 DOI: 10.3217/978-3-85125-467-9-30

Incorporating neuroscience priors into brain-computer interfaces to detect attentional state

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Introduction: There exist a number of open challenges facing brain-computer interfaces (BCIs) for both clinical and commercial applications. In electroencephalography (EEG) based BCIs, several of these issues stem from analyzing recorded data in the sensor space (i.e., the surface of the scalp) where the electrodes are placed. Here, we focus on two of these obstacles: First, inclusion of priors from neuroscience (e.g., localization of brain regions associated with particular tasks) is difficult when analyzing data in the sensor space as the vast majority of neuroscience operates in the cortical domain. Second, the bulk of BCI research has focused on three canonical paradigms: P300, motor-imagery, and visually evoked potential BCIs all of which are well developed, but presumably, there remain many more brain regions useful for control that could advance the field as a whole [1].

Materials and Methods: Source imaging is a method for estimating cortical sources of activity from non-invasive recordings [2]. We modeled the entire cortex using ~7000 distributed current dipoles each of which represents a small patch of cortex. Using the MNE-Python library, we solved the inverse problem allowing estimation of cortical activity at each dipole from (non-invasive) EEG data. Source imaging also provides a principled path to include neuroscience priors from other research – particularly, from neuroimaging. To this point, the right temporoparietal junction (RTPJ) was recently discovered to be significantly more active when switching auditory attention compared to maintaining it to a single sound source [3]. We hypothesized that a source-based approach incorporating this knowledge (by targeting activity from only this region) would provide significantly better single-trial classification accuracy compared to a naive sensor space approach.

We tested our hypothesis by comparing a sensor-based and a source-based BCI approach both attempting to classify (offline) if a subject switched or maintained attention in an auditory task (previously conducted in the laboratory) [3]. Briefly, subjects listened to one of two talkers and were instructed to either maintain attention to one throughout a trial or switch halfway through. For both approaches, we employed different dimensionality reduction techniques: principal component analysis (PCA), independent component analysis (ICA), and common spatial patterns (CSP) using an identical range of parameters for each. Support vector machines were used to classify the resulting signal and we employed 10-fold cross validation to obtain a stable accuracy estimate.

Results: We found that the source-based approach significantly outperformed its sensor-based counterpart ($p=0.003$; corrected 2-way repeated-measures ANOVA) conferring a 5.2% absolute accuracy increase between the best sensor- and source-based strategies. Interestingly, the relative difference between the dimensionality reduction techniques appeared to diminish once in the source space.

Discussion: These results suggest that the source space provides an avenue to target more informative signals for classification by incorporating neuroscience priors. The absolute accuracy attained here may not be robust enough to be useful for immediate use; however, the significant gains relative to a sensor approach gives credence to the notion that neuroscience priors can provide a significant performance gain across multiple signal processing strategies. Importantly, this work also demonstrates that activity from a region not associated with the canonical BCI paradigms can be objectively targeted to provide a useful control signal. Note that source imaging is not amenable to all BCI studies; the additional time and cost required to obtain a structural MRI scan will be prohibitive in some cases. That said, there are simplified source imaging techniques that require only 3D localization of electrodes and a generic head model. Future research will evaluate the necessity of MRI information by testing these simplified techniques.

Significance: In this study, we found that leveraging neuroscience priors via the source space provides a significant increase in classification accuracy and seems to reduce the dependence of this accuracy on the dimensionality technique chosen.

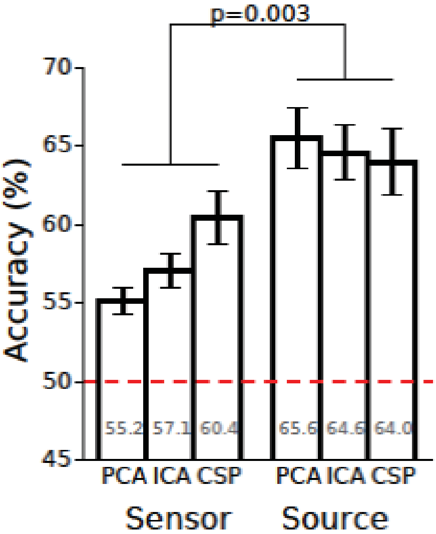

Figure 1. *Accuracy of sensor- and source-space approaches (using 3 dimensionality reduction techniques) when predicting a switch in attention. Source space yields significant improvement. Bars indicate mean (± SEM) and the red line represents chance.*

Acknowledgements: Funded by NSF GRFP to M.W. and AFOSR to A.L.

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