Current Versus Optimal Laplacian Estimates via t-Lead Electrodes on Human Electroencephalogram Data

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Introduction

t-Lead is a commercial tripolar concentric ring electrode (CREmedical, Kingston, RI), specifically designed for noninvasive electrophysiological measurement applications, including studies involving human subjects. Utilizing the ability of concentric ring electrodes to directly estimate the second spatial derivative (surface Laplacian) at each individual electrode by combining differential voltages recorded between the central disc and the rings with specific coefficients makes them of significant importance in biomedicine. Our recent research showed that optimal coefficients (6,-1) maximizing the accuracy of Laplacian estimation for the electrodes with dimensions similar to the t-Lead are different from the currently used coefficients (16,-1) [1]. This study applies time and frequency domain (cross-correlation and coherence respectively) signal synchrony measures to human electroencephalogram (EEG) data to access the difference due to current and optimal coefficients. This is important since the diagnostic value may be impacted by the differences in the estimated Laplacian signal. Two bipolar Laplacian estimates were also added to the analysis.

Methods

The resting EEG data for six healthy human subjects was adopted from [2], [3] where this dataset was also used to asses synchrony between EEG signals. Six healthy human subjects (ages 24-40, one female) had their resting EEG data band pass filtered (0.1-100Hz) and recorded at 1200 samples per second via gUSB amplifier with normalized unit gain (g.tec medical engineering GmbH, Schiedlberg, Austria), resulting in a total duration of 1730s, 173 segments total when divided into non-overlapping segments of 10s each. The subjects were instructed to remain motionless and seated in a chair to reduce artifacts due to movement. Individual (recording surface) and differential signals from t-Lead electrode and from conventional disc electrode were simultaneously monitored at location P4 of the standard 10-20 system with the right mastoid process serving as ground and reference. Skin-to-electrode impedances were kept under 5kΩ. Signals from the t-Lead were additionally preamplified via custom preamplifier with a gain of 6. All the signal processing was performed using Matlab (Mathworks, Natick, MA) including digital filtering (zero-phase fifth-order Butterworth) with a band pass of 1-100Hz and 60Hz notch. Neuronal signal synchrony metrics in the time and frequency domains were applied to six pairs of signals from t-Lead. Cross-correlation and coherence were calculated for all 173 10s signal segments normalized to zero mean and unit variance. Cross-correlation coefficients were calculated at lag zero as well as at the optimal lag to account for any time delay between signals. The coherence coefficients corresponding to the frequency range of 1-100Hz were averaged for each segment using Welch's averaged modified periodogram method with overlapping (50%) and Hanning window of 1024 samples. The magnitude squared coherence estimate was calculated for each segment and the coefficients corresponding to the pairwise comparisons were averaged using the 1-100Hz frequency range. Six pairwise comparisons including all the combinations of optimal and suboptimal tripolar (tEEG) as well as of larger and smaller bipolar (bEEG) Laplacian estimates were performed. The Laplacian estimation involves combining differential voltages between the rings and central disc. For the suboptimal estimate current coefficients (16,-1) were originally derived for t-Lead using a simple model of electrode dimensions with a median ring radii ratio of 1 to 2. The optimal estimate used coefficients (6,-1) from [1]. Estimate of the Laplacian via BCREs is the differential voltage between a ring and central disc. The estimates for smaller and larger BCREs were derived using the middle ring and the outer ring, respectively.

Figure 1. t-Lead electrodes from CREmedical (https://cremedical.com/product-2-2/).

Results

Three signal synchrony metrics obtained for all of the pairs of signals compared is presented in Table 1.

Three of the comparisons resulted in very high cross-correlation and coherence (0.9 to 1.0) while the remaining three (all including the larger bipolar estimate) did not.

Table 1. Three signal synchrony metrics calculated for six pairs of signals being compared.

Signals being compared	Signal synchrony metric (mean ± standard deviation)		
	Maximum cross-correlation	Zero lag cross-correlation	Average coherence
tEEG (suboptimal) vs tEEG (optimal)	0.997 ± 0.0008	0.997 ± 0.0008	0.991 ± 0.0007
tEEG (suboptimal) vs bEEG (smaller)	0.999 ± 0.0003	0.999 ± 0.0003	0.997 ± 0.0003
tEEG (optimal) vs bEEG (smaller)	0.992 ± 0.0019	0.992 ± 0.0019	0.979 ± 0.0019
tEEG (suboptimal) vs bEEG (larger)	0.707 ± 0.0939	0.706 ± 0.0941	0.281 ± 0.1011
tEEG (optimal) vs bEEG (larger)	0.648 ± 0.1078	0.647 ± 0.1086	0.231 ± 0.088
bEEG (smaller) vs bEEG (larger)	0.736 ± 0.0859	0.736 ± 0.086	0.313 ± 0.107

Discussion

High signal synchrony between tripolar Laplacian estimates could indicate that the difference due to optimal and suboptimal coefficients may not be significant though further investigation is required going beyond synchrony measures. Results for larger bipolar Laplacian estimate are consistent with prior results of Laplacian estimation accuracy increasing as the electrode size decreases. While the suboptimal Laplacian estimation coefficients may be sufficient, the real limitation is the t-Lead geometry itself which still corresponds to over 4 times the median Laplacian estimation errors compared to the optimal tripolar concentric ring electrode configuration [1]. Signal synchrony in both time and frequency domains may turn out to be a valuable tool when comparing different Laplacian estimates for the same electrode geometry. Consistency between zero lag and maximum cross-correlations for all comparison pairs means that there was no substantial time delay between different data channels. Same would have likely been true for [2] if segments were normalized for both cross-correlation calculations like it was done in this study and not just for the maximum one as in [2]. Future work directions include but are not limited to assessing nonlinear synchrony metrics as well as individual frequency bands for coherence.

References

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