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Principal Component Analysis and Generalized Eigenvector Decomposition of the neurophysiology of auditory memory

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Magnetoencephalography (MEG) is a neuroimaging technique that captures the magnetic fields generated by neuronal activity, offering millisecond-scale temporal resolution and fine-grained spatial information, making it ideal for exploring the complex dynamics of the human brain. In cognitive neuroscience, event-related experimental designs are commonly used to investigate how the brain processes sensory stimuli and performs cognitive tasks. However, MEG data are inherently high-dimensional and characterized by intricate spatiotemporal patterns, overlapping neural sources, artifacts, and noise, which pose significant challenges for analysis. This study addresses these challenges by developing and validating efficient, data-driven strategies to decompose and interpret complex MEG signals, with a focus on their spatiotemporal structure. Principal Component Analysis (PCA) and Generalized Eigenvector Decomposition (GED) are applied to MEG recordings from a melody recognition task designed to probe auditory memory across age groups. PCA is used to extract broadband brain networks from data averaged across participants and experimental conditions, with robustness confirmed via statistical randomization and single-subject analyses. GED isolates frequency-specific components, allowing the tracking of oscillatory mechanisms involved in memory processes, particularly those that vary with aging. A Morlet wavelet-based time-frequency analysis, followed by statistical testing, reveals consistent neural patterns across conditions and age cohorts. PCA uncovers networks in auditory cortices, medial cingulate, hippocampus, and prefrontal areas. GED highlights age-sensitive frequency components, especially in the alpha and beta bands, frequencies linked to cognitive decline and memory efficiency. By systematically comparing results with existing neuroimaging literature and testing the methods under various computational settings, this work provides a robust framework for analyzing biologically complex, high-dimensional neurophysiological data. Importantly, the present approach avoids reliance on predefined regions of interest, allowing for an unbiased exploration of brain networks. The results show the potential of linear decomposition techniques in unveiling the biomedical relevance of spatiotemporal dynamics in MEG data, offering insights into aging-related changes in brain function.

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