

TractSpLearn: Specialized Shared-Manifold Learning for Individualized Detection of Subtle White Matter Alterations in Mild Traumatic Brain Injury

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Abstract

Traumatic brain injury (TBI) refers to brain damage caused by an external mechanical force, such as a forceful bump, blow, or jolt to the head, or skull penetration by an object. Beyond the initial impact, TBI often triggers a cascade of secondary pathophysiological processes. Patients with TBI may experience persistent cognitive impairments, emotional and behavioural disturbances, and sensory or motor deficits. TBI often leads to subtle white matter damage that remains undetected on conventional MRI. Diffusion kurtosis imaging (DKI) is an advanced diffusion MRI technique that extends diffusion tensor imaging (DTI) by providing information on non-Gaussian diffusion in white matter pathways. With the advent of ultra-high-field MRI, spatial resolution and signal-to-noise ratio (SNR) have been significantly enhanced, enabling more precise visualization of subtle abnormalities. Building on these advances, we propose TractSpLearn, which jointly considers within-group variability and between-group differences. This framework enables more reliable, individualized detection of microstructural alterations and holds promise for improving the monitoring of TBI progression and recovery. To assess the performance of the proposed method, we compared it with the original TractLearn using two cohort comparisons: (i) healthy controls (HC) and athletes with persistent post-concussive syndrome (PPCS), and (ii) the same HC cohort and athletes with repeated head injuries (RHI). The results indicate that TractSpLearn yielded more stable individualized tract-level abnormality maps, reduced cohort-related confounds, and improved sensitivity to subject-specific microstructural alterations.