Longitudinal study of concussion-related diffusion MRI changes in college athletes: modeling tracts via hierarchical generalized additive models

Nathan M. Muncy[1,*], Heather C. Bouchard[1], and Aron K. Barbey[1]

[1]Center for Brain, Behavior and Biology, University of Nebraska-Lincoln, Lincoln, Nebraska, USA

[*]Corresponding author. Email: nmuncy2@unl.edu

Abstract

Sports-related traumatic brain injuries affect 1.6-3.8 million individuals in the US each year, and diffusion weighted imaging can measure the complex timeline of resulting axolemmal changes. Such longitudinal data is difficult to model statistically, however, given the high-dimensionality, semi-parametric and interdependent scalar values, and non-linear spatial (within-tract) and temporal (across visit) properties. Proposal: hierarchical generalized additive models (HGAMs) are well-suited to fit such data with the requisite flexibility and sensitivity to investigate (a) the spatial and temporal changes of white matter tracts, and (b) how such changes relate to diagnostic assessments. Methods: we utilized MRI and IMPACT data collected from 67 college athletes (9 female, age=19.43[1.68]) at three visits: start-of-season, post-concussion, and return-to-play. Diffusion tensors were modeled via constrained spherical deconvolution and probabilistic tractography from pyAFQ yielded 100 scalar values per white matter bundle. Results: By fitting the scalar profiles with longitudinal HGAMs we detected within-tract changes as a function of visit, revealing distinct patterns of post-injury disruption and recovery. Critically, it is unlikely that such changes would have been detected with standard techniques given their linear assumptions and limited dimensionality. Further, we examined whether these evolving diffusion metrics correlated with cognitive outcomes using HGAM tensor product interaction smooths and found moderate evidence linking white matter alterations to IMPACT composite scores. Merit: HGAMs offer a powerful framework to capture the complex progression of brain injury. Our findings suggest that HGAMs enhance our understanding of the spatiotemporal dynamics of brain injury and may enable more accurate tracking of injury and recovery.

KEYWORDS: DWI, MRI, GAM, TBI

1 Introduction

Introduction here.

2 Methods

2.1 Participants

Participants here.

2.2 ImPACT

Description of ImPACT.

2.3 MRI Protocol

Magnetic Resonance Imaging (MRI) data was collected on a 3 Tesla Siemens MAGNETOM Skyra scanner at the Center for Brain, Behavior and Biology (University of Nebraska-Lincoln) utilizing a 32-channel coil. For each of three sessions (Base, Post, and RTP), participants contributed T1 and diffusion weighted images (T1w, DWI). T1w Multi-Echo Magnetization Prepared - RApid GRadient Echo (MEMP-RAGE) structural scans were acquired with the following parameters: TR = 2530 ms, TE = 1.69, 3.55, 5.41, and 7.27 ms, flip angle = 7°, voxel size = 1 mm^3, FoV = 256 $\times$ 256, slices = 176 interleaved. DWI scans were acquired via TR = 3000 ms, TE = 95 ms, flip angle = 90°, voxel size = 1.719 $\times$ 1.719 $\times$ 2.4 mm^3, 134 slices, multi-band acceleration factor = 3, directions = 128, bandwidth = 1500 Hz/Px, shells = 1 (b-value = 1000 s/mm^2), reference volumes = 6 (b-values = 0 s/mm^2). A set of field maps for the DWI scans were collected using the same acquisition direction (anterior-posterior, AP) and reversed (posterior-anterior, PA).

2.4 MRI Data Processing

Description of DWI processing.

2.5 GAM specification

Description of GAM.

3 Results

3.1 ImPACT

Impact results.

3.2 DWI Tracts

Tract results.

3.3 DWI Tracts Interactions - ImPACT

Description of DWI-ImPACT interaction.

3.4 DWI Tracts Interactions - Time

Description of DWI-time interaction.

4 Discussion

Discussion.

Acknowledgments

People. Grant.

5 Supplemental Materials

Supplemental Materials.

5.1 Tables

Supplemental Tables.

5.2 Figures

Supplemental Figures.