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# Anatomically Accurate Infant Head Models for EEG Source Localization

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**Abstract.** Children differ from adults in head size, skull morphology, and tissue conductivity. We conducted a simulation to examine the error of source localization when a rescaled adult head model and different skull conductivities are used for EEG source localization in children. We have proven by simulation that source localization accuracy is the best with an infant specific head model including the age specific skull structure and conductivity.

## 1. Introduction

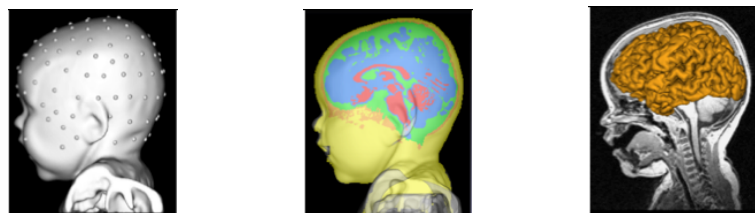
Dense array electroencephalography (dEEG) is an important noninvasive imaging modality for elucidating normal cognitive development in children and brain monitoring in neonates intensive care units. At present, the use and validation of dEEG and Electromagnetic Source Localization (ESL) in infants and children is hindered by the lack of pediatric head models. To generate an ESL solution, two independently specified problems must be solved: (1) the forward problem which specifies how currents move from their site of generation in cortex to the scalp, and (2) the inverse problem which is highly underspecified, and works from the recorded scalp potentials to the source of those signals. While many studies have shown that properly constrained realistic head models based on the high resolution MRI generate more accurate ESL solutions, the computability and necessity of additional variables such as tissue inhomogeneity and anisotropy are less well understood. While this is true of the current head models for normal adult populations, it is even more critical for pediatric populations where both the shape and density of the skull and the volume and composition of the brain are changing rapidly during first few years of life. Therefore, accurate ESL requires an accurate lead field matrix (LFM), specifying the forward lead fields, from each cortical source to each head surface electrode. Children differ from adults in head geometry, skull thickness, and tissue conductivity. We conducted a simulation to examine the error when an adult skull model and different skull conductivities are used in pediatric ESL. Specifically, we analyze three pediatric head models based on 1) a 7 months old infant MRI coregistered with the same subject CT, 2) the same MRI with warped adult CT atlas skull and adjusted thickness, and 3) an adult head rescaled to the 7 month old infant size.

The effects of the geometry (like presence or absence of fontanelles) and the skull conductivity specifications were examined. All three models were analyzed for six conductivity values ranging from the lowest value reported in the literature [1] 0.004 S/m through the average adult value 0.018 S/m to the average scalp conductivity (effectively no skull) and 18 ( $3 \times 6$ ) LFMs have been generated by our in-house finite difference forward solver for ESL. We have chosen a set of representative dipoles near fontanelles on the infant cortical surface in the model as the “synthetic ground truth” EEG data assuming 0.1 S/m to be the true infant skull conductivity value, and localized the sources with the minimum norm (MN) and sLORETA [2] distributed source localization methods using the rest of LFMs for 3 geometries with 6 skull conductivity specifications.

## 2. Methods

### 2.1. Forward problem

MRI image segmentation and registration were conducted with the EGI MRI/CT software package, BrainK[3] that is capable of cortical surface extraction and skull data warping to subject specific head shapes obtained from MRI scans. Sensor positions and head shapes are provided by the Geodesic Photogrammetry System (GPS) [4]. For the ground truth and reference, a true infant model(True) was created using subject specific MRI/CT data acquired at Washington University [5] and sensor positions for a 7 month-old baby (figure 1). After the segmentation and cortex tessellation, the oriented dipoles grid was constructed and LFMs were generated with our in-house finite difference solver [6]. We calculated 18 different LFMs, comparing 3 geometries and 6 skull conductivities. For comparison an adult skull was warped (Warped) to match subject specific MRI and an adult model (Adult) was simply rescaled to match the pediatric sensor positions, retaining the adult tissue morphology. In both cases the fontanelle structure was lost (figure 2). The ground truth EEG was calculated assuming a uniform skull conductivity of 0.1 S/m and the true infant model for several dipole locations: near the fontanelles, the eyeball and deep in the brain. The skull conductivities were varied according to the set of values 0.004 S/m, 0.018 S/m, 0.1 S/m, 0.2 S/m, 0.35 S/m and 0.45 S/m.



(a) Sensors on Scalp (b) Segmentation (c) Cortical surface

**Figure 1.** Sensors on pediatric head were registered by geodesic photogrammetry. A relative thresholding method segmented the scalp, skull, CSF, and gray and white matter. The cortical surface was extracted.



(a) True (b) Warped (c) Adult

**Figure 2.** Skulls of three geometries. The true model contains frontal and occipital fontanelles. Both warped and adult head models don't have fontanelles.

## 2.2. Inverse problem

We use the MN and sLORETA methods of ESL. The distributed source localization can be stated as following: for measured  $\Phi$  and known  $K$ , find  $J$  given  $\Phi = KJ$ , where  $\Phi$  is the electric potential at the electrodes of size  $N_e$ ,  $J$  is the (unknown) amplitude of each current dipole of size  $N_v$ , and  $K$  is the lead field matrix linking the current sources to the electric potential of size  $N_e \times N_v$ . The MN solution is  $\hat{J} = \arg \min_J \{\|\Phi - KJ\|^2 + \alpha\|J\|^2\}$ , where  $\alpha$  is a non-negative regularization parameter and  $\|\cdot\|^2$  represents the square of the  $l_2$ -norm. The MN solution  $\hat{J}$  is  $\hat{J} = K^T[KK^T + \alpha I_{N_e}]^{-1}\Phi$ . The sLORETA solution  $\hat{J}^*$  is  $\hat{J}_l^* = [C_j]_{ll}^{-1/2} \hat{J}_l$ , where  $l = 1, \dots, N_v$  and  $C_j = K^T[KK^T + \alpha I_{N_e}]^{-1}K$ .

After the inverse problems are solved, the source solutions are validated by estimating the localization error distance (LED). The LED is the Euclidean distance between the locations of true dipole and the dipole with maximum intensity in the source distribution. To separate the effect of conductivity variation from differences in the geometry on source estimates, the ground truth EEG was calculated in each model assuming a uniform skull conductivity of 0.1 S/m. The sources were localized using all 6 LFMs with different conductivities. To see the effect of the head geometry, we have focused on a dipole near the rear fontanelles in the subject specific model with the skull conductivity of 0.1 S/m. The forward projection of the dipole was considered as the true EEG. We performed the source localization of this EEG data with the 3 LFMs created for 3 different geometries with skull conductivity 0.1 S/m.

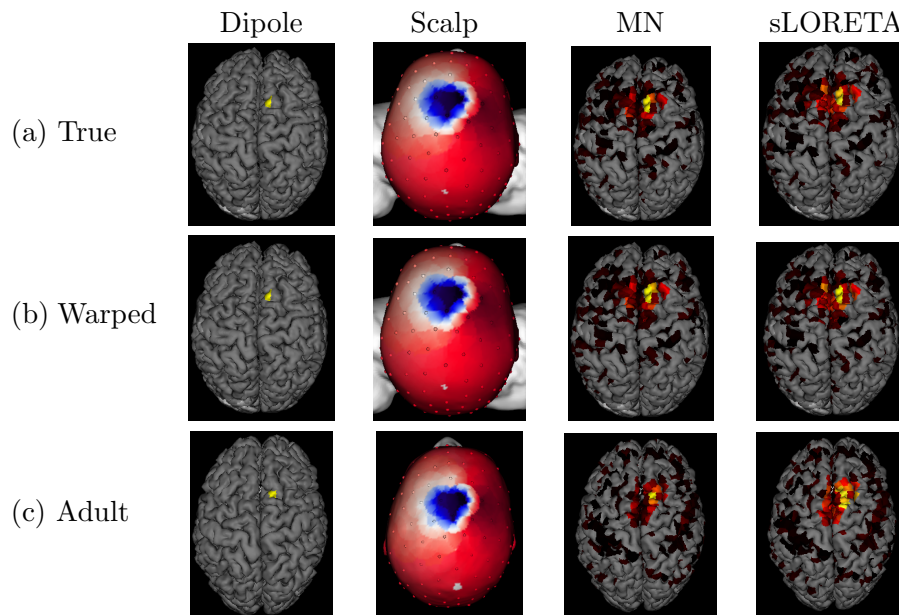
## 3. Results

Table 1 summarizes the LEDs to assess the effect of skull conductivity. The LED is minimal, for both MN and sLORETA solutions, when the conductivity values used in the head model matches with those used to generate the synthetic EEG data. Use of the head models with the correct skull conductivity values results in the minimal LEDs. When skull conductivity values are small (skull is more resistive), the errors are larger.

The effect of head geometry on source localization can be seen in figure 3. A dipole was placed near the frontal fontanelle in the true model with skull conductivity of 0.1 S/m. Scalp potentials of the forward projections of the chosen dipole shows that the potential distribution is very focal. Since the dipole is located near the head surface, it can be easily localized. LEDs for true and warped head models are 0 mm but 5.39 mm for adult head model in both the MN and sLORETA methods. Placing the dipoles in other brain regions we showed that accurate head geometries are significantly more important for the deep sources than the shallow ones.

**Table 1.** The mean of LED is in mm. LFMs with 0.1 S/m obtain the minimum LED in three geometries by both MN and sLORETA.

Method	Head Geometry	Skull Conductivity (S/m)					
		0.004	0.018	0.1*	0.2	0.35	0.45
MN	True	17.3	15.5	15.1	15.1	15.2	15.2
	Warped	18.4	16.2	15.2	15.3	15.4	15.5
	Adult	19.8	18.3	13.9	14.9	16.3	16.6
sLORETA	True	3.7	0.3	0	0	0	0.0
	Warped	7.6	1.1	0	0	0.0	0.1
	Adult	10.6	4.6	0	0.1	0.5	1.0



**Figure 3.** From left to right: a probe dipole near the frontal fontanelle in the true model is placed at the same location in both comparison cases; scalp potential of the forward projections of the probe dipole; localized sources using MN and sLORETA.

#### 4. Conclusions

Accurate ESL with infants and young children requires electrical lead fields (head models) constructed to match both the unique geometries and skull conductivities of the appropriate age child instead of using rescaled adult head models. The actual conductivity values for infant skull are not well known presently, but unlikely to be in the adult range of low values. Therefore further studies are needed and methods like bounded EIT [6] can be used for noninvasive regional tissue conductivity estimates in infants.

#### Acknowledgments

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#### References

- [1] Roche-Labarbe N, Aarabi A, Kongolo G, Gondry-Jouet C, Dumpelmann M, Grebe R and Wallois F 2008 *Human Brain Mapping* **29** 167–176
- [2] Pascual-Marqui R D 2002 *Methods and Findings in Experimental and Clinical Pharmacology* **24** 5–12
- [3] Li K, Malony A and Tucker D M 2006 *First International Conference on Computer Vision Theory and Applications (VISAPP), Portugal, February* pp 354–364
- [4] Russell G S, Eriksen K J, Poolman P, Luu P and Tucker D M 2005 *Clinical Neurophysiology* **116** 1130–40
- [5] Larson-Prior L, Prior F, Smith K, Mattson C, Song J, Nolan T S, Luu P, Tucker D and Turovets S 2013 *IEEE Explore, EMBC, June 2013*
- [6] Salman A, Turovets S, Malony A and Volkov V 2008 *International Workshop on OpenMP (IWOMP 2005/2006) LNCS 4315* pp 119–130