International Journal of Bioelectromagnetism
Vol. 9 No. 2 2007

The Influence of Electrode Size on EEG Lead Field Sensitivity Distributions

Katrina Wendel, Nathaniel G. Narra, Markus Hannula, Jari Hyttinen, and Jaakko Malmivuo
Ragnar Granit Institute
Tampere University of Technology, 33101 Tampere, Finland
katrina.wendel@tut.fi

Abstract

We examined the effect of electrode contact size on EEG measurement sensitivity distributions. We used concentric spheres and realistic head models to evaluate electrode diameters of 1 mm, 5 mm, 10 mm and 15 mm. We used the half sensitivity volume (HSV) to evaluate the results. The spherical model results show that the farther the electrode pairs are spaced (i.e. lower resolution EEG) the more the cortical sensitivity distributions are affected by the electrode contact area; however, the realistic models indicate that the cerebrospinal fluid (CSF) thickness overshadows the influence of electrode contact size.

1. INTRODUCTION

In this paper we analyze the effect of electrode size on lead field sensitivity distributions, although surface EEG electrodes are commonly modeled as point electrodes regardless of the complexity of the tissue geometry. The study by Ollikainen et al. [1] concludes that the point electrode model (PEM) is sufficient in EEG studies when the electrodes cover less than 50% of the scalp surface. They evaluated 2D spherical models that excluded the CSF and used a scalp-to-skull conductivity ratio of 80:1. Contrarily, Law [2] claims that 1.0 cm diameter electrode yields the best results for their spline functions. Our models include CSF thickness variation to analyze the influence of different electrode sizes.

2. METHODS

We used the four concentric spheres and the realistic head model configuration in [3]. We varied the spherical-model CSF thickness from 3.5 mm to 2.0 mm and 0 mm, while expanding the brain to fill the void. Our segmentation of the Visible Human Woman (VHW) was down-sampled from the 0.33 mm voxel resolution to 1.65 mm in all directions. Each tissue was segmented, contoured, splined, and lofted together. The VHW model extends from the apex to the transverse plane cutting through standard electrode locations F_{P0}, F_{P1}, and F_{P2}. Likewise, we shrank the CSF from 2.8 mm to 2.0 mm and 0 mm to formulate two more realistic sets. In all models, we set the brain, CSF, and scalp conductivities to 0.25 S/m, 1.79 S/m, and 0.45 S/m, respectively [4], and the skull conductivity was defined by the brain-to-skull conductivity ratios σ_{Br}/σ_{Sk} of 5, 10, 15, 20, and 80.

We constructed the electrodes as simple recessed electrodes [5]. The electrode locations are selected along the central sulcus according to the 10-20 down to the 5-5 EEG standard measurement locations. In our notation we specify these locations by the angle of electrode separation. Lastly, our electrode diameters measure 1 mm, 5 mm, 10 mm, and 15 mm.

We simulated the sensitivity distributions by feeding a reciprocal unit current through each bipolar electrode pair. The spatial region of the current distribution maps the measurement sensitivity distributions. These distributions are determined according to the current density $\mathbf{J}$, where $\mathbf{J} = -\sigma\nabla\Phi + \mathbf{J}^e$, which is a function of the scalar potential Φ and the externally applied current density $\mathbf{J}^e$, assuming bioelectric currents and voltages to be quasistatic [6]. We evaluate these simulations according to their half sensitivity volumes (HSV) to identify the area where the top 50% of the current density isosensitivity surfaces are within the brain [6].

3. RESULTS

The comparison of the HSV between models identifies the relative spatial resolution of the model configuration. The results from the spherical models and realistic models are presented in Fig. 1. Comparisons of the realistic HSV data yield no significant change according to the conductivity of the skull, although the spherical model results vary. Additional realistic HSV results at

35° for σ_{Br}/σ_{Sk} of 10 diminish as follows: 7.2%, 7.1%, 6.1%, 6.0%, 5.9%, 5.5%, and 3.8% for CSF thicknesses and electrode radii of thick 5 mm and 10 mm, thin 5 mm, 10 mm, and 15 mm, no CSF 15 mm and 10 mm, respectively (thick CSF = 2.8 mm, thin CSF = 2.0 mm, no CSF = 0 mm).

4. DISCUSSION

Simpler models often reduce the complexity of the geometry and/or the parameters. In these models the influence of the electrode size increases with the angle of electrode separation. However, the realistic geometry suppressed this effect for σ_{Br}/σ_{Sk} between 5 and 20. Consequently, the sensitivity distributions of these models were primarily influenced by the change in CSF thickness and the σ_{Br}/σ_{Sk}.

5. CONCLUSION

By presenting our results in the form of sensitivity distributions, we present data and distributions relevant to the forward and inverse EEG problems, transcutaneous electrical neural stimulation (TENS), and the current carrying pairs of bioimpedance electrodes. These results indicate that spherical models should specify electrode dimensions according to experimental setups, whereas, the realistic HSV results indicate that the change in electrode diameter is negligible.

References

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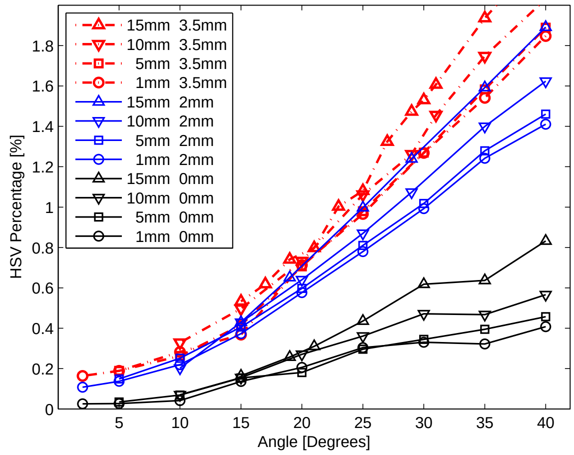
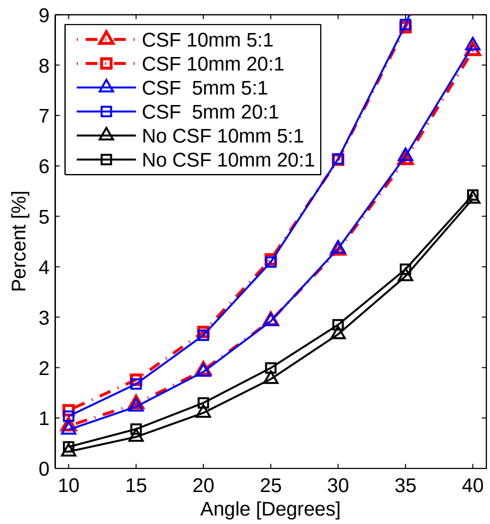


(a) Spherical Models: HSV



(b) Realistic Models: HSV

Figure 1. Percentage of the brain mapping the HSV versus electrode separation angle. (a) Spherical model results for σ_{Br}/σ_{Sk} of 10. Legend: Electrode diameter (left value), CSF thickness (right value). (b) Realistic model results. Legend: CSF thickness (2.8 mm or 0 mm), electrode diameter, and σ_{Br}/σ_{Sk}.