Nonlinear time series analysis of simultaneous resting-state EEG and fMRI brain activity

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ABSTRACT

Introduction: Traditional methods for analysing EEG and fMRI data often assume that the relationships between different brain regions are linear and can be captured using straightforward mathematical relationships like correlations. While linear methods are simple and computationally efficient, they might miss complex interactions in brain dynamics, such as the full extent of how brain regions influence each other through feedback loops or other nonlinear interactions. Moreover, we know little about the dynamic relationship between brain activity at the localized scale of EEG data versus the global scale of fMRI data. Because the brain operates through intricate, dynamic interactions that are inherently nonlinear, we sought to uncover hidden patterns and relationships by leveraging both linear and nonlinear time series analysis methods on a recently published open-access dataset of simultaneously recorded EEG and fMRI activity on a healthy 29-year-old male subject at rest. **Materials and Methods:** Pre-processed EEG and fMRI recordings of "Subject 4" at rest for one 600-s session were obtained from Telesford, QK, et al. *Scientific Data*, 10:554, 2023. All analyses were performed in MATLAB using a combination of algorithms from the Nolitia, EEGLAB, GIFT, and SPM toolboxes. Our analysis pipeline for both EEG and fMRI pre-processed data is as follows. Data were decomposed with Independent Component Analysis (ICA) to extract relevant brain activation components, which were either algorithmically (EEG) or visually (fMRI) selected. The time series of the six components chosen from each EEG and fMRI data were further analysed using nonlinear techniques: test for nonlinearity, phase-space reconstruction, and recurrence analysis. The captured source localizations (EEG) and spatial activations (fMRI) were then mapped to a standard atlas and the brain regions were compared. **Results:** Brain regions in the resting state of the healthy subject under investigation seemed to conform to canonical resting-state brain networks using our analysis method. More EEG source signals demonstrated significant nonlinearity compared to fMRI source signals. The patterns of observed EEG recurrence plots were more dynamic and rapid compared to the more spatially coherent patterns in fMRI recurrence plots. Evidence of a possible convergence in some recurrent patterns between the two modalities exists. **Conclusion:** Combining ICA for component extraction with nonlinear time series analysis for detailed dynamic analysis holds promise as a comprehensive approach to analysing brain function under non-invasive neuroimaging methodologies. It remains to be determined whether the patterns observed in one subject can be generalized to a group of healthy subjects in the resting state, and how the patterns may change on a task-based paradigm. This approach unlocks possibilities for better biomarkers for neurological conditions, more precise mapping of brain networks, and ultimately, a deeper understanding of the brain's complex dynamics.