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A Review on EEG - fMRI Data Fusion: Multimodal Neuroimaging Approach

Prof N B Gohil
Asst. Professor, EC Department, Shantilal Shah Engineering college, Bhavnagar, Gujarat

Abstract: In the last few years, the functional brain imaging community has witnessed numerous efforts (and per- haps even more discussion) directed at multimodality data fusion: combining high-quality localization information provided by the hemodynamic-based brain imaging methods like fMRI with high- quality temporal data generated by the electromagnetic-based techniques such as EEG .

I. INTRODUCTION

Almost every neuroscientist, and certainly every functional neuro imager, tries in one way or another to combine data from multiple methods. Three distinct approaches are used.

(1)Converging evidence

Converging evidence is the most common method, although it is, typically, not an explicit attempt at combining data from different techniques. Converging evidence can, of course, be more formally assessed by performing meta-analyses of data that have been transformed into some canonical coordinate system and evaluating to what extent there is agreement across studies and recording modalities One can implement the converging evidence approach in one study by doing the same experiment multiple times using different recording techniques: the same subjects perform the same task while undergoing, for example, fMRI in one session and MEG in a separate session. took this approach in a study on the somatosensory system testing whether bimanual (vs. unimanual) stimulation has distinct spatial activation patterns (fMRI) and is also associated with neuro-physiological responses that differ in their timing, amplitude, and spatial origin (MEG). Finally, in the clinical domain, converging evidence across recording techniques is of critical importance. For example, the pre- surgical mapping carried out with fMRI or MEG that might be provided to a neurosurgeon to aid in surgical planning must agree closely with intracranial recordings.

(2) Direct data fusion

In the direct data fusion approach, two data sets are directly combined using some mathematical/ statistical algorithm. The main assumption, is that the critical signals generated by each method correspond to the same set of underlying neural generators. The most common method that has been employed to combine hemodynamic and electromagnetic data assumes that there are a few underlying equivalent current dipoles that generate the EEG data, and uses the local maxima obtained by fMRI as constraints on localizing these EEG dipole sources. Other source estimation methods for EEG/MEG are possible, however, such as assuming that the sources of the EEG/MEG data are spatially distributed and these lead to temporally continuous EEG/MEG values through- out the brain (or, depending on the method, at the cortical surface). The LORETA method is one such distributed source modeling method (LORETA stands for low-resolution, electric tomography algorithm; it provides the smoothest possible 3D current distribution in the brain that can generate the observed scalp field). One problem with all these source estimation procedures is well-known the inverse problem of determining a unique set of sources that yield the surface-recorded distribution of electromagnetic activity is ill-posed; in the absence of constraints, there is no unique solution. This lack of uniqueness obviously affects any data fusion effort.
Nonetheless, several critical issues remain unresolved by this approach, and these will need to be addressed by future research. First, in collapsing the electromagnetic data over time, are the local maxima so produced somewhat artificial creations? Second, the local maxima obtained from fMRI data generally correspond to the case where two or more conditions are contrasted against one another This can result in important nodes in the neural network under study being missed, because such a node may be as active during one condition as during another; what changes between conditions is the interregional functional connectivity. The net effect is that attempting a correspondence between local maxima would miss such “inactivated” nodes. Once again we are confronted with the serious issue of how to relate the sources of the signals between the two data types.

(3)Computational neural modeling

The third way by which diverse data can be "com- pared" is through the use of computational neural models that can simulate the different data types.The idea here is to construct a large-scale biologically realistic neural net- work model that can perform the cognitive tasks under investigation. The model would be constructed so as to be able to generate simulated fMRI d a t a and simulated EEG data that can be compared to experimentally observed values. The critical notion is that data types with different spatiotemporal properties are not compared directly to one another, but are compared inside a neural model that incorporates specific hypotheses about how particular cognitive operations are mediated neurally. That is, the assumptions one makes are about how macroscopically-measured data are related to neuronal physiology, not about how these data are related to each other. The major disadvantage of this approach is that modeling is meant to simplify what actually is going on, and thus it is hard to know if lack of agreement between computational and experimental results means the model and its corresponding hypotheses are too simple, or just wrong. The other major limitation of this approach is that no such model has been constructed; there are dynamic recurrent network models that relate neuronal electrophysiological data to fMRI as well as models that relate neuronal data to EEG/MEG signals. But still no model yet exists that can simulate both types of data, although the construction of such models is underway.

Efforts at direct data fusion will continue, as will efforts at constructing large-scale neural models that can simulate both hemodynamic and electromagnetic data. It will likely be the case that the difficulties and limitations that each approach encounters will actually strengthen our knowledge through mutual feedback as to how to proceed to multimodality integration.

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