Head Movement Compensation for Pediatric MEG Data using Signal-Space Separation (SSS)

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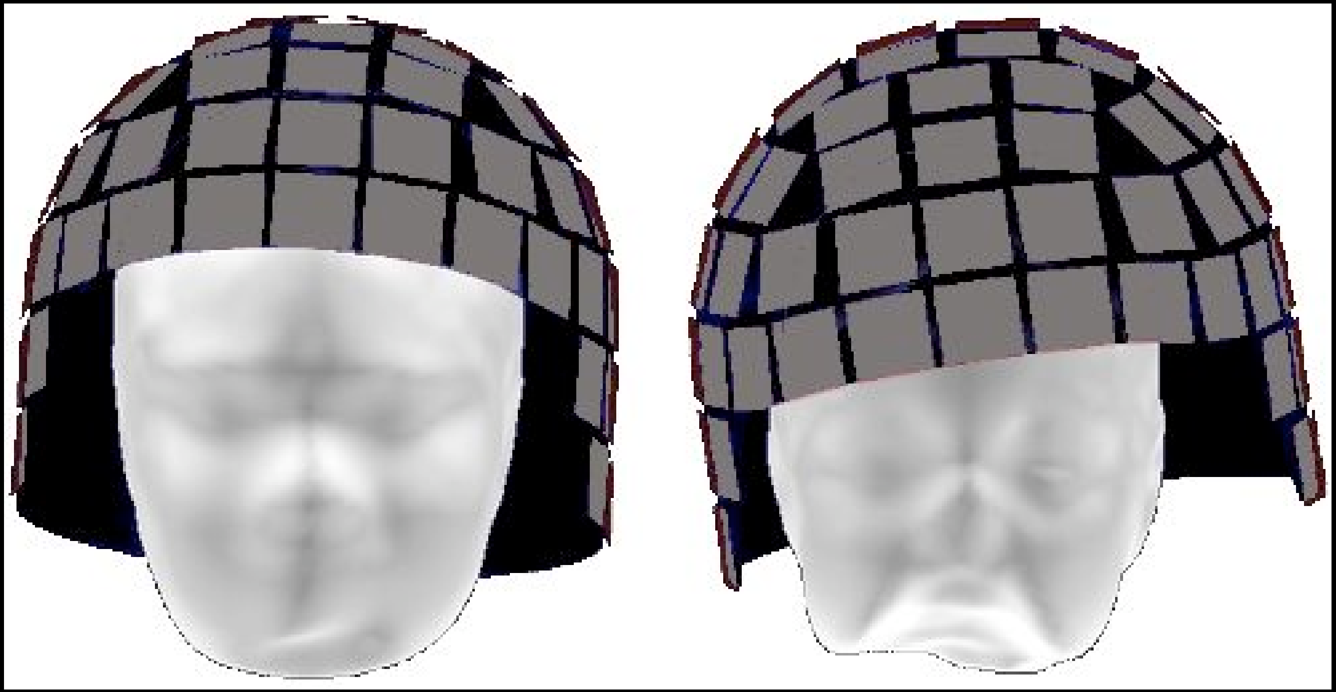
Overview

- Quantitative assessment of head movement in children
- Dipole localization error due to head movement
- SSS-correction and Equivalent Current Dipoles (ECD)
- SSS-correction and Minimum Norm Estimates (MNE)
- Practical use of continuous HPI and SSS tools

Collection of evoked MEG data with children

- Large heartbeat artifact in data due to closer proximity of heart to MEG sensors
- Large number of blink-related trial rejections
- Small head size compared to the sensor array
- Head movement during long (~1hr) cognitive task

Head position inside MEG helmet



Adult Child

MEG recording

- 20 children (8-12 years old)
- MEG signals recorded continuously
  - Sampling rate: 601 Hz
  - Filter 0.03-200 Hz
- Averaged offline with -100 to 800 ms epoch
- Rejection criteria:
  - >150μV in EOG, > 500 fT in gradiometers
- Baseline corrected (100 ms pre-stimulus), and low pass filtered at 40 Hz
- Low amplitude sinusoidal currents were fed to 4 HPI coils positioned on subject's head

Auditory Oddball Task

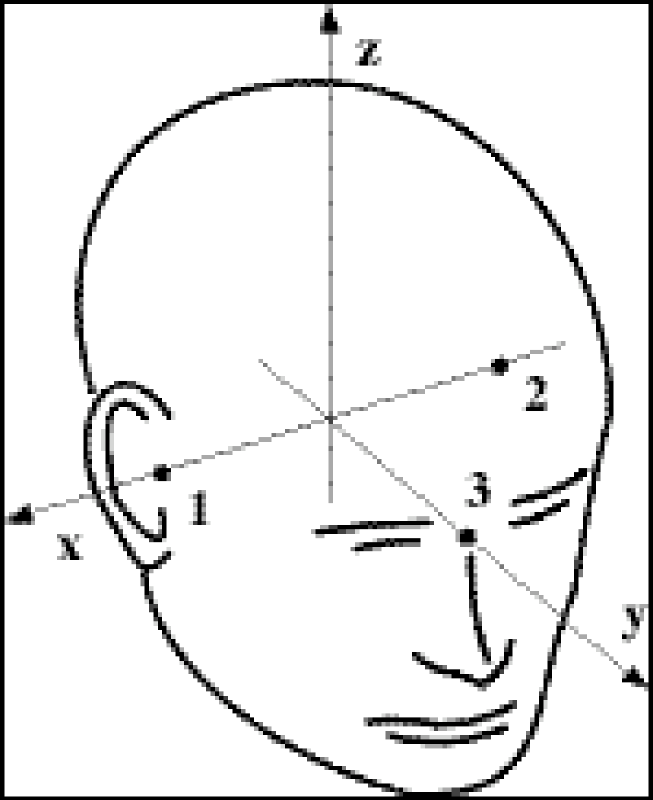
- Subjects listened to a stream of standards interspersed with occasional deviants

/pat/	/bat/	/cat/	/rat/
standard	deviant	deviant	deviant

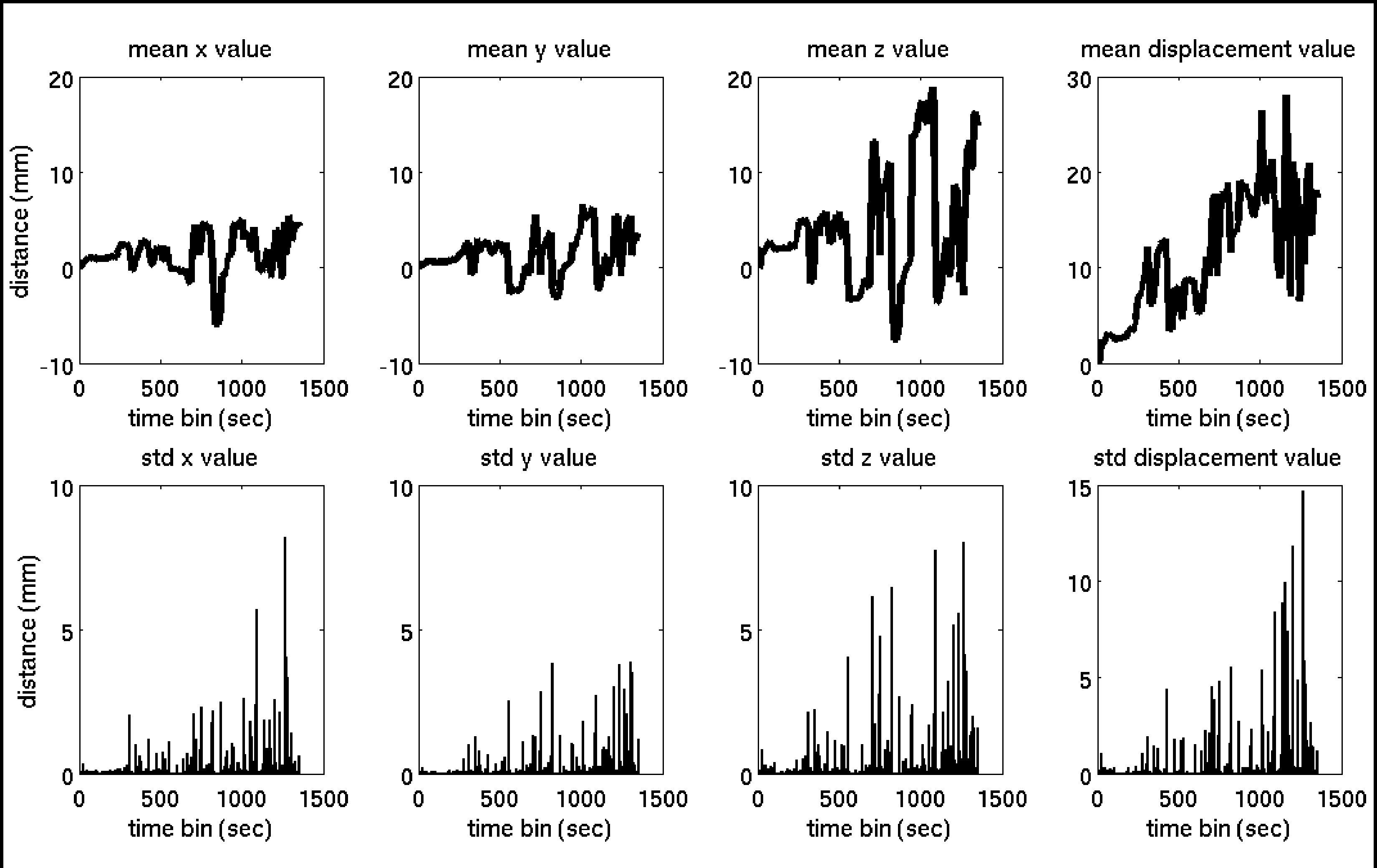
1000 standards with 100 deviants of each condition (8% each)

Assessment of Head Movement

- Position and orientation of head computed every 200 ms
- Translation (*x*, *y*, *z*) and displacement vectors of head motion were segmented into 10-second bins
- Average and variance of head motion in each time bin was calculated



Relative head motion for one child



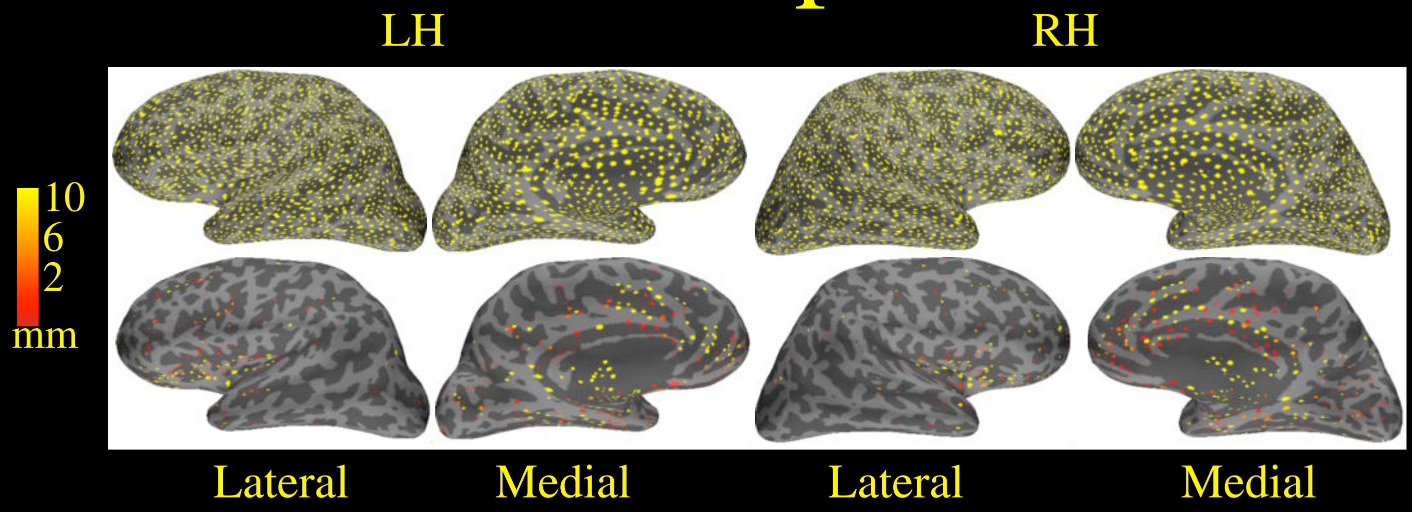
Summary for all subjects

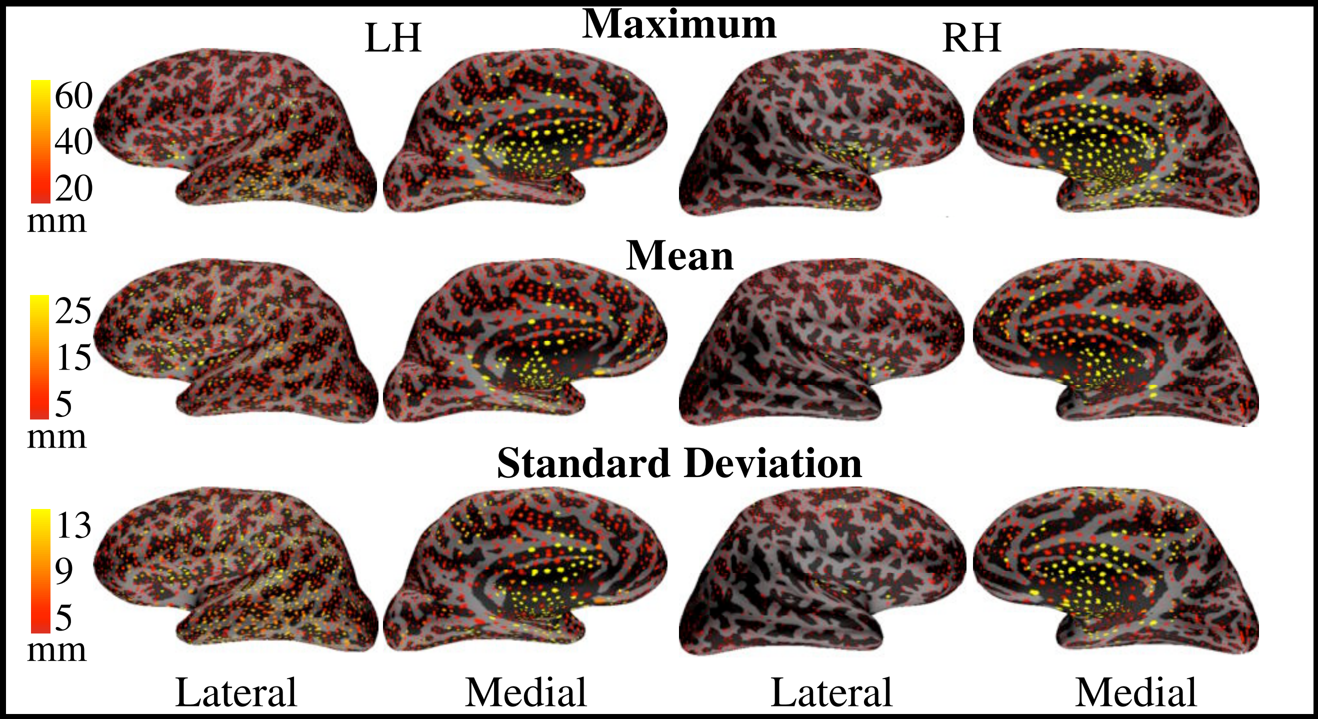
- Average displacement of head: 12 mm (range 3-26 mm)
- Average variance
  - *x*: 3.7 mm, *y*: 15 mm, *z*: 23 mm
- More variation in head movement for *z*-direction relative to *x*- and *y*-directions ($p < 0.01$, $p < 0.05$)
- More variation in head movement for *y*-direction relative to *x*-direction ($p < 0.01$)

Dipole localization error due to head movement

- MRI (TR = 2530 ms, TE = 3.25ms, flip angle = 7º, voxel size = 1.3 x 1.0 x 1.3 mm^3)
- Source space with ~7000 sources (5 mm spacing)
- Forward model calculated using BEM and initial head position
- Additional forward models at 1 second intervals using HPI information
- All forward solutions treated as simulated data
  - Current dipoles fit to field patterns (mne_dipole_fit)
  - Sensor positions in all cases corresponded to initial HPI measurement

Simulated Dipole Results





Simulated Dipole Results cont.

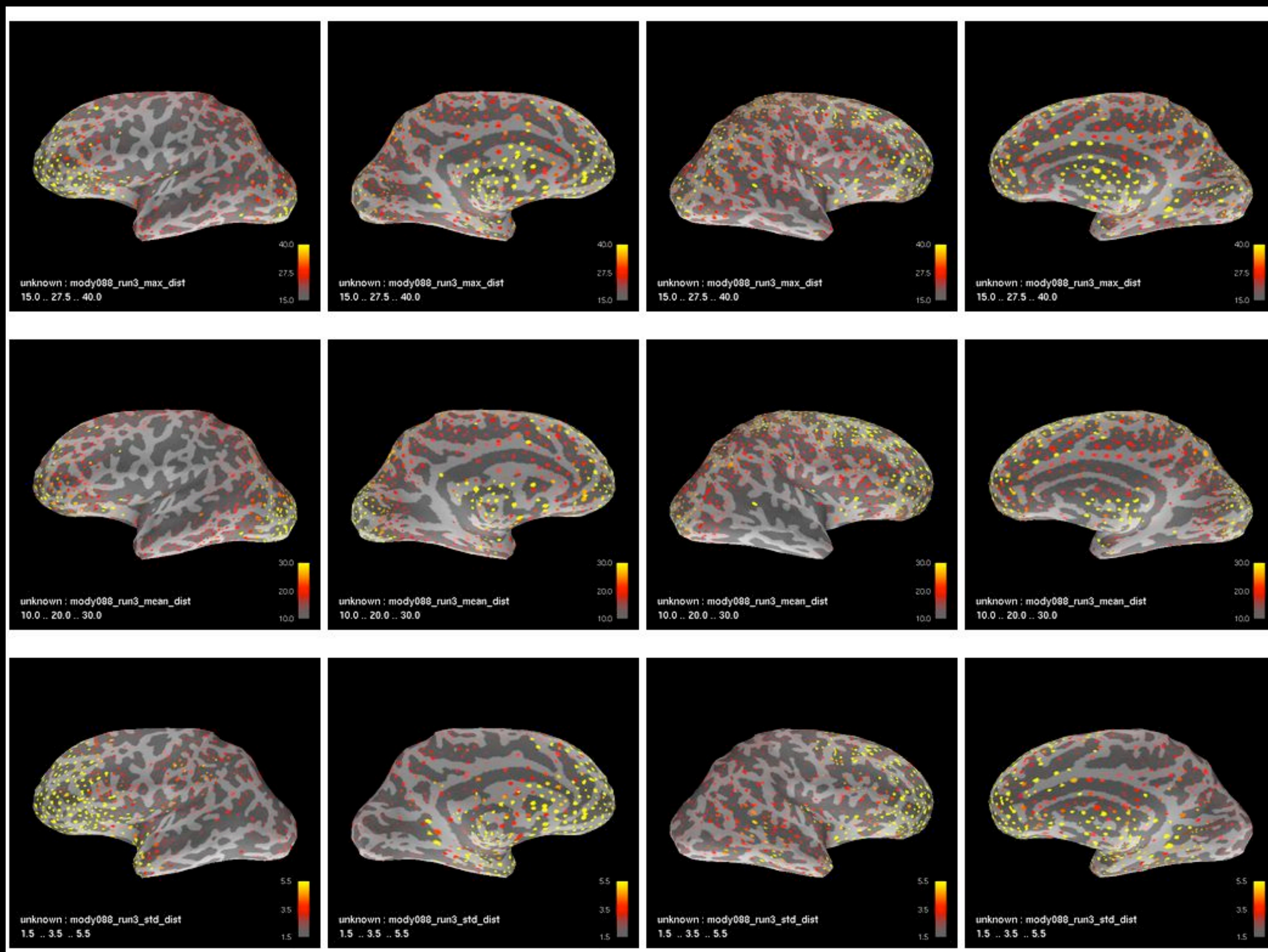
Another Subject

LH RH

Max

Mean

St. Dev



Movement Compensation with SSS

1) $\mathbf{B} = -\ {}_{0}\nabla V, \nabla^{2} V = 0$

2) $V(\mathbf{r}) = \sum_{l=0}\sum_{m=-l}^{l} \alpha_{lm} \frac{Y_{lm}(\theta,\varphi)}{r^{l+1}} + \sum_{l=0}\sum_{m=-l}^{l} \beta_{lm} r^{l} Y_{lm}(\theta,\varphi)$

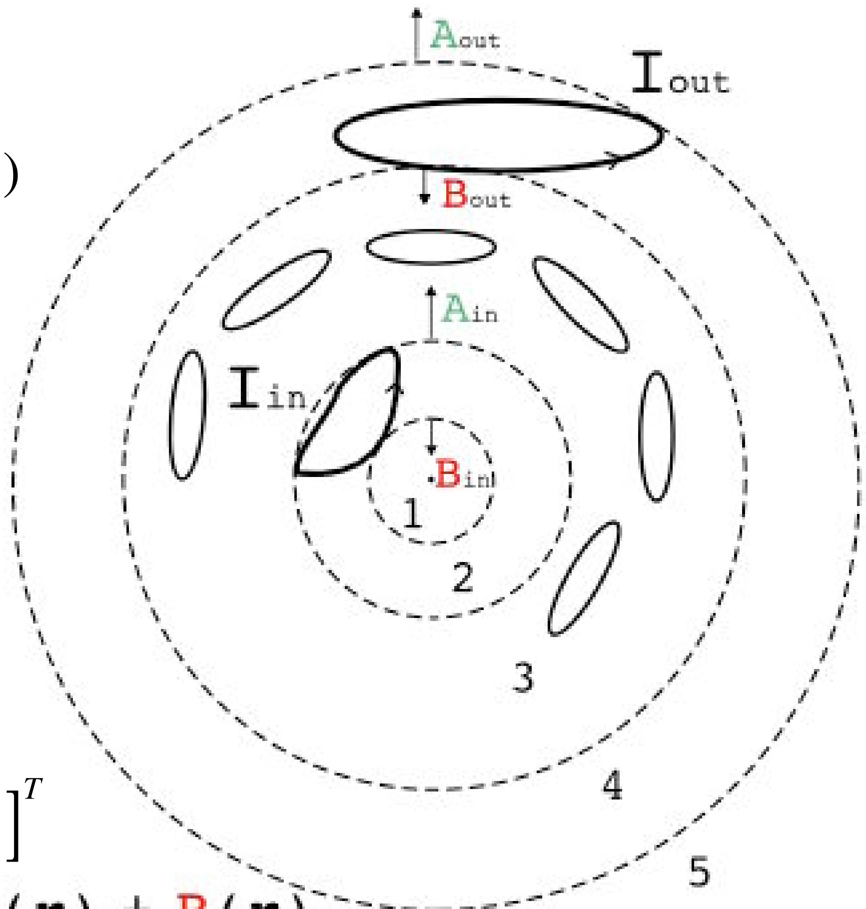
$\alpha_{lm}, \beta_{lm} = scalars, r = \|\mathbf{r}\|$

3) $\phi = \sum_{l=1}^{L_{in}} \sum_{m=-l}^{l} \alpha_{lm} \mathbf{a}_{lm} + \sum_{l=1}^{L_{out}} \sum_{m=-l}^{l} \beta_{lm} \mathbf{b}_{lm}$

4) $\phi = \mathbf{S}\mathbf{x} = [\mathbf{S}_{in}\mathbf{S}_{out}] \begin{bmatrix} \mathbf{x}_{in} \\ \mathbf{x}_{out} \end{bmatrix}$

$\mathbf{S}_{in} = \left[\mathbf{a}_{1,-1} \ldots \mathbf{a}_{L_{in},L_{out}}\right], \mathbf{S}_{out} = \left[\mathbf{b}_{1,-1} \ldots \mathbf{b}_{L_{in},L_{out}}\right]$

$\mathbf{x}_{in} = \left[\alpha_{1,-1} \ldots \alpha_{L_{in},L_{out}}\right]^{T}, \mathbf{x}_{out} = \left[\beta_{1,-1} \ldots \beta_{L_{in},L_{out}}\right]^{T}$



V(r) = A(r) + B(r)

From Taulu et al., 2005

Movement Compensation with SSS

- Calculate harmonic amplitudes attached to head (from continuous hpi)
- Model movement of subject as movement of sensor array
- Calculate signals in a virtual array locked to the subject's head

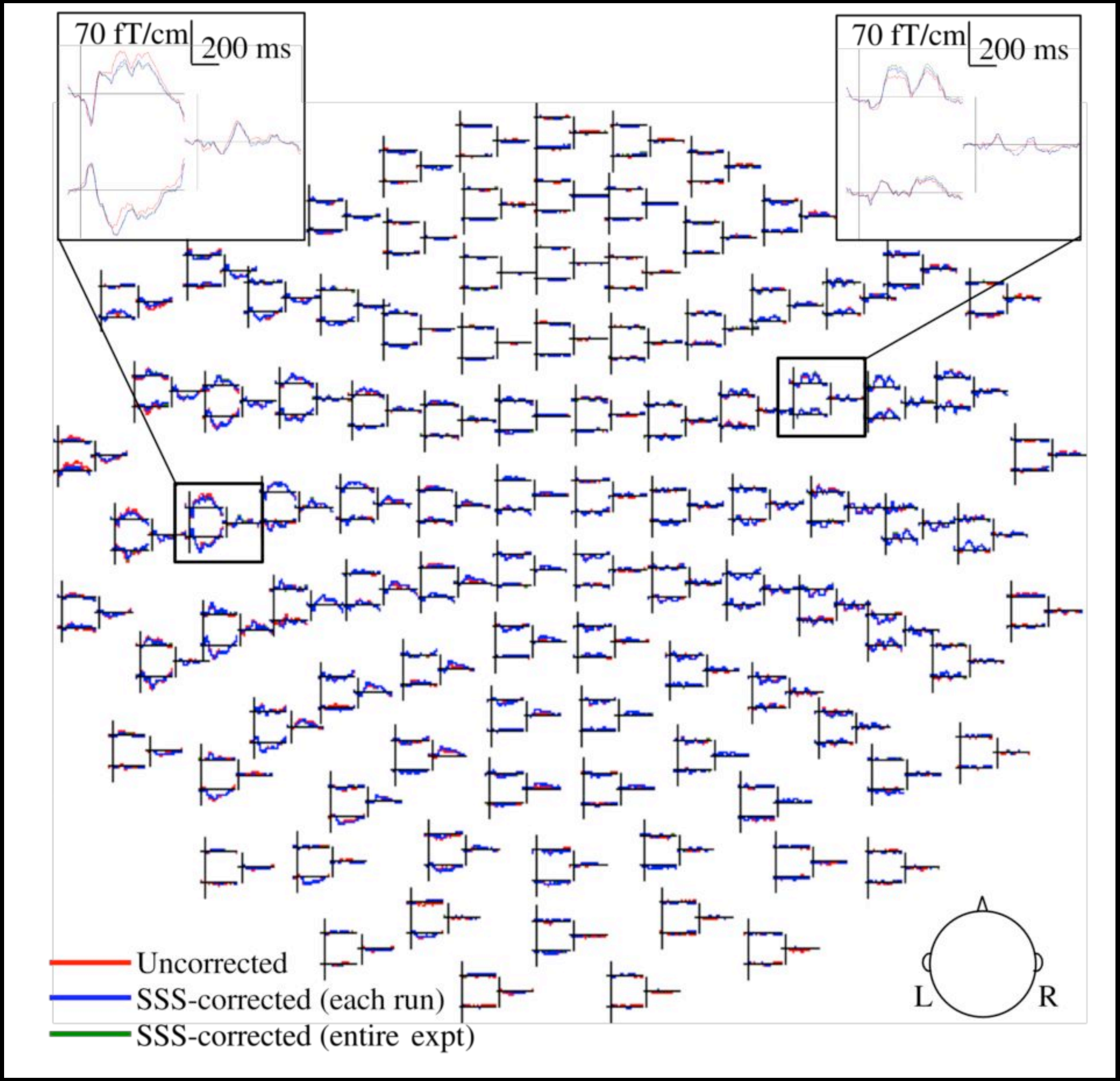
$$\hat{\mathbf{x}} = \begin{bmatrix} \hat{\mathbf{x}}_{in} \\ \hat{\mathbf{x}}_{out} \end{bmatrix} = \mathbf{S}^{\dagger} \phi$$

$$\hat{\phi}_{in} = \mathbf{S}_{in} \hat{\mathbf{x}}_{in}$$

Equivalent Current Dipole (ECD) modeling

- N100m response to repeated stimulus “pat”
- Spherical source model with origin at (x = 0, y = 0, z = 40 mm)
- SSS applied two ways
  - Within each run
  - All data transformed to head position at beginning of experiment
- Single dipole fit to N100m response in each hemisphere with and without SSS-correction
- Dependent variable: increase in GOF of the fitted ECD after SSS-correction

MEG sensor data for one child



Mean change in location
LH: 5 mm
RH: 5.6 mm

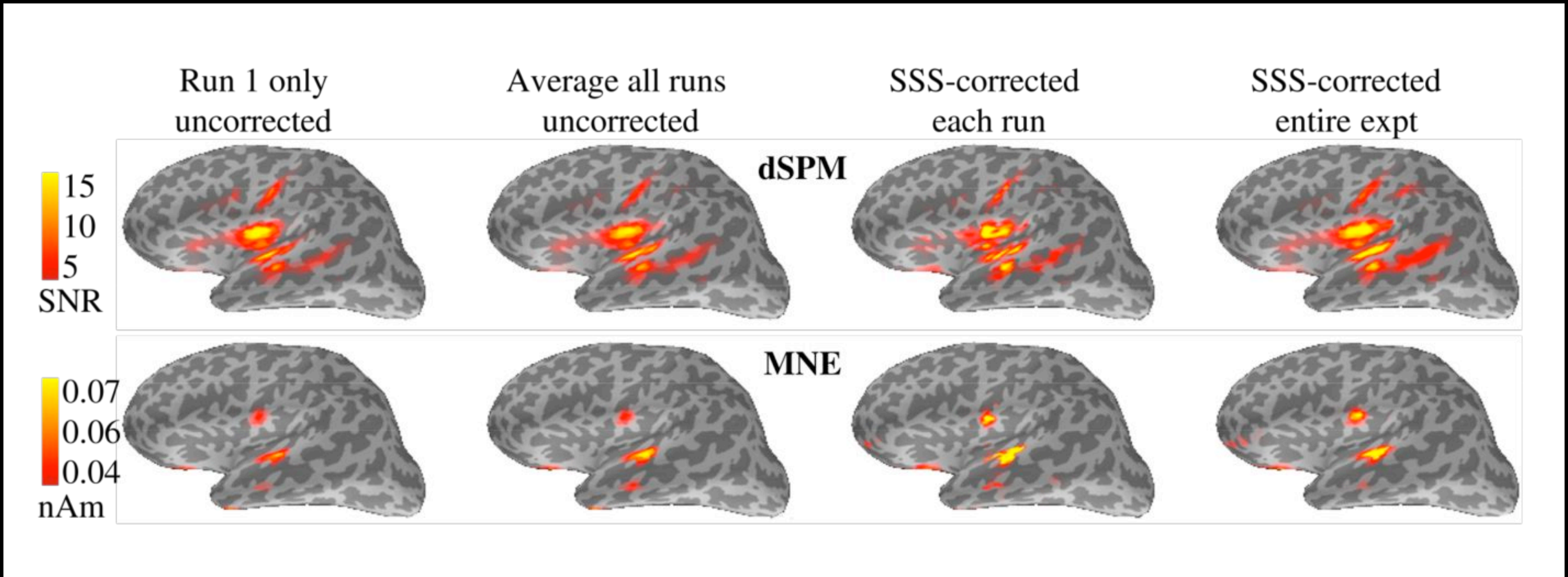
Mean increase in GOF
LH: 1.52% ($p<0.01$)
RH: 0.97 % (n.s.)

Increase in GOF in
LH: 15/20 subjects
RH: 14/20 subjects

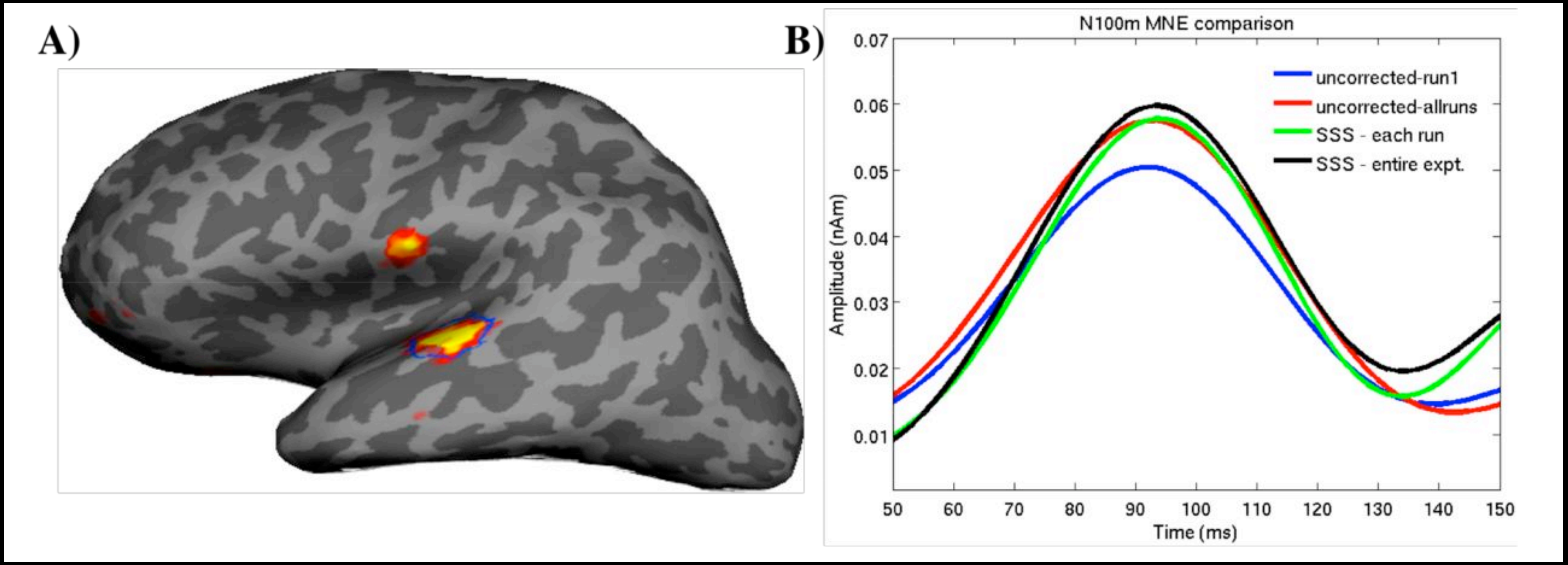
Minimum-Norm Estimates and SSS

- Forward solution was computed using
  - Initial head position from run 1 only
  - Average of head positions from each of 5 runs
  - SSS-correction within each run
  - SSS-correction to head position at beginning of experiment
- Dependent variable: difference in mean MNE amplitude within a small cortical patch surrounding peak N100m response

Results for one child



MNE Results for one child



Group statistics:

Series of planned pairwise *t*-tests showed that peak N100m response in
LH: SSS-entire expt. > SSS-each run = uncorrected-allruns > uncorrected-run1
RH: SSS-entire expt. > SSS-each run > uncorrected-allruns > uncorrected-run1

Discussion

- Averaging forward solutions from several runs gives a more robust signal than using the forward solution from run 1 alone (Uutela et al., 2001)
- SSS-correction further sharpened the N100m response significantly
  - SSS-correction to the head position at the beginning of the experiment gave the largest N100m values

Conclusions

- SSS is an effective way to compensate for head movements in children during MEG recordings
- Sharpening of brain responses resulting in higher effective SNR may be crucial for some cognitive expts. if choice of stimuli and/or attention of child is limited

Using Continuous HPI

- Attach HPI coils as usual
- Take initial HPI measurement
- After starting MEG recording, run the script ./neuro/dacq/bin/cont_hpi_on
  - Continuous hpi will start
  - You can filter it out of the display by applying LPF to display
- After finishing MEG recording, run the script ./neuro/dacq/bin/cont_hpi_off
- The continuous HPI measurements will be stored in the raw measurement files

Using the SSS program MaxFilter

- Software located on megws1, megws2, megws3
- command line $NEUROMAG_ROOT/bin/util/maxfilter

where $NEURMAG_ROOT is /space/orsay/8/megdev/megsw-neuromag

- Run MaxFilter on raw data files
  - **<u>Very important</u>** to mark bad channels in raw file
  - maxfilter -f <infile.fif> -o <outfile.fif> -v -movecomp -hp
  - maxfilter -help
- Average data as usual
- Make sure you look at data in xplotter before making MNE/dSPM movies!
- Manual located at $NEUROMAG_ROOT/manuals/MaxFilter.pdf

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