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Postconcussion Symptoms Are Associated with Cerebral Cortical Thickness in Healthy Collegiate and Preparatory School Ice Hockey Players

Matthew D. Albaugh, PhD[1], Catherine Orr, PhD[1], Joshua P. Nickerson, MD[2], Cole Zweber, BS[1], James R. Slauterbeck, MD[3], Scott Hipko, BS[2,4], Jay Gonyea, BS[2,4], Trevor Andrews, PhD[2,4,5], J. Curtis Brackenbury[6], Richard Watts, PhD[2,4], and James J. Hudziak, MD[1]

Objective To investigate the degree to which concussion history and postconcussive symptoms are associated with cortical morphology among male hockey players.

Study design Male subjects (n = 29), ranging in age from 14 to 23 years (mean 17.8 years), were recruited from preparatory school and collegiate ice hockey teams and underwent neuroimaging and baseline Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) testing. Cerebral cortical thickness was regressed against ImPACT Total Symptom Score (TSS), concussion history, as well as baseline measures of psychopathology. Reconstruction of surfaces and cortical thickness analysis were conducted with FreeSurfer (version 5.3.0).

Results ImPACT TSS was inversely associated with local cortical thickness in widespread brain areas. Associations were revealed in a host of frontal as well as bilateral temporoparietal cortices. Conversely, concussion history was not associated with cortical thickness. An "Age by Concussion History" interaction was associated with thickness in the right ventrolateral and right parietal cortices. Post-hoc analysis revealed that concussed participants did not exhibit age-related cortical thinning in these regions.

Conclusion We have identified an association between brain structure and postconcussive symptoms among young, otherwise-healthy male athletes. Postconcussive symptoms and related reductions in cortical thickness may be tied to participation in a full-contact sport that involves frequent blows to the head. *(J Pediatr 2015;166:394-400)*.

Participation in full-contact sports such as ice hockey involves frequent, repetitive blows to the head. Each year, there are an estimated 1.6-3.8 million sports-related brain injuries.[1] Young hockey players are particularly at risk for sports-related head trauma. Research indicates that cerebral concussion accounts for 15%-22.2% of all reported injuries in male youth hockey players.[2-4] As a result, recent consideration and concern has been directed towards understanding the long-term sequelae of concussion.[5]

Sports-related concussions incurred earlier in life are associated with cognitive decline and depressive symptomatology in subsequent decades.[6] Relative to age-matched controls, former athletes with history of sports concussion exhibit accelerated rates of cerebral cortical thinning in regions implicated in executive control and aspects of emotion regulation.[7] This accelerated cortical thinning, in turn, has been correlated with cognitive decline in former concussed athletes.[7] Among former professional football players, cognitive impairment and depressive symptoms have been linked to reduced white matter microstructure in numerous fiber pathways in the brain, as well as decreased regional cerebral blood flow.[8] These findings suggest that blows to the head suffered earlier in life produce lasting changes in the brain, altering normative aging processes decades after initial brain trauma. Furthermore, participation in full contact sports and associated frequent subconcussive hits to the head may produce changes in brain structure and function, as well as postconcussive symptoms. Professional soccer players without a history of symptomatic concussion exhibited alterations in white matter microstructure when compared with age-matched athlete swimmers.[9]

In the present study, we tested the extent to which concussion history is related to cerebral cortical thickness in a group of healthy male ice hockey players. We also investigate putative associations between self-reported postconcussive symptoms and

ADHD	Attention-deficit/hyperactivity disorder
ASEBA	Achenbach System of Empirically-Based Assessment
ASR	Adult Self-Report
FLAIR	Fluid-attenuated inversion recovery
ICV	Intracranial volume
ImPACT	Immediate Post-Concussion Assessment and Cognitive Testing
PTSD	Posttraumatic stress disorder
SLF	Superior longitudinal fasciculus
TBI	Traumatic brain injury
TSS	Total Symptom Score
YSR	Youth Self-Report

From the [1]Vermont Center for Children, Youth, and Families, Division of Child Psychiatry, [2]Department of Radiology, and [3]Department of Orthopaedics and Rehabilitation, University of Vermont College of Medicine; [4]University of Vermont MRI Center for Biomedical Imaging, Burlington, VT; [5]Philips Healthcare, Cleveland, OH; and [6]DC Hybrid Skating, Milwaukee, WI

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cerebral cortical thickness. We hypothesized that, even among healthy young athletes, cortical morphology would be associated with previous concussive episodes as well as postconcussive symptoms. Specifically, we hypothesized that both concussion history and postconcussive symptoms would be inversely associated with cerebral cortical thickness—a metric posited to reflect cytoarchitectonic integrity of the cortex.

Methods

Male subjects (n = 29) were recruited from preparatory school and collegiate ice hockey teams and were between 14 and 23 years of age (mean [M] = 17.8, SD = 2.2). Baseline neuroimaging and behavioral data were collected between July 2012 and June 2013. Staff members at an elite hockey training camp were informed of the study, and camp attendees were made aware of the study through several announcements and an information session. Of the 29 subjects who enrolled in the study, 27 underwent both neuroimaging and cognitive testing (2 subjects were unable to complete cognitive testing). Self-reported concussion history was available for all 29 subjects. Specifically, a positive concussion history was defined as a self-report of having previously received a diagnosis of a sports-related concussion by a medical professional. For those participants who reported a history of concussion (n = 16), frequency ranged from 1 to 4 (M 2.13), and, at the time of baseline assessment, all were at least 3 months removed from their most recent concussion (M 40.6 months). All participants were deemed fit to play by team physicians. Five of the 29 participants reported that they had received formal diagnoses of attention-deficit/hyperactivity disorder (ADHD). Three of these 5 participants were taking psychostimulant medication at the time of the baseline assessment. Informed consent was obtained from all participants 18 years of age and older, and, for participants younger than the age of 18, parental consent was obtained as well as child assent. The study was approved by the University of Vermont Institutional Review Board.

Immediate Post-Concussion Assessment and Cognitive Testing

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) is a widely used computerized test battery that assesses verbal and visual memory, processing speed, reaction time, and impulse control.[10] ImPACT also includes the Post-Concussion Symptom Scale, which consists of 22 commonly reported symptoms (eg, difficulty concentrating, difficulty remembering, difficulty regulating emotion). During this portion of the ImPACT, the test-taker is asked to rate the current severity of 22 concussion symptoms using a 7-point Likert scale, yielding a Total Symptom Score (TSS). Previous studies indicate that the ImPACT battery is both a reliable and sensitive instrument with regard to the assessment of mild traumatic brain injury (TBI) among high school and collegiate athletes.[11-13] In the present study, we used the TSS to assess postconcussive symptoms. Given the positive skewness of the TSS data, a logarithmic transformation was applied before morphometric analysis.

Youth Self-Report and Adult Self-Report

The Youth Self-Report (YSR), for individuals 18 years of age and younger, and the Adult Self-Report (ASR), for individuals 18 years of age and older, are 2 instruments from the Achenbach System of Empirically-Based Assessment (ASEBA).[14,15] The ASEBA instruments each contain 113 behavioral items to be answered on a 0-2 scale. These self-report measures yield quantitative scores for a number of empirically derived syndrome scales, including anxious/depression, attention problems, and aggressive behavior.

Analysis of Imaging Data

Magnetic resonance imaging data were acquired using a Philips Achieva TX 3T with an 8-channel head coil. Anatomical data were acquired using three-dimensional T1 turbo field echo (1 mm × 1 mm × 1 mm) and three-dimensional T2-fluid-attenuated inversion recovery (FLAIR) turbo spin echo (0.6 mm × 0.6 mm × 1.2 mm) sequences.

Reconstruction of cerebral cortical surfaces was performed via the use of the publicly available FreeSurfer package (version 5.3.0; http://surfer.nmr.mgh.harvard.edu). In summary, steps include removal of nonbrain tissue using a hybrid watershed/surface deformation procedure,[16] automated Talairach transformation, segmentation of subcortical white matter and gray matter structures,[17,18] nonparametric nonuniform intensity normalization (N3) of intensity values,[19] tessellation of the gray matter white matter boundary, topology correction,[20,21] and surface deformation following intensity gradients to place optimally the gray/white and gray/cerebrospinal fluid borders at the location where the greatest shift in intensity defines the transition to the other tissue class.[22-24] Steps of the FreeSurfer processing stream are further detailed in previous publications.[17,18,20,22-25]

After initial cortical surface reconstruction, FLAIR scans were used in order to refine each subject's pial surface (invoking the -FLAIRpial flag in FreeSurfer). This step was carried out to exclude further portions of nonbrain tissue (eg, dura mater) from the cortical reconstruction. All FreeSurfer output was manually reviewed by one of the coauthors, paying particular attention to the accuracy of pial surfaces (eg, inclusion of dura, and other nonbrain tissue), as well as potential errors with regard to the white matter surface.

Data subsequently underwent registration to a spherical atlas, using individual cortical folding patterns to match cortical geometry across subjects.[23] Representations of cerebral cortical thickness, calculated as the closest distance from the gray/white boundary to the gray/cerebrospinal fluid boundary at each vertex on the tessellated surface, were generated for each subject.[25] The metric of cortical thickness has been validated against histological analysis[26] as well as manual measurements.[27,28]