Chapter 7
Hybrid AI Model for Brain Age Estimation in Forensics Combining Structural and Functional Imaging

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ABSTRACT

Brain age is used in forensic investigations to assess age-related traits, neurodegenerative diseases, and injuries. Separate systems that use structural neuroimaging (MRI) or functional imaging (fMRI) have low accuracy and reliability due to the lack of consideration that structure and function are biologically linked in the brain. Structural techniques, such as convolutional neural networks (CNNs), do not consider how physical changes, such as atrophy, influence functional patterns. These also do not consider how physical changes influence function patterns. Functional approaches based on recurrent neural networks (RNNs) can identify temporal activity but not structural changes. It shows a mixed AI model that combines an RNN with long short-term memory (LSTM) for functional fMRI analysis and CNNs for structural MRI analysis to get around these problems. These fusions improve the

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understanding of the brain aging mechanism by merging temporal and geographical data. Comprehensive preprocessing, hyperparameter adjustment, and cross-validation are required for model durability.

INTRODUCTION

Because it is useful in assessing brain injuries, age development, and overall brain health, accurate brain age estimation is a popular study area in forensic science (Adekola et al., 2024). Environmental factors, illness, and injury can impact the brain, causing anatomical and functional changes as the body ages. Estimating brain age is particularly useful for forensic applications, such as determining the impact of trauma, identifying disease processes, and determining the age of unidentified people with criminal investigations or missing person cases (Pranav et al., 2023). Assessment of brain age has mostly relied on functional imaging methods, such as functional magnetic resonance imaging (fMRI), and structural imaging measurements, such as magnetic resonance imaging (MRI). Despite their usefulness, these methods aim to isolate the brain's dynamic activity or static physical structure. Their capacity to give a precise and thorough assessment of brain age has been hampered by the lack of characterization of the link between structural and functional changes that occur with aging. When CNNs process neuroimaging data, their primary focus is on structural imaging (Bose et al., 2024). These help find physical changes in the brain, like grey matter volume loss, ventricular enlargement, and tissue shrinkage atrophy. However, these disregard patterns of time-varying brain activity critical to cognition and cognitive aging. However, one can combine structural imaging techniques with functional imaging techniques (Aragani, 2024).

Functional imaging techniques don't look at the structure changes that come with aging. Still, these use RNNs to learn about the temporal within-subject variability in the fMRI signal. In the context of a more accurate and reliable brain age assessment, such a mismatch between structural and functional analysis performs very badly, especially in forensic settings when a thorough examination is essential (Sehrawat, 2024). These highlight the importance of the research in filling the knowledge gap in brain age estimation, which could lead to the formation of distinct classes of brain imbalance and a more thorough approach to brain age estimation. Combining structural and functional imaging data reveals brain aging in terms of neuron shape and function. It is crucial in forensic research because neurological disorders, traumatic brain damage, and other pathological processes can cause changes that are difficult to detect with a single imaging modality. For instance, an MRI scan may reveal structural damage from a traumatic brain injury, but fMRI is the sole way to detect functional changes in neuronal activity (Bose et al., 2024).

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