EEG Source Imaging in Epilepsy Evaluations

December 6, 2011

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American Epilepsy Society | Annual Meeting
Disclosure

No conflict of interest
Learning Objectives

- Realize that EEG as a basic and unique method in epilepsy evaluation provides more information when methods of source imaging are applied
- Understand how simultaneous EEG adds information to MEG
What are the goals of EEG source analysis?

1. Every EEG reviewer builds a hypothesis on the localization of the underlying cortical generator of interictal and/or ictal epileptic activity.
2. Quality of this hypothesis depends on experience.
3. Source analysis leads to more stable hypotheses and allows for better visualization by MRI coregistration.

12 y, m, refractory epilepsy with tonic/hypermotor seizures.
EEG source analysis: different models

Raw data

Averaged spikes (n=36)

- Fp2-F8
- F8-T4
- T4-T6
- T6-O2
- Fp2-F4
- F4-C1
- C4-P4
- P4-O2
- Fz-C2
- Cz-Pz
- Fp1-F3
- F3-C3
- C3-P3
- P3-O1
- Fp1-F7
- F7-T3
- T3-T5
- T5-O1

Discrete source model (regional source)

L2 minimum norm

Bilateral beamformer 10-45 Hz

LAURA
Success of EEG source localization depends on:

- Head model
  - Realistic >> spherical
    - Finite element method > boundary element method
    - Individual > standard

FEM model
Wolters et al., Neuroimage 2006

Chen et al., Med Phys 2010
Hallez et al., Phys Med Biol 2009
Michel et al., Clin Neurophysiol 2004
Scheler et al., Hum Brain Map 2007
Wolters et al., Neuroimage 2006
Success of EEG source localization depends on...

• Head model

• **Number of electrodes**
  
  • “Dense-array EEG” = 128-256 electrodes
    
    Holmes et al., Ped Neurosurg 2008
  
  • 63 vs. 128 channels no relevant difference for most cases
    
    Lantz et al., Clin Neurophysiol 2003

Brodbeck et al., Brain 2011
Lantz et al., Clin Neurophysiol 2003
Michel et al., Clin Neurophysiol 2004
Wang et al., Clin Neurophysiol 2011
Success of EEG source localization depends on...

- Head model
- Number of electrodes
  - Important: Inclusion of subtemporal positions

Ebersole, J Clin Neurophysiol 1997
Ebersole & Wade, Neurology 1991
Kobayashi et al., Clin Neurophysiol 2000
Sperli et al., Epilepsia 2006
Hamaneh et al., J Clin Neurophysiol 2011
Success of EEG source localization depends on...

• Head model
• Number of electrodes
• Analysis of spike onset instead of (potentially propagated) peak activity
  → Averaging of similar spikes

Bast et al., Neuroimage 2005
Bast et al., J Clin Neurophysiol 2006
Huppertz et al., Neuroimage 2001
Michel et al., Clin Neurophysiol 2004
Ramantani et al., J Clin Neurophysiol 2006
Zumsteg et al., Clin Neurophysiol 2005
EEG source analysis: onset ↔ propagation

-40 ms

Peak

156 averages, 5 – 45 Hz
EEG dipole localization depends on SNR

Bast et al., J Clin Neurophysiol 2006
EEG source analysis in presurgical epilepsy evaluation

✓ Comparison with invasive recordings

Assaf & Ebersole, Epilepsia 1997
Holmes et al., Neurosurgery 2010
Merlet & Gotman, Clin Neurophysiol 2001
Ray et al., Clin Neurophysiol 2006
Zumsteg et al., Clin Neurophysiol 2005

✓ Epilepsy surgery

Correct localization on lobar level > 90%

Michel et al., Clin Neurophysiol 2004
Sperli et al., Epilepsia 2006
• Interictal LAURA (routine ↔ dense array)  
  + realistic head model (standard ↔ individual)

• Sensitivity (localization within resection zone and seizure free)  
  • Individual head model and 128-256 electrodes  84.1  
  • Standard head model and 19-29 electrodes  59.1

• Specificity (localization outside resection zone and not seizure free)  
  • Individual head model and 128-256 electrodes  87.5  
  • Standard head model and 19-29 electrodes  62.5

Sensitivity > Structural MRI/PET/ictal SPECT

• Follow-up > 1 year  
• Outcome Engel 1/2 77%

• Long-term EEG in all (19-29 electrodes)  
• 55 additional dense array (128-256 electrodes)
Ictal EEG

• Methods of interictal EEG source analysis
  → ictal patterns

• Cave
  • Artifacts

• Modeling of earliest rhythmic pattern

Assaf & Ebersole, 1997
Assaf & Ebersole, 1999
Boon et al., Epilepsia 1996
Boon et al., J Clin Neurophysiol 2002
Holmes et al., Ped Neurosurgery 2008
Holmes et al., Neurosurgery 2010
Stern et al., J Clin Neurophysiol 2009
...
Impact of ictal EEG source analysis on decision making in presurgical epilepsy work-up

- Prospective study
- 100 patients
  - 83 lesional
    - 53 with unilateral mTLE
- 27 channel EEG
- Ictal recordings in 93
  - 31 analyzable without artifacts
- New and relevant information in 14 cases

Boon et al., J Clin Neurophysiol 2002
Fixed source montages are feasible and allow for quick overview

Left temporobasal spike (91 avr)
Dipole and CLARA
Onset -12 ms

See also: Assaf & Ebersole, Epilepsia 1997
Fixed source montages are feasible and allow for quick overview.

See also: Assaf & Ebersole, Epilepsia 1997
Why MEG should be combined with EEG

Is EEG old fashioned?

MEG
Better, bigger, higher...

Castle and “old bridge”, Heidelberg
Why MEG should be combined with EEG

Bast et al., Neuroimage 2005
Why MEG should be combined with EEG

Simulation

EEG

MEG

- maximum signal
- minimum signal
- no signal
Why MEG should be combined with EEG
Impact on Clinical Care and Practice

- EEG source imaging adds information that has impact on decision making in presurgical work-up. It has a sensitivity of up to 84% (specificity 87.5%) compared to resection zone in seizure free patients.
- Use more than 10-20 electrodes!
  - The more the better...
    (at least 32 channels, better ≥ 128)
  - Include subtemporal locations!
- Apply realistic head models!
- If you have access to MEG
  - Don’t forget to record EEG simultaneously!
  - Use adequate methods for both when comparing EEG with MEG!
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