# EE 791 Lecture 6A

EEG Fallacies

Mar 1, 2018

# EEG is not an Epiphenomenon

- EEG has had a resurgence in the last two decades so is not a measure peripheral to genuine scientific interest
- EEG has very good temporal resolution but poor spatial resolution
- Intracranial electrode recordings are based on electrode size
- Scalp recordings are not based on electrode size
- Each profession prefers its own scale, electrophysiologists intracranial with very small electrodes, psychologists and clinicians surface representing larger brain function

# EEG Practice and Theory

- Variety of models and expertises in electrophysiology and biomedical engineering
- (I) Volume conduction models of electrical potentials recorded at a distance from generating sources
- (II) Models of dynamic behaviour of brain current sources
- In I superposition applies even if conductive volume is anisotropic and inhomogeneous
- In II microscopic models of brain sources do not lend themselves to experimental verification

# Treating Sources as Dipole

$$\Phi(r,\theta) \cong \frac{I d \cos\theta}{4\pi\sigma r^2} \qquad r \gg d$$

$d$ is distance between poles of dipole, $\sigma$ is conductivity of fluid, $I$ is dipole strength.

$$\therefore \Phi(r_1, r_2) = \frac{I d \cos\theta}{4\pi\sigma}\left(\frac{1}{r_1^2} - \frac{1}{r_2^2}\right)$$

If $I = 10\,\mu A$, $d = 1\,mm$, $\sigma^{-1} = 350\,\Omega\cdot cm$.

$$I(r, 0) \cong 464\,\mu V \qquad r = 2.5\,mm.$$
$$\cong 12\,\mu V \qquad r = 1.5\,cm. \text{ ideally}$$

# Effect of Dipole Sheets Cortical Contributions

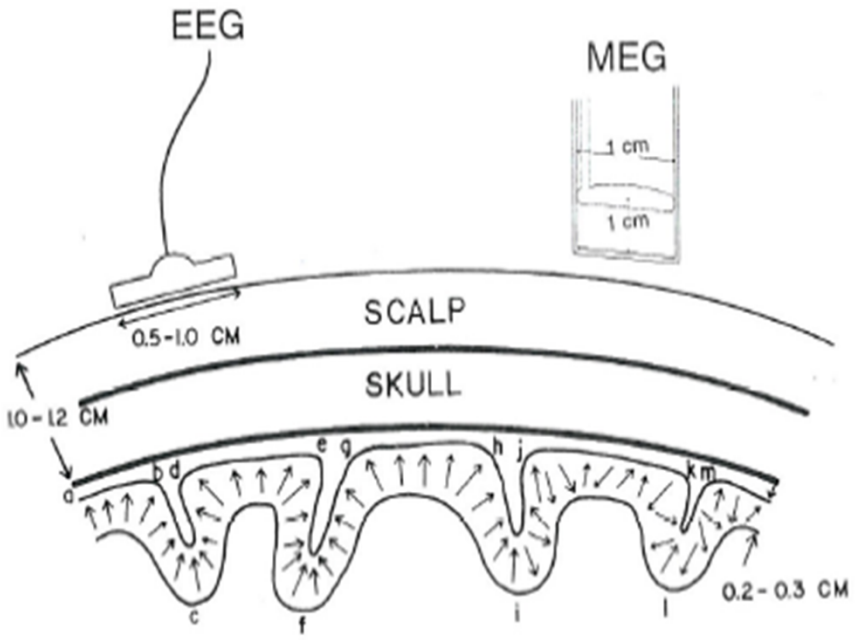


Figure 2-3 Neocortical sources can be generally pictured as *dipole layers* (or "dipole sheets," in and out of cortical fissures and sulci) with mesosource strength varying as a function of cortical location. EEG is most sensitive to correlated dipole layer in gyri (regions ab, de, gh), less sensitive to correlated dipole layer in sulcus (region hi), and insensitive to opposing dipole layer in sulci (regions bcd, efg) and random layer (region ijklm). MEG is most sensitive to correlated and minimally apposed dipole layer (hi) and much less sensitive to all other sources shown, which are opposing, random, or radial dipoles. Modified version reproduced with permission from Nunez (1995).

# Ratio of Dura to Scalp Potential

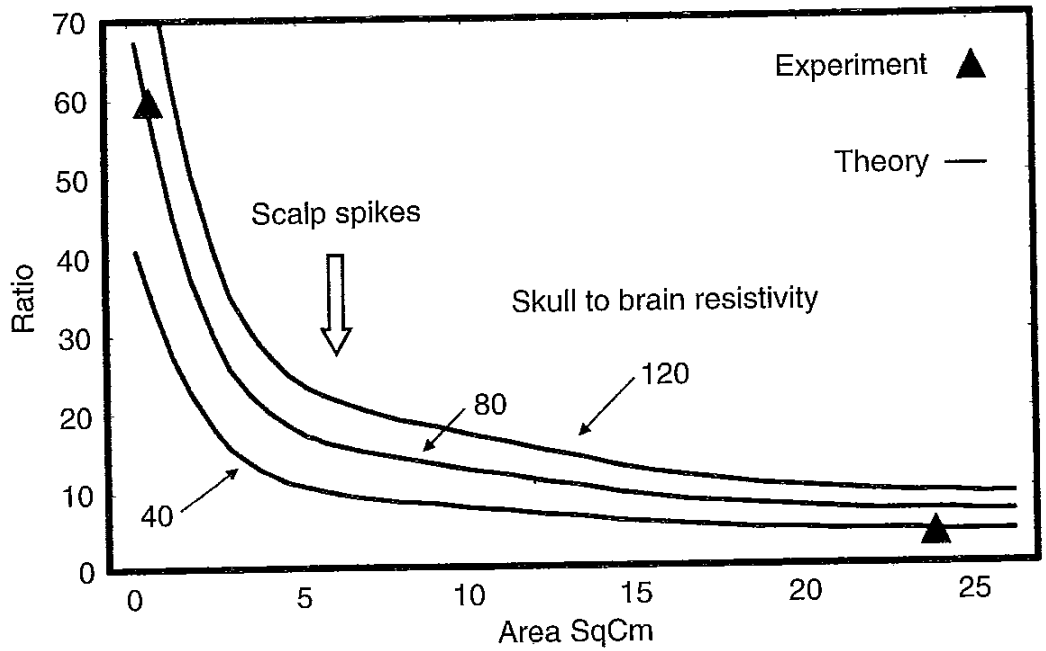


Figure 1-20 Theoretical estimates of the ratio of dura potential to scalp potential expressed as a function of "synchronous area" of active cortical sources. The three curves were generated by assuming cortical dipole layers of constant (mesoscopic) sources in the 3-sphere head model. The assumed skull to brain (or scalp) resistivity ratios are shown (40, 80, 120). The two triangles are the only available experimental points known to us (Abraham and Ajmone-Marsan 1958; Goldensohn 1979). The large arrow near the steep upturn in the curves indicates the clinical observation that epileptic spikes must be "synchronous" over at least 6 $cm^2$ of cortex in order be recognized on the scalp (Cooper et al. 1965; Ebersole 1997). Reproduced with permission from Nunez et al. (2001).

# Experimental Observations

- RMS of spontaneous cortical EEG is 2 -5 times simultaneously recorded scalp potentials
- At least 6 $cm^2$ of cortex must be synchronously active to record scalp potential
- Alpha and sleep rhythms recorded from several cm deep in brain have similar magnitudes to cortical surface potentials
- EEG frequency spectra recorded at scalp and cortex similar in range 0 – 15 Hz, much more beta at cortex surface

# EEG Forward Problem

- Sources and their locations in brain are known – unique solution for scalp potentials
- No current flux enters or leaves head or neck
- Use dipole moment per unit volume to describe sources
- Used to study common EEG problems and guide interpretations

# Simulation using 4200 Dipoles

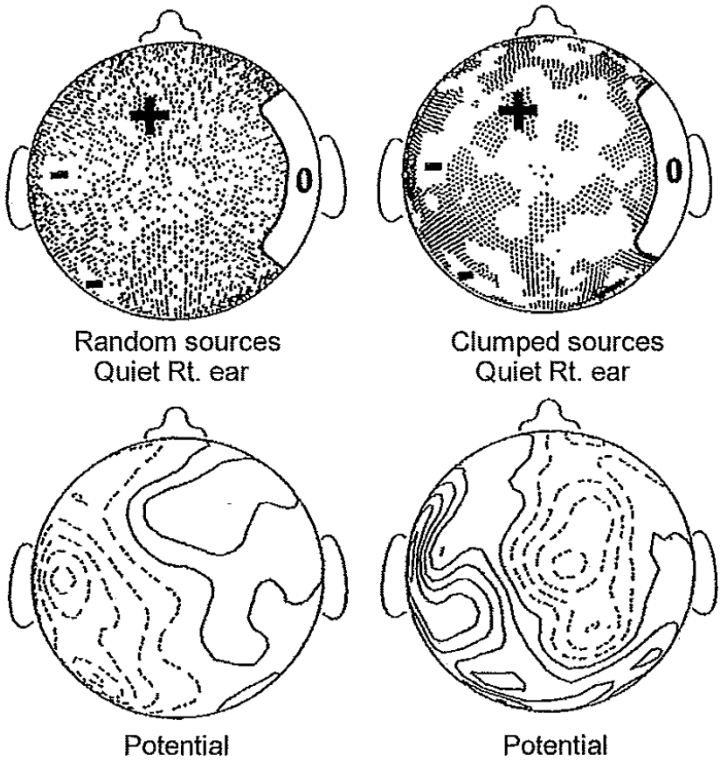


Figure 2-1 A simulation using 4200 radial dipoles (macrocolumn-scale mesosources) in a 3-sphere model of the head (brain, skull, and scalp). (*Upper row*) Filled and empty spaces indicate positive and negative source regions, respectively, with random magnitudes. The region near the right ear labeled "0" has no sources. The three clumped regions indicated by the ± signs remain unchanged as the background source pattern changes from random (upper left) to clumped (upper right). (*Lower row*) Calculated scalp potential maps predicted for a reference electrode on the right ear or mastoid. Reproduced with permission from Nunez and Westdorp (1994).

# EEG Inverse Problem

- Record signals from 20 – 128 locations
- Assume N dipole sources each with 6 parameters (3 spatial, two angle, dipole moment - μamp mm)
- Can obtain some optimum fit
- No unique solution

# EEG Inverse Problem cont'd

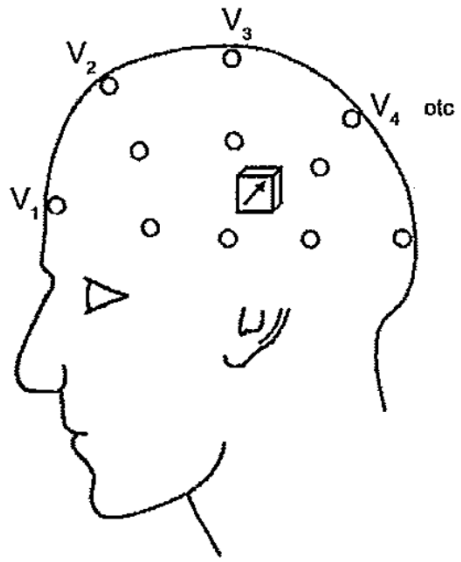


Figure 2-2 Dipole searches employing sophisticated computer algorithms are based on potentials recorded at perhaps 20 to 128 surface locations, either for fixed time slices or over some time window. If $N$ dipoles are assumed, the algorithms attempt to calculate the $6N$ parameters that best fit the recorded data—three location coordinates, two axis angles, and one strength (dipole moment) for each dipole. Application of additional *constraints* (often assumptions) may be used to reduce the number of parameters to be found.

# Physical and Mathematical Models

- Phantom heads with implanted current sources
- Test new software algorithms and hardware
- Trusted by medical scientists
- Mathematical models not readily trusted
- Must be based on physical principles (simplified)
- Used to create physical prototypes

# Errors in Developing Models

- Attributing strange non-ohmic properties to tissue
- No magnetic induction effects in tissue at frequencies below $10^6$ Hz
- Correcting volume conduction distortion using MRI or CT data. Need both geometry and electrical properties
- Placing all mathematical models in same category
- Confusing metaphor and genuine theory, e.g. Neural Network Models
- Inappropriate crossing of spatial scales
- Limitations placed on Fourier analysis requiring the system to be linear

# Quiet Reference Myth

- Reference should have no electrical source near it (we don't know the source locations)
- A number of coherent sources far away can contribute to reference source
- Arbitrary reference locations can lead to erroneous results and conclusions
- Linked ear reference?

# Artifact Free Data

- Be wary of phrase “artefact free data”
- Eye blinks and excessive eye-movement can be recognized and the data rejected
- High electrode impedance can result in 60 Hz and movement artifact (interpreted as delta or even theta)
- Attributing beta-2 and gamma activity to scalp muscle artifact
- ECG artifact in lower electrodes

# New Data Analysis Methods in Search of Application

- Visual analysis very effective if done by trained clinicians. Computer methods must complement this
- Multi-channel stochastic signals difficult to quantify visually
- Necessary to go beyond 10-20 system (what advantages)
- Inappropriate computer method
- Test new methods with physical models
- Never ignore raw data
- Results must make scientific sense (even post hoc)
- **Use Common Sense**