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Functional connectome fingerprinting: Individualized brain mapping using resting-state FMRI.

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Introduction

Functional connectome fingerprinting is an emerging approach in neuroscience that leverages resting-state functional magnetic resonance imaging (rs-fMRI) to identify unique patterns of brain connectivity that can serve as a "fingerprint" for an individual. Unlike traditional neuroimaging methods that focus on group-level analyses, connectome fingerprinting emphasizes person-specific differences in brain network organization, enabling individualized brain mapping. This approach is based on the observation that functional connectivity patterns, which measure the temporal correlations between spatially distinct brain regions, remain relatively stable within an individual over time yet differ sufficiently across individuals to allow reliable identification. By capturing these unique connectivity signatures, researchers can potentially develop precision medicine tools for mental health, neurological disorders, and cognitive profiling. The concept of connectome fingerprinting aligns with broader trends in neuroscience toward personalized and predictive approaches, offering a powerful framework for understanding brain function at the individual level [1].

The process of functional connectome fingerprinting begins with the acquisition of high-quality rs-fMRI data, typically collected over a period of several minutes while the subject lies quietly in the scanner. Preprocessing steps—such as motion correction, temporal filtering, and spatial normalization—are critical for ensuring that the extracted connectivity patterns reflect true neural signals rather than noise or artifacts. The brain is then parcellated into regions of interest (ROIs) using anatomical or functional atlases, and functional connectivity matrices are constructed by computing correlation coefficients between the time series of these ROIs. The resulting connectivity matrix serves as a high-dimensional representation of the brain's functional network architecture. To establish a "fingerprint," connectivity matrices from the same individual, acquired at different times or in different sessions, are compared against those from other individuals, with a high within-subject similarity indicating a robust fingerprint [2].

Functional connectome fingerprinting has demonstrated impressive accuracy in identifying individuals, even across different scanning sessions and months apart. Studies have shown that certain brain networks, particularly higher-order association networks such as the frontoparietal and default mode networks, contribute disproportionately to the distinctiveness of an individual's connectome. These networks are involved in executive functions, self-referential processing, and cognitive control,

suggesting that variability in these domains may underpin the uniqueness of brain connectivity profiles. Furthermore, connectome fingerprints are not only stable but also predictive: individual differences in connectivity patterns have been linked to behavioral traits, cognitive abilities, and susceptibility to psychiatric conditions. This predictive power opens the door to using fingerprinting for longitudinal monitoring of brain changes in health and disease [3].

The applications of functional connectome fingerprinting extend beyond individual identification to various domains of neuroscience and clinical research. In psychiatry, for example, altered connectivity patterns have been associated with conditions such as depression, schizophrenia, and autism spectrum disorder. By comparing patient fingerprints to normative patterns, clinicians could potentially detect early deviations indicative of emerging pathology. In neurology, connectome fingerprinting could be used to monitor recovery after brain injury or to assess the effectiveness of rehabilitation interventions. In cognitive neuroscience, it provides a tool for studying how individual differences in brain connectivity relate to learning, memory, and problem-solving abilities. Moreover, the approach could enhance brain-computer interface (BCI) technologies by providing highly individualized connectivity maps to optimize neural decoding algorithms. These diverse applications highlight the versatility of connectome fingerprinting as both a research and clinical tool [4].

Despite its promise, functional connectome fingerprinting faces several challenges that must be addressed for widespread adoption. The reliability of fingerprints can be affected by factors such as head motion, scanner variability, and preprocessing choices, necessitating rigorous standardization of acquisition and analysis pipelines. The amount of data required to generate robust fingerprints—often several minutes of high-quality rs-fMRI—may be challenging to obtain in certain populations, such as young children or patients with movement disorders. Additionally, the high dimensionality of connectivity matrices poses analytical challenges, requiring sophisticated statistical and machine learning methods to handle the complexity without overfitting. Ethical considerations also arise, particularly regarding privacy and the potential misuse of brain-based identification in non-clinical contexts. Addressing these challenges will require coordinated efforts in methodological refinement, data sharing, and ethical oversight to ensure that functional connectome fingerprinting is both scientifically robust and socially responsible [5].

Conclusion

Functional connectome fingerprinting represents a significant advance in the ability to map and understand individual brain connectivity patterns using resting-state fMRI. By focusing on person-specific functional network architecture, this approach offers a powerful framework for precision neuroscience, with applications ranging from mental health diagnosis to cognitive profiling and neurorehabilitation. While methodological and ethical challenges remain, ongoing improvements in imaging technology, data analysis, and standardization are likely to enhance the reliability and applicability of connectome fingerprints. As the field evolves, functional connectome fingerprinting has the potential to become a cornerstone of individualized brain mapping, contributing to more personalized, predictive, and effective approaches in neuroscience and clinical care.

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