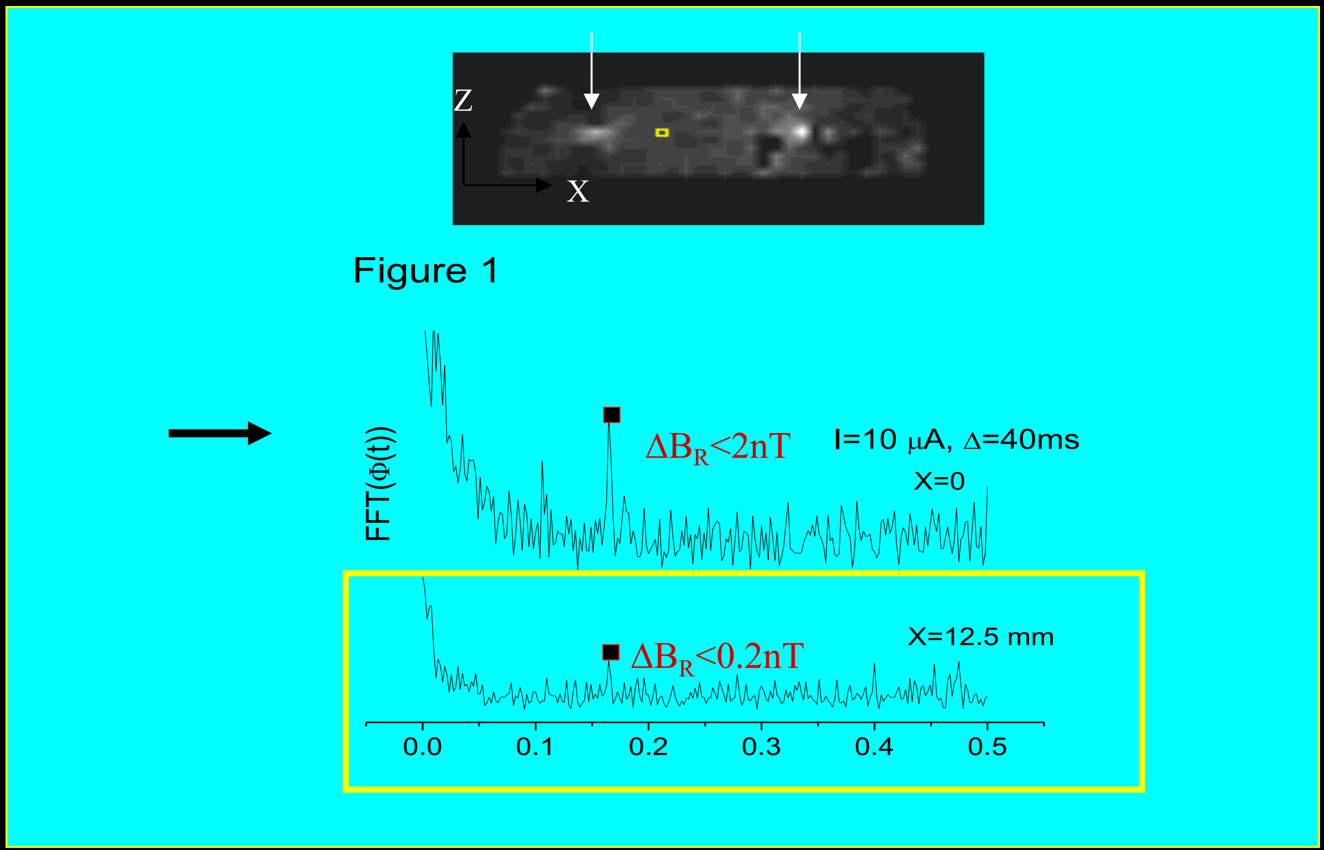


Spectral image

J. Bodurka, P. A. Bandettini. Toward direct mapping of neuronal activity: MRI detection of ultra weak transient magnetic field changes, Magn. Reson. Med. 47: 1052-1058, (2002).

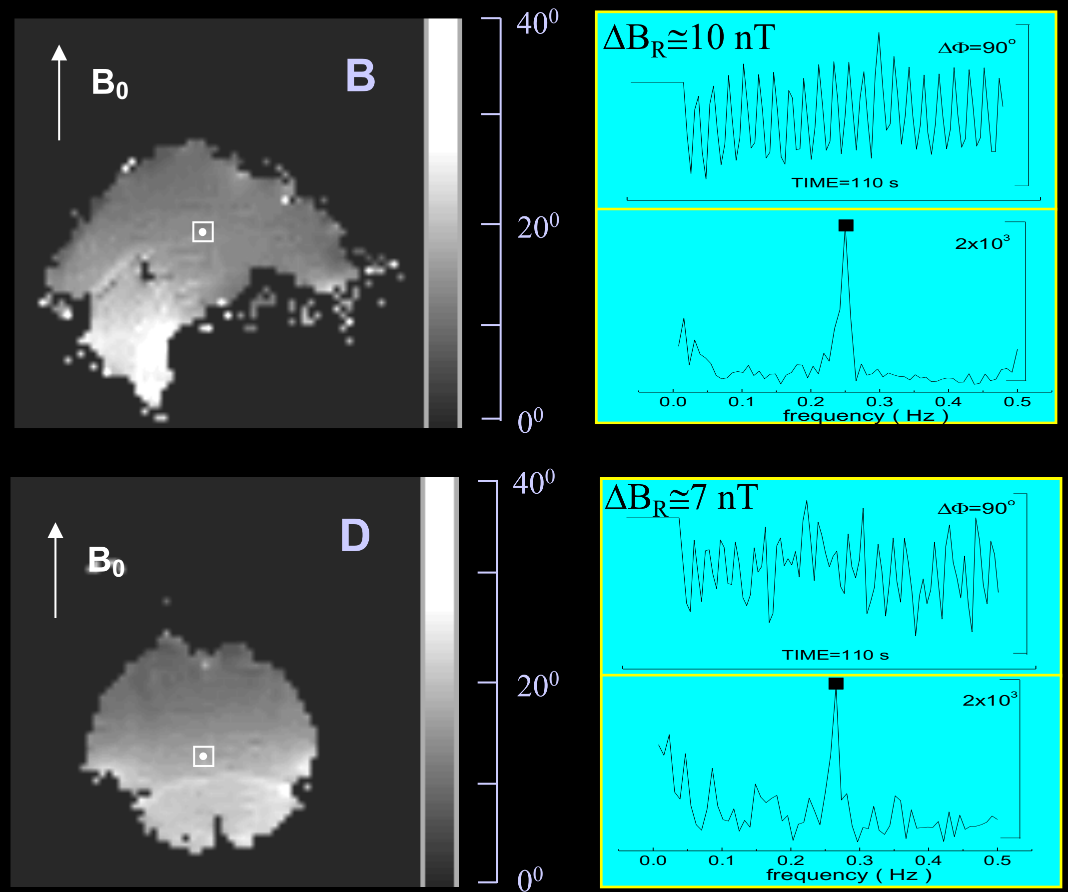




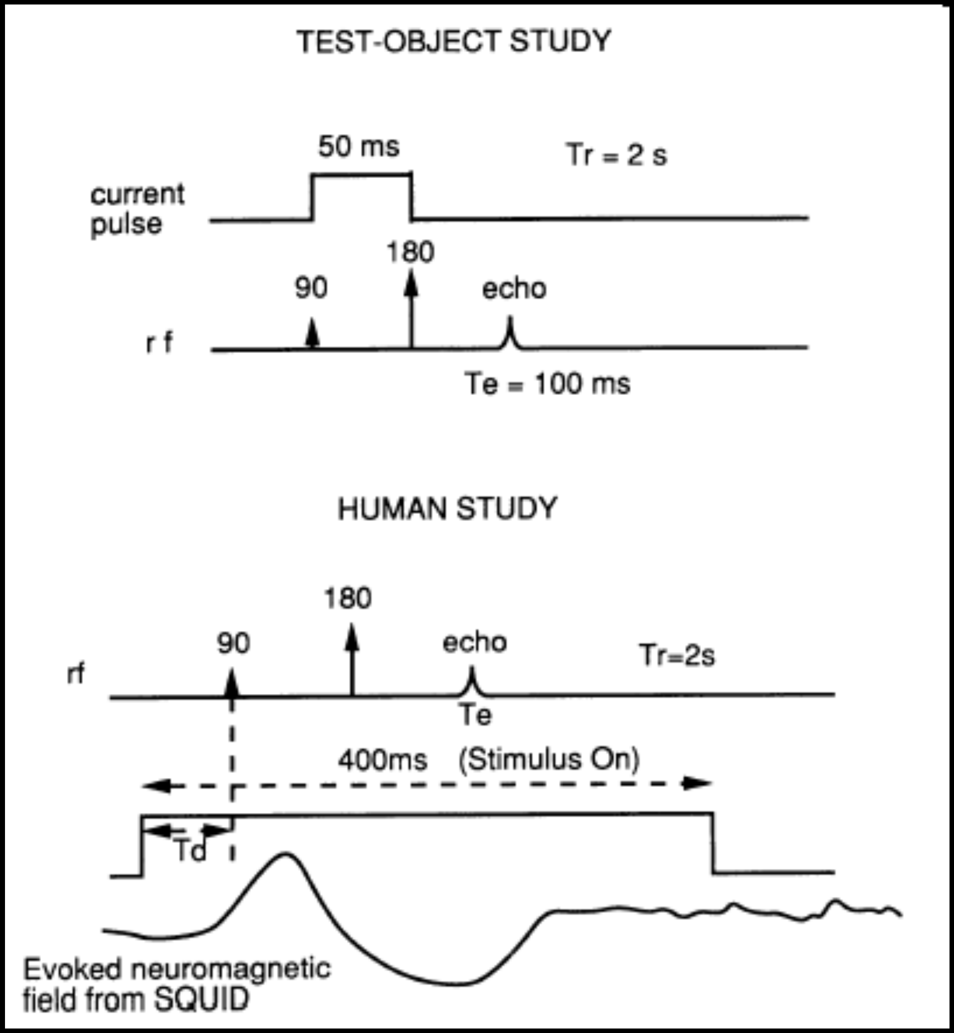


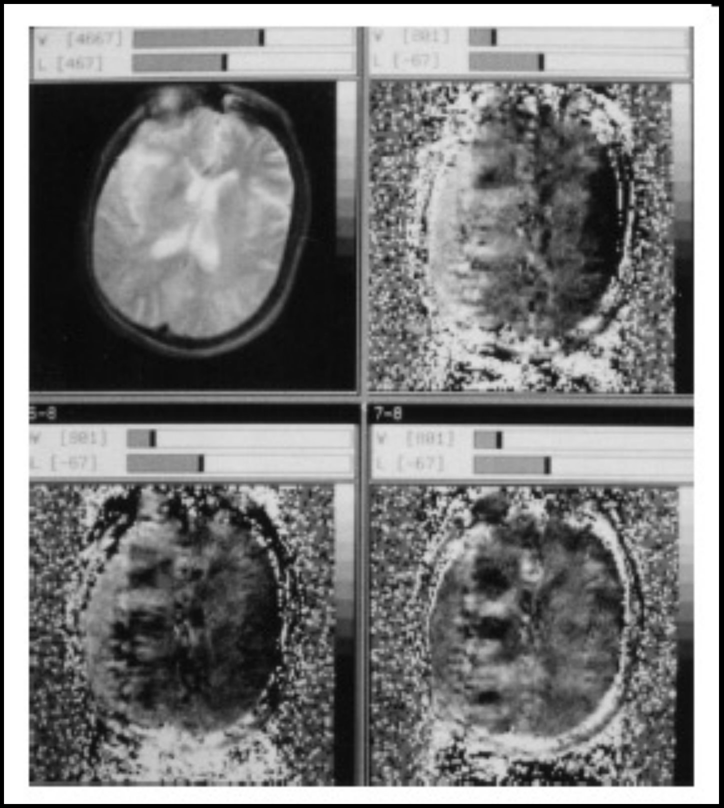
J. Bodurka, P. A. Bandettini. Toward direct mapping of neuronal activity: MRI detection of ultra weak transient magnetic field changes, Magn. Reson. Med. 47: 1052-1058, (2002).

Human Respiration



The use of spin-echo to “tune” to transients..

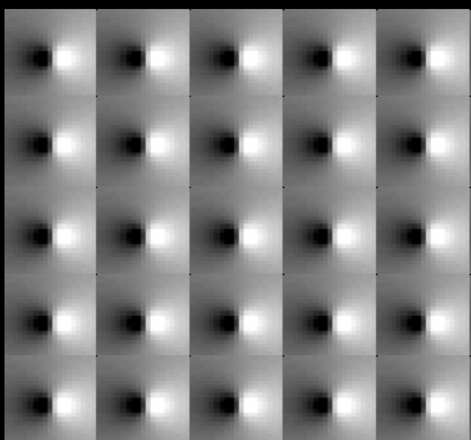


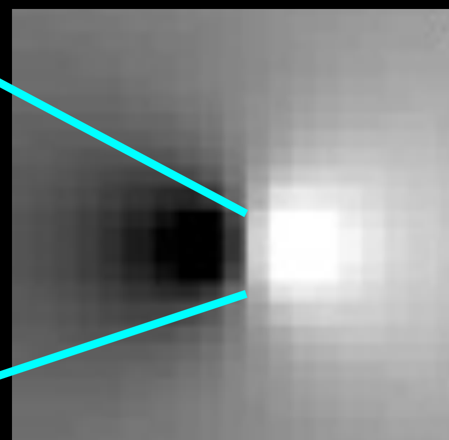


M. Singh, *Sensitivity of MR phase shift to detect evoked neuromagnetic fields inside the head.*

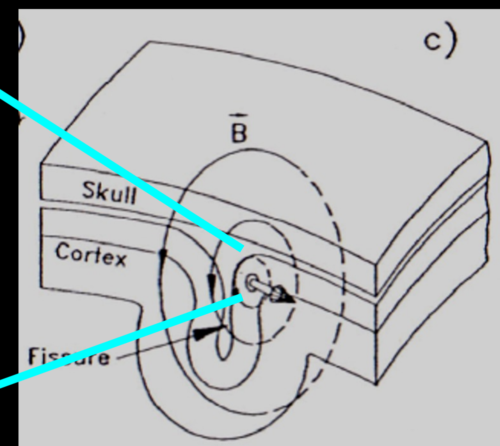
IEEE Transactions on Nuclear Science. 41: 349-351, (1994).

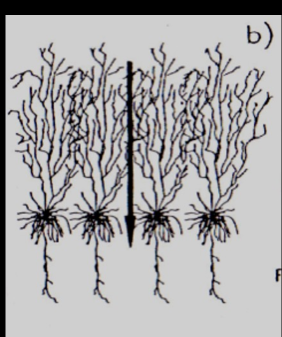
Phase vs. Magnitude...





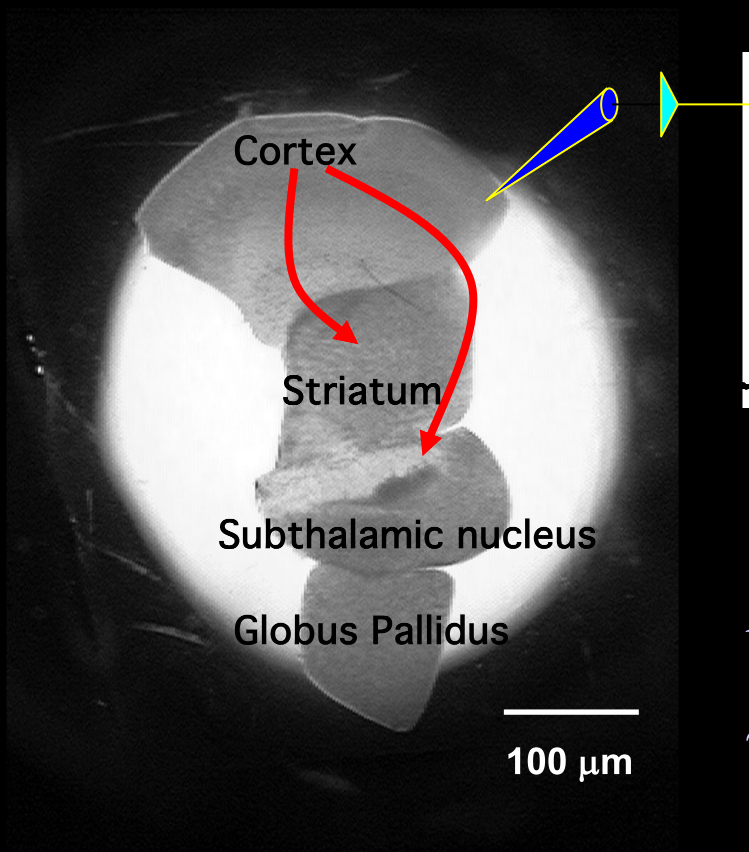
0.1 to 0.3 Deg.

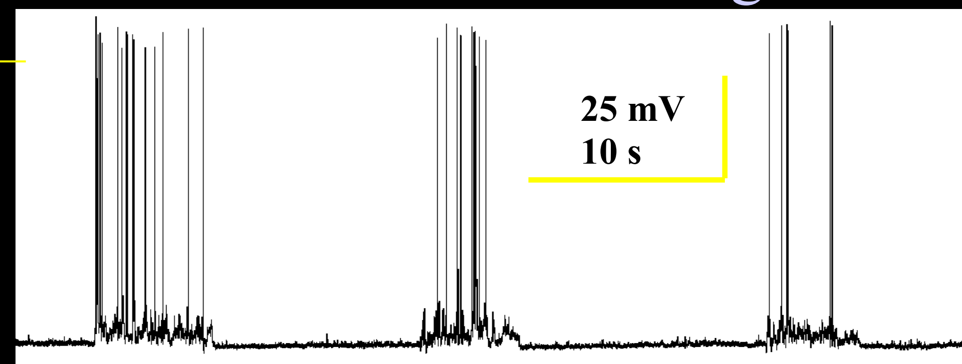




in vitro model

Patch electrode recording





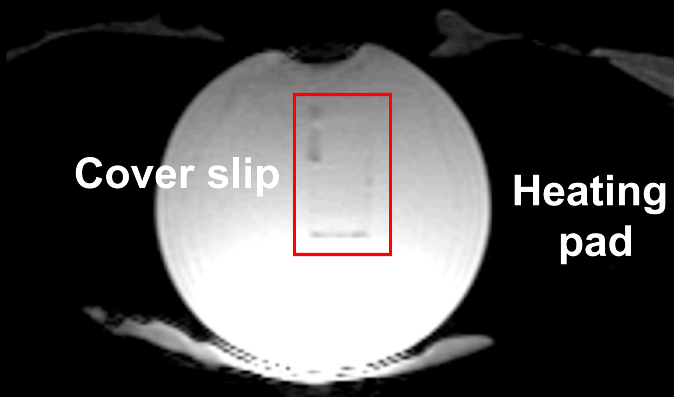
•coronal sections of newborn-rat brains ; in-plane:~1mm^2, thickness: ~60-100 µm

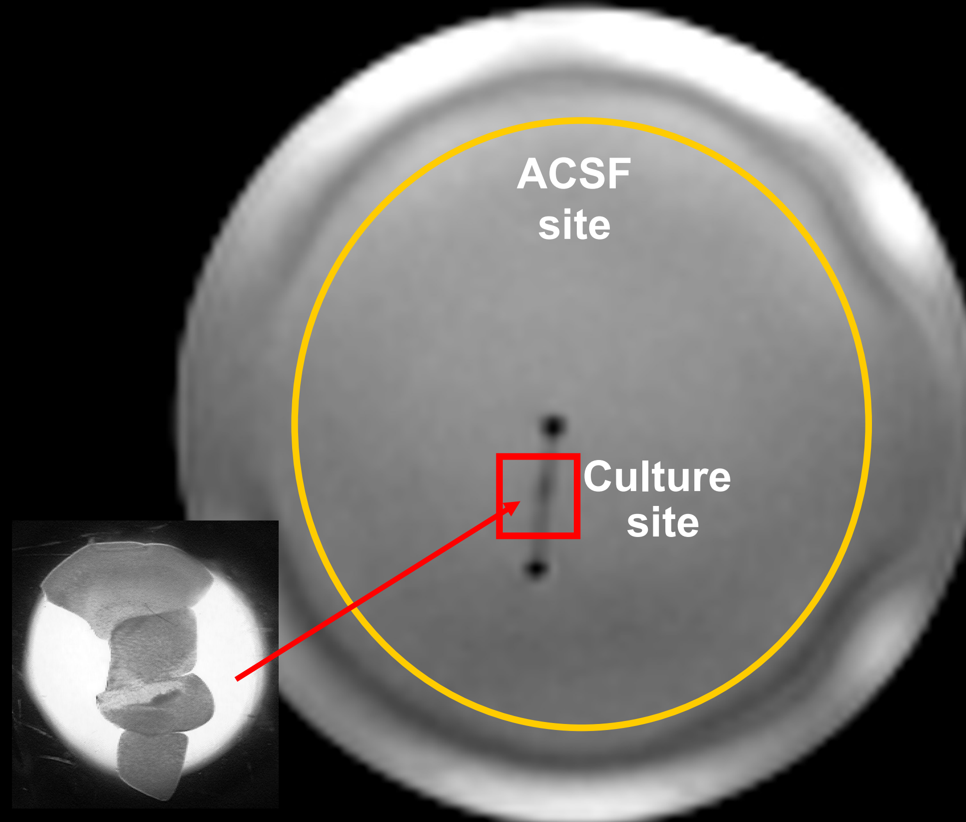
Neuronal Population: 10,000-50,000

- Spontaneous synchronized activity ; current: ~ 180nA-2µA, ΔB: ~ 60pT-0.5nT

Plenz, D. and S.T. Kital. Nature, 1999. **400**: p. 677-682.

methods - *imaging*





Imaging

- 3T, Surface coil receive
- FSE structural images (256x256)
- SE EPI single shot, TE: 60ms, TR:1s, flip angle: 90^0,

  FOV: 18cm, matrix: 64x64, 4 slices (3mm)

methods - *imaging*

Six Experiments

two conditions per experiment

Active	**Inactive**
600 images	**600 images**
neuronal activity present	**neuronal activity terminated via TTX administration**

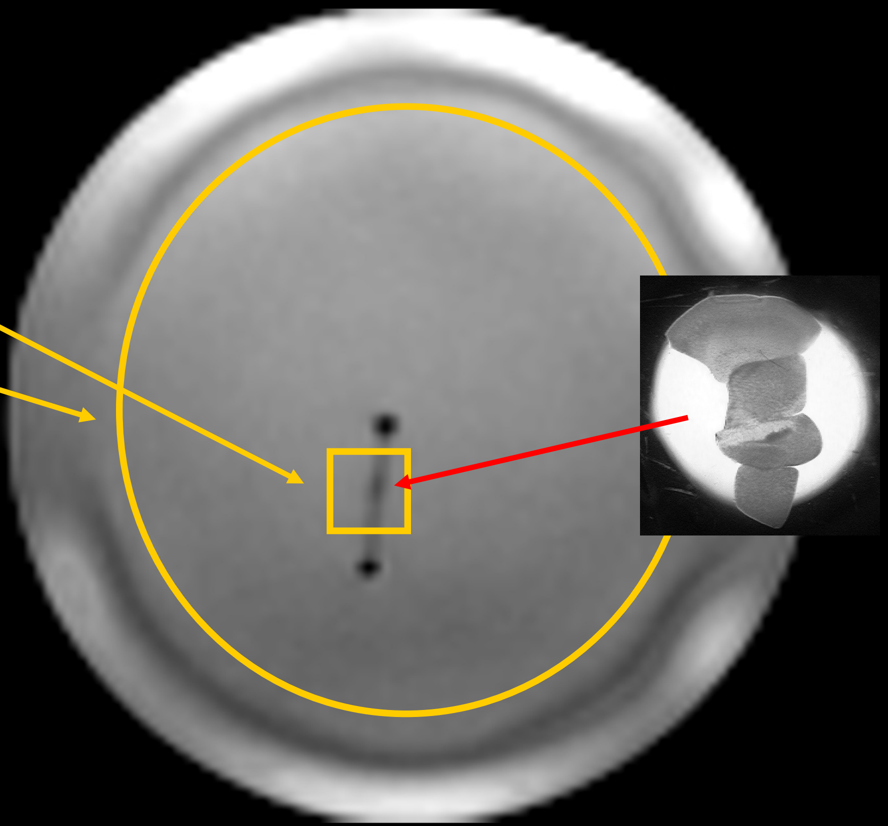
methods - *analysis*

Phase images

- Spectrum for each voxel
- Two voxel groups (all slices)

Culture (~9 voxels)

CSF (~420 voxels)

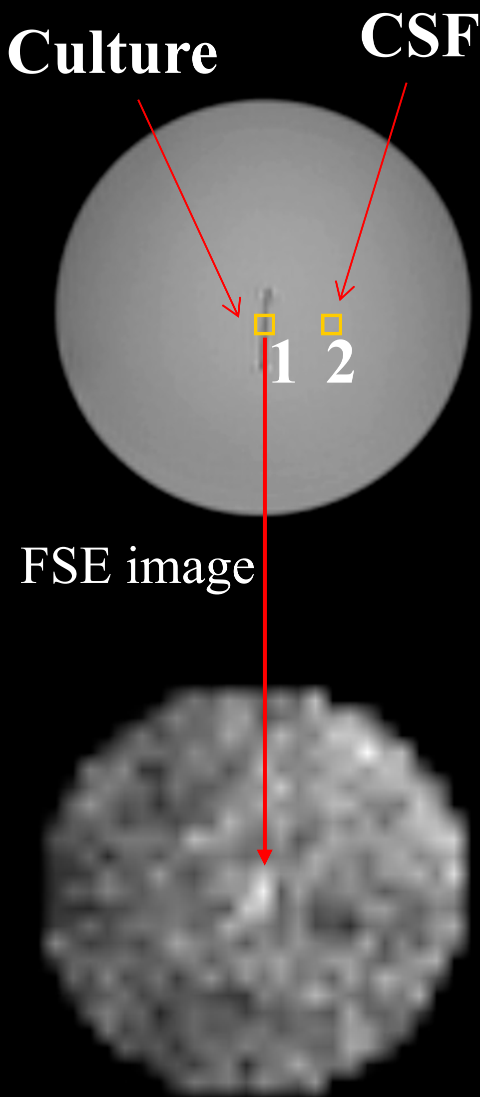


Principal Component Analysis

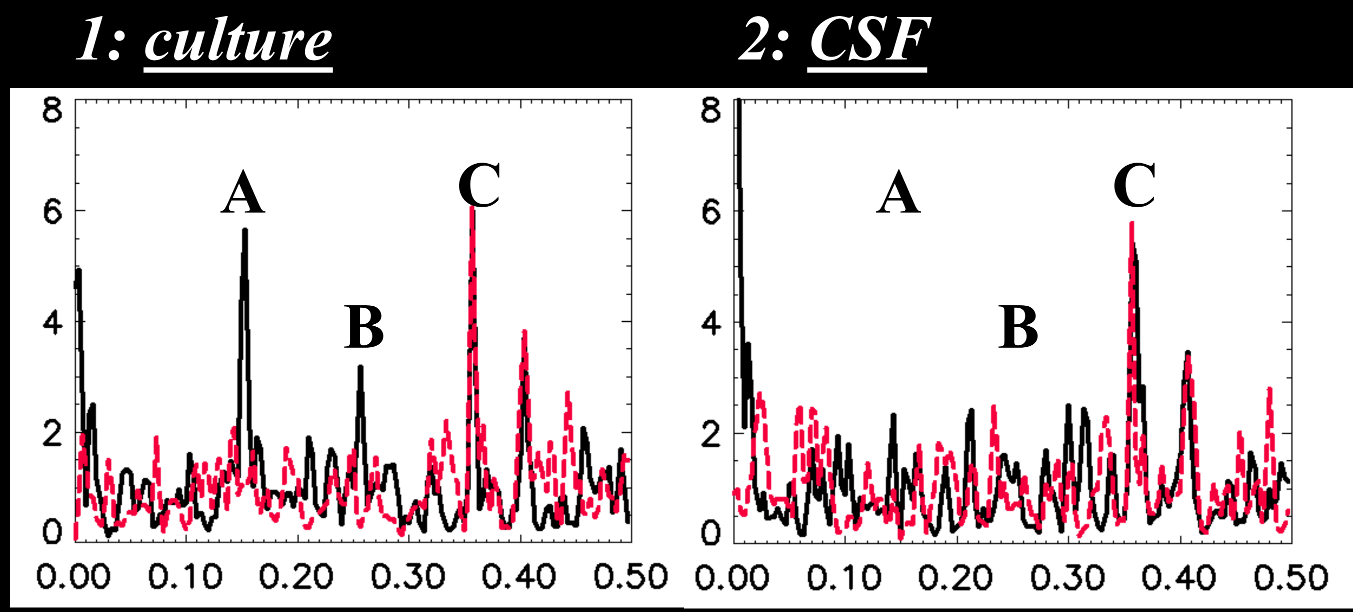
of the Spectrum

per group

results



0.15Hz map

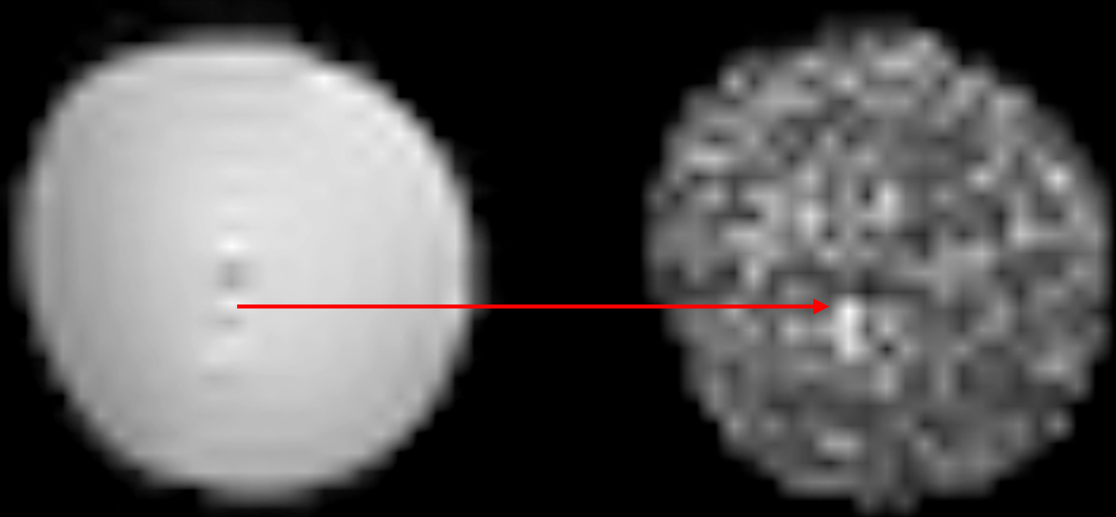


Active condition: black line
Inactive condition: red line

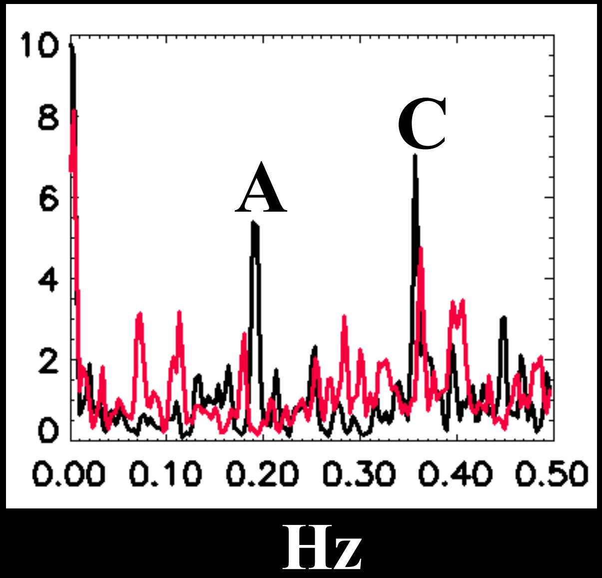
A: 0.15 Hz activity, on/off frequency
B: activity
C: scanner noise (cooling-pump)

results

Echo Planar Image **0.19Hz map**



Culture



A: 0.19 Hz activity
C: scanner cooling-pump

Active condition: black line
Inactive condition: red line

Strategies for Detection

- Time shifted sampling
- Under sampling

Time shifted sampling

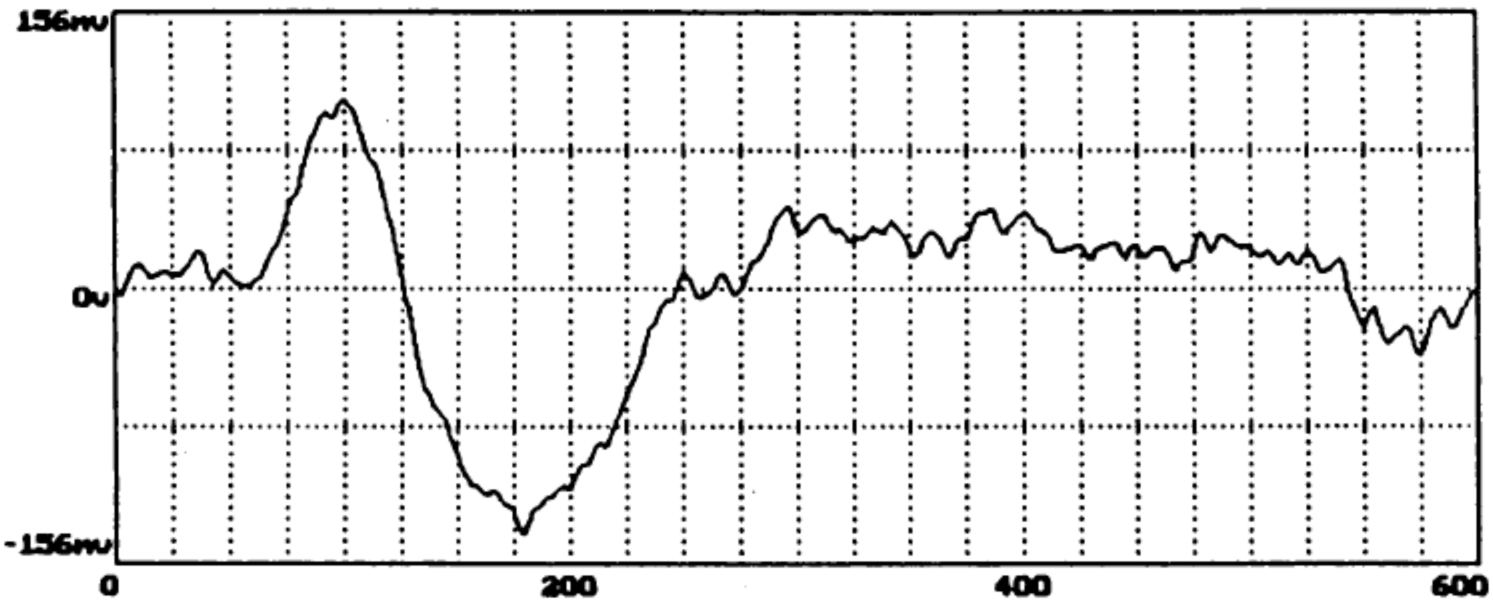
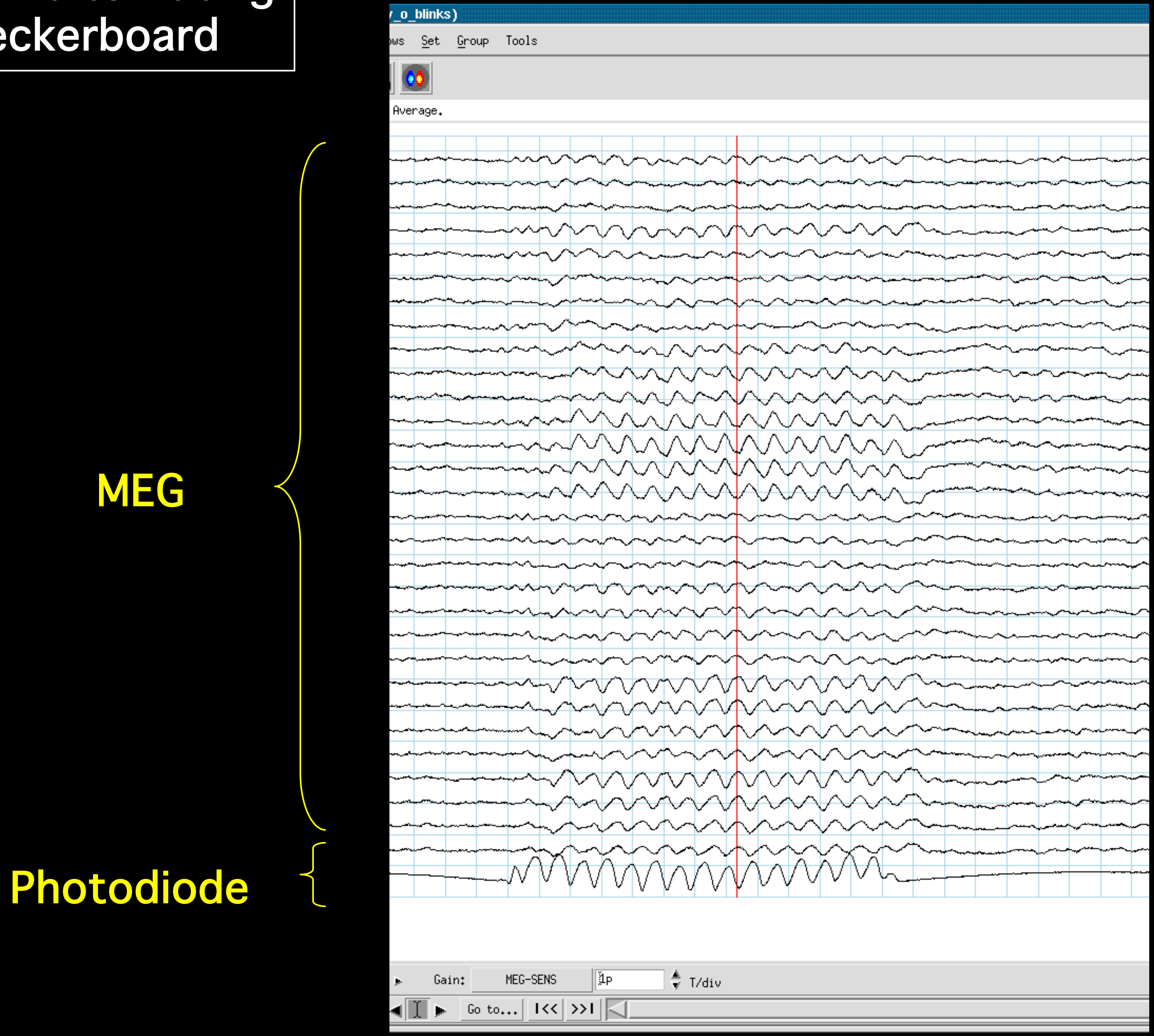


Fig. 4. A typical neuromagnetic field measurement normal to the head in response to auditory stimulation. A 50 ms wide prominent peak is seen at about 100 ms post-stimulus, followed by a wider, polarity reversed peak at about 200 ms.

M. Singh, *Sensitivity of MR phase shift to detect evoked neuromagnetic fields inside the head.* **IEEE Transactions on Nuclear Science. 41: 349-351, (1994).**

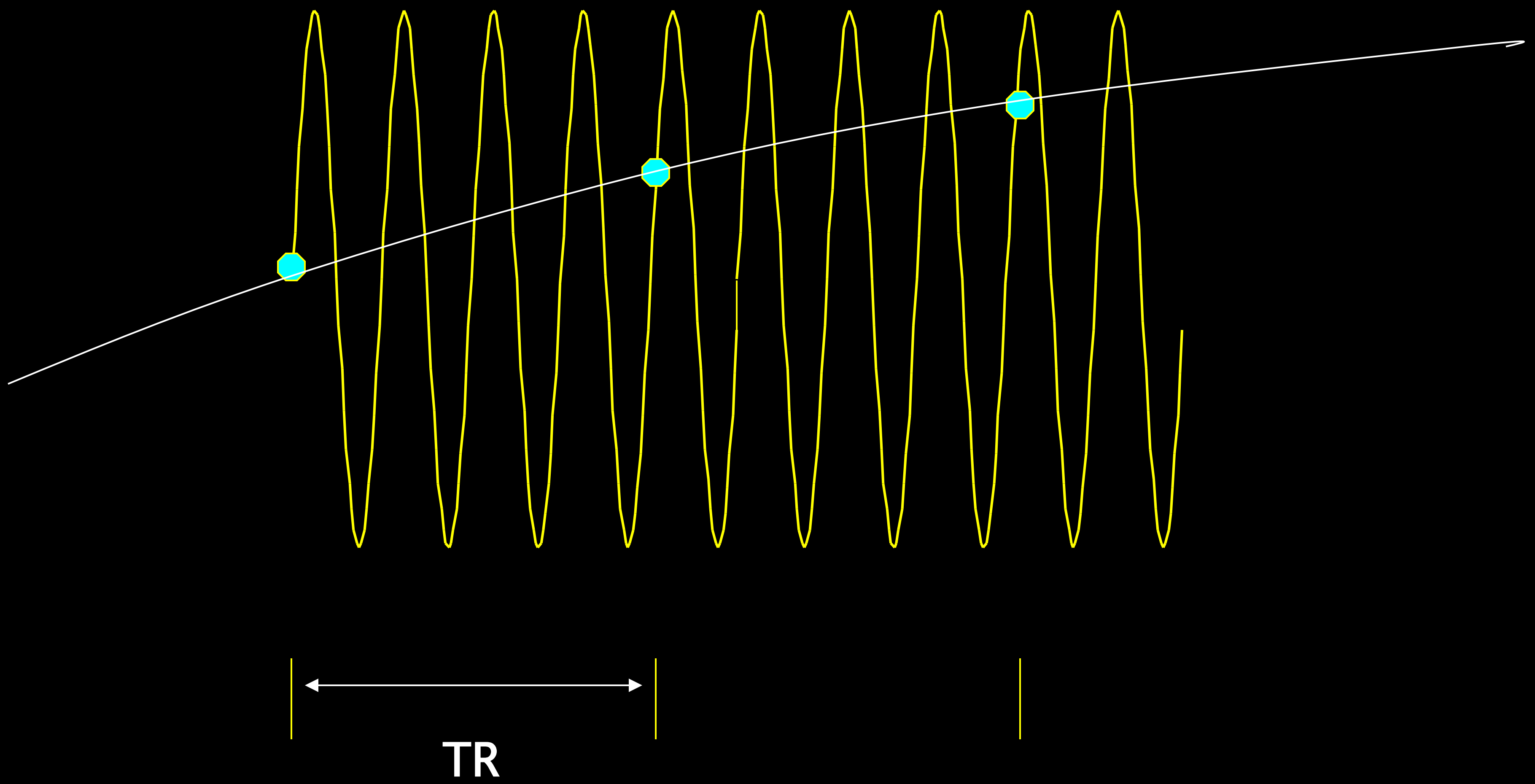
Undersampling

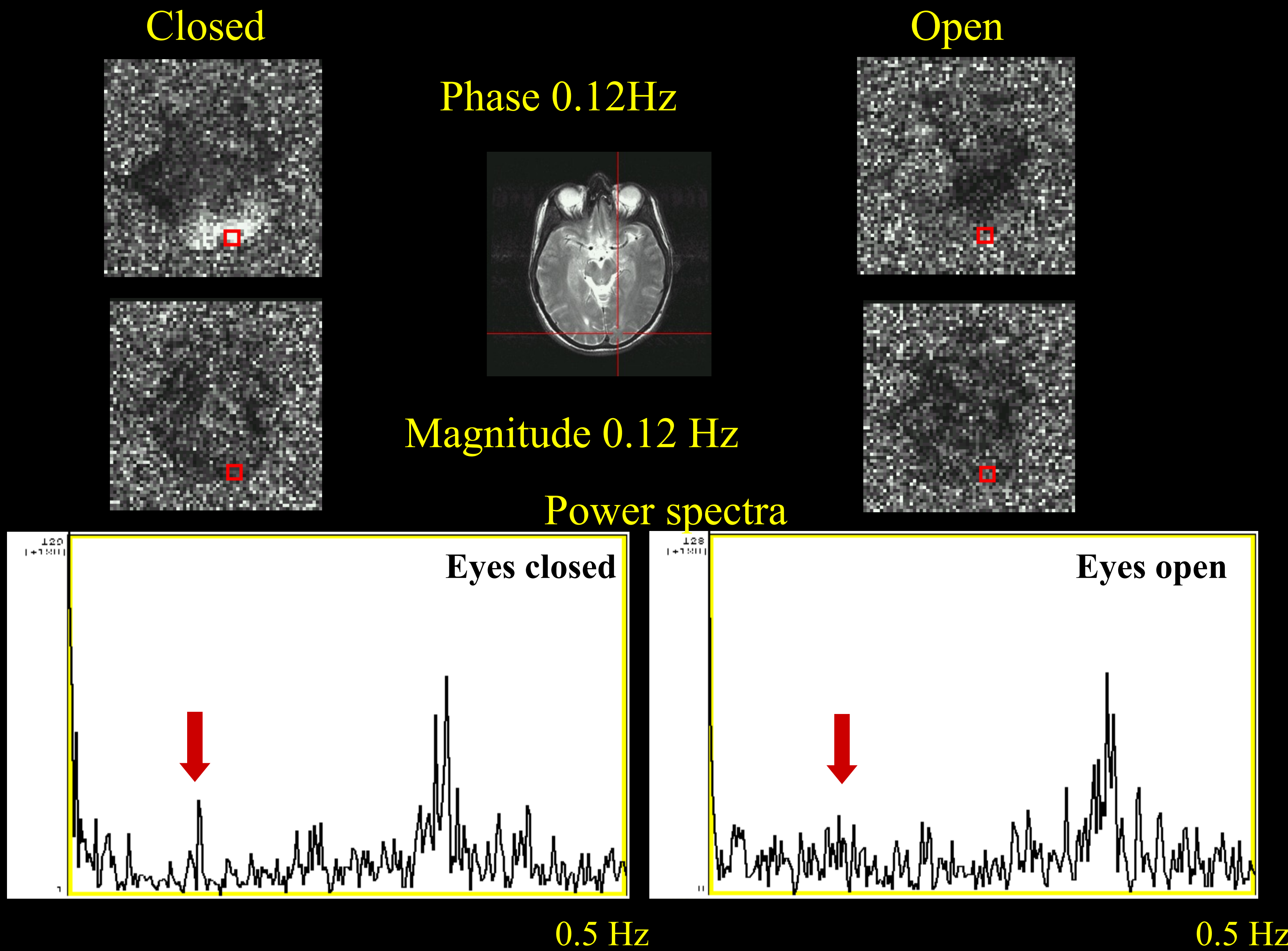
8 Hz alternating checkerboard



Undersampling

Alternating Checkerboard Frequency




Closed
Open
Phase 0.12Hz
Magnitude 0.12 Hz
Power spectra
Eyes closed
Eyes open
0.5 Hz
0.5 Hz

Caution, Despair, Hope...

- Need to rule out BOLD or other mechanisms

- Noise is larger than effect
- MR sampling rate is slow

- Neuronal activation timing is variable and unspecified
- Models describing spatial distribution and locally induced magnetic fields remain relatively uncharacterized...therefore could be off by up to an order of magnitude.

- Well characterized stimuli
- "Transient-tuned" pulse sequences (spin-echo, multi-echo)
- Sensitivity and/or resolution improvements
- Simultaneous electrophysiology – animal models?
- Synchronization improvements.