Research Article

Cognitive Deficits and LD/ADHD Among College Football Athletes and Undisclosed Inclusion in Concussion Research

Ted Tatosⁱ and Don Comrieⁱⁱ

Abstract

Concussion research in the United States commonly relies on collegiate athletes as study subjects. Such research recognizes learning disabilities and attention deficit disorders (LD/ADHD) as co-morbidities that should be addressed in concussion research and management. This study had three objectives: 1) to investigate the prevalence of such diagnoses and examine neuropsychological test results among incoming college football players at a major US university; 2) to examine how LD/ADHD diagnoses were addressed in concussion research that included such athletes; and 3) to address the implication of these results for ongoing concussion research using college athletes, including the NCAA-DoD CARE Consortium. Authors observed LD/ADHD rates among football athletes exceeding 50% in multiple cohort-years, a degree of magnitude greater than the rate among general college student populations. Neuropsychological testing revealed scores among some incoming freshman college football players consistent with those of severe traumatic brain injury (TBI) patients. Evidence of cognitive impairment among incoming college football players raises concern over the potential effects of cumulative exposure to head trauma and the increased risk associated with continued participation in collision sports. The prevalence of prescriptions for stimulant medication among this population limits its ability to serve as a proxy for other populations, including the military, to which results from college athlete samples may be extrapolated in error.

Introduction

The findings and subsequent research presented in this article began with the discovery and analysis of de-identified neuropsychological test results, learning disabilities and attention deficit disorders (LD/ADHD) diagnosis rates, and stimulant medication prescriptions among incoming athletes at the University of North Carolina at Chapel Hill (UNC-CH) over the 2004-2012 period. These results were contained in documents publicly released by the university itself pursuant to public records requests from two newspapers, the News and Observer and The Daily Tar Heel. These records stemmed from an independent investigation conducted by Kenneth Wainstein of the law firm Cadwalader, Wickersham & Taft into long-standing academic fraud at the school. The investigation's findings resulted in UNC-CH being placed on probation by its accreditation agency.

Because concussion research relying on college athletes as study subjects are commonly used to create normative baselines and extrapolate to other populations, understanding the characteristics of both the study and target populations informs the external validity of the study results. The Department of Defense (DoD) Blast Injury Research Program's Literature Review observes that "Most research examining brain injury thresholds come from sports medicine."¹ Generally, the sample population should coincide with the target population.² If systematic differences exist between the study and target populations concerning confounding factors such as LD/ADHD that can distort the true effects of brain injury, and researchers ignore such differences, the resulting normative data will be biased. Unless studies account for such confounding factors, which compete with the exposure of interest, either by exclusion or control, any causal links will be difficult to establish.³ Failure to address systematic differences between study and target populations can perpetuate

ⁱ Ted Tatos is an adjunct professor of economics at the University of Utah and Director of the firm Empirical Analytics, LLC. He was responsible for the document research, statistical analysis, drafting and review of the manuscript, and literature review. (Corresponding author: ttatos@eaecon.com)

ⁱⁱ Don Comrie is the CEO of NeuroLabs, Inc. and was responsible for literature review and critical review of the manuscript.

Received: February 2019

Accepted for Publication: May 2019

Published Online: June 2019

uncertainty and raise doubts about causality that could have been addressed, at least in part, through proper study design. A large prevalence of LD/ADHD diagnoses among college athletes, who may also be medicated with stimulants, in the study population, compromises the ability to extrapolate study results to other populations, including the military, where such confounding factors are either far less prevalent or nonexistent.

This study examines publicly-available primary source material and documents the prevalence of LD/ADHD concussion risk factors among incoming freshman football players. Neuropsychological test scores from these athletes are analyzed and compared to normal, ADHD, and brain injury normative scores from the literature. LD/ADHD diagnosis rates observed among incoming UNC athletes, particularly football athletes, who represent the focus of this study, exceeded those reported among the US undergraduate population levels by over an order of magnitude (10x) in some years. These diagnoses, along with the accompanying prescriptions for stimulant medication to treat symptoms of ADHD were of particular interest, because UNC-CH represents one of the top concussion research centers in the US and regularly conducts such studies using football athletes as subjects. Such diagnoses have been recognized as co-morbidities and modifying factors in concussion research. Individuals with LD/ADHD, those taking stimulant medications, or both have been excluded from concussion research studies or treated as a separate population for the last two decades.

We find evidence that established protocol treating LD/ADHD and stimulant medication use as exclusionary criteria were not followed in numerous studies authored by UNC concussion researchers. These studies included athletes with these conditions without adequate disclosure or control. Athletes do not appear to have been advised of the risks associated with their participation thus raising doubts about whether their consent to participate in such studies was properly informed and whether the guidelines set forth in the *Belmont Report* were followed.

We also found football athletes whose neuropsychological test scores at matriculation were consistent with traumatic brain injury patients, raising the question whether subsequent LD/ADHD diagnoses resulted from a previous brain injury sustained from participation in a collision sport. Finally, we find that recently published research from the NCAA-DoD Concussion Assessment, Research, and Education (CARE) Consortium, which relies on college athletes among its study subjects, also fails to treat LD/ADHD or stimulant medication use as exclusion criteria. Such failure limits the generalizability of these results to the military population, the benefit of which is the stated purpose of the Congressionally Directed Military Research

Program (CDMRP) on Psychological Health/Traumatic Brain Injury⁴ under which the CARE Consortium is funded.

Our findings have several implications. The inclusion of LD/ADHD athletes in concussion research may result in normative baselines that are too low and thus inapplicable to other populations. For example, military concussion protocols borrow from concussion research using college athletes and sports protocols.⁵ A major reason is that, while both football athletes and military service people face increased risk of head trauma, college athletics represents a more controlled study environment than combat. Reliance on such potentially erroneous baselines may result in premature return-to activity, placing both athletes and military personnel at greater risk for subsequent injury. Such baselines may also give the misleading indication that cognitive recovery has occurred when it has not, leading to an underestimate of the risks of participating in collision sports. Furthermore, undisclosed inclusion of LD/ADHD athletes in concussion studies can pollute the research, particularly when citations of such studies propagate throughout the literature or such studies are included in meta-analyses.

Background

Relevance of Neuropsychological Testing Among College Athletes in Concussion Research

Neuropsychological testing among incoming college athletes is commonplace among athletic departments. For academic accommodation eligibility purposes, the National Collegiate Athletic Association (NCAA) defines a disability as: “as a current impairment that has a substantial educational impact on a student’s academic performance and requires accommodation.”⁶ Education-impacting disabilities (EIDs) include specific learning disabilities/disorders (e.g., disabilities in math, reading, writing) and ADHD. Academic accommodations to diagnosed students may consist of extra time on tests, assistant note-takers, separate testing facilities, and other forms of support.

Academic Testing of Athletes for Cognitive Disorders at UNC-CH

During the 2004-2012 period covered by our study, a neuropsychologist hired by UNC’s athletic department screened and tested matriculating athletes at UNC for the presence of EIDs. Such screening commonly occurred during the summer session prior to matriculation. Initial screening consisted of the following tests: CNS-VS, Wender Utah Rating Scale (WURS), Brown Attention Deficit Disorder scale (BADD), the NeuroPsych Questionnaire (NPQ, a computerized symptom checklist), and three sub-sections of the Scholastic Aptitude Test for Adults (SATA): reading vocabulary, math calculation, and writing mechanics.

Additional assessment instruments included the Beck Depression Inventory (BDI) and Beck Anxiety Inventory (BAI). While the CNS-VS test was used as part of the screening process from 2004-2009, the neuropsychologist substituted the ImPACT test for CNS-VS beginning in 2010. Athletes identified as ADHD or LD during the screening process were subsequently administered a full neuropsychological assessment using standard clinical procedures that also included the Wechsler Adult Intelligence Scale (WAIS-III or IV) and the full SATA battery. Paper and pencil testing were also employed. ADHD diagnosis was conferred to students who met the Diagnostic and Statistical Manual for Mental Disorders (DSM-IV-TR, or DSM-5) criteria, with the exception of symptoms prior to age seven. The reason for this exception was because many athletes came from disadvantaged backgrounds and often from rural areas with limited availability to diagnostic services.⁷

A brief summary of the testing process extracted in its original form from the UNC documents appears in Figure 1 below.

Figure 1: UNC's Description of Educational Testing for Scholarship Athletes⁸

Cognitive Disorders as Modifying Factors in Concussion Research

Since the work of Collins et al. (1999)⁹, LD/ADHD have been treated as co-morbid modifying factors in concussion research.^{10,11} Recent research has continued to emphasize that accounting for such concussion co-morbidities is critical to the proper interpretation of neuropsychological test results.¹² Nuwer et al. explain that "Concussion symptoms can be difficult to separate from ADHD baseline symptoms... Many postconcussion symptoms present as a clinical picture similar to ADHD itself."¹³ The Institute of Medicine and National Research Council of the National Academies

("IOM-NRC") report titled *Sports-Related Concussion in Youth: Improving the Science, Changing the Culture*, identifies ADHD and learning disabilities as co-morbid conditions in neuropsychological testing and recommends collection of such data in concussion evaluation, noting that the presence of these factors may affect test outcomes.¹⁴ The NCAA recognizes LD/ADHD as co-morbidities that may accompany concussions and ADHD as a modifier that may prolong recovery from brain injury.¹⁵ Position statements from various medical and sports organizations, including the International Consensus Conferences on Concussion in Sport,¹⁶ the Australian Institute for Sport and Australian Medical Association,¹⁷ and the American Medical Society for Sports Medicine¹⁸ have listed LD/ADHD as concussion modifiers. The American Academy of Neurology's 2013 summary of evidence-based guideline update, whose author list includes a top UNC concussion researcher, cited the Collins study referenced above in finding that pre-existing learning disability may be a risk factor for chronic cognitive impairment.¹⁹

Concussion research using NCAA collegiate athletes has recognized the need to control for the presence of LD/ADHD as modifying factors.²⁰ Over the last twenty years, articles detailing studies that either control for LD/ADHD or treat them as exclusion criteria are legion. For example, UNC research published in 2002 that investigated the presence of long-term or chronic neuropsychological dysfunction among collegiate soccer players at the university found that controlling for LD and attention deficit disorder (ADD) affected the statistical significance of inter-group differences among soccer players, non-soccer athletes, and student controls. (The paper states: "None of the P values for group differences remotely approached statistical significance after controlling for concussion history or learning disability or attention deficit disorder.")²¹ The effects of such risk factors have also been acknowledged in concussion litigation. In the NFL class-action concussion litigation, UCLA Prof. Christopher Giza, an expert retained by the NFL, explained in his declaration that:²²

Persistent symptomatology after a single concussion is heavily influenced by premorbid risk factors such as migraine, learning difficulties, anxiety, and other neurobehavioral diagnoses.

Previous work by Alosco et al. found a 10% prevalence of ADHD among college athletes and that "50.4% of athletes with ADHD reported a history of at least one prior concussion vs. 14.4% of athletes without ADHD, which represented a significant difference ($p < 0.01$)."²³ Research has provided evidence for ADHD as an antecedent risk factor for mild traumatic brain injury (mTBI) in college athletes, which complicates diagnosis and treatment.²⁴ Both LD and ADHD are considered additional risk factors for

concussion in the baseline test of the National Football League (NFL) sideline concussion tool.²⁵ Athletes with LD/ADHD scored lower on computerized neurocognitive tests (CNTs), indicating that separate normative data for these specific populations should be used in concussion management or testing using CNT batteries.²⁶ Using a sample of Finnish athletes, Peltonen et al.²⁷ found that:

Application of standard age-based norms to adolescent athletes with a history of LD has the potential to negatively skew clinical decision-making. Separate reference values for LD athletes are warranted due to their unique developmental cognitive trajectories.

The literature is unambiguous with respect to the recommended treatment of LD/ADHD diagnoses in concussion research: patients with LD/ADHD have either traditionally been excluded from mTBI studies or treated as special populations.^{28,29,30,31,32}

Materials and Methods

Between October 2015 and June 2017, UNC-CH publicly released nearly two million internal documents as a result of an independent investigation into academic fraud at the university.^{33,34} After redaction, the university uploaded these documents in digitized portable document format (PDF) on its web site at in eight separate tranches (<https://carolinacommittment.unc.edu/records/>). These publicly released documents offer perhaps the clearest view to date into the relationship between a top university and its high-profile athletic program. The primary sources discussed in this study include significant details regarding neuropsychological testing performed on athletes during the period from 2004-2012, the prevalence of LD/ADHD among athletes, stimulant medication prescription rates, athlete exit interviews, and emails indicating concerns about the health and welfare of athletes at the university.

From the full document release, two primary data collections emerged for analysis: 1) LD/ADHD diagnosis rates and stimulant prescription rates obtained from annual cohort-level data tables, end-of-year reports, and emails; and 2) de-identified neuropsychological testing results for incoming UNC athletes (N=182, of which n=137 were football players), during 2004-2012. The individual data in source 2) were used in making the diagnoses observed at the cohort-level in source 1). To be clear, both data sources are public and can be found in the documents that UNC has released.

Optical character recognition was used (OCR) to enable text searching in documents lacking that capability, and one of this study's authors searched the documents both individually and using text search algorithms. The dataset of 182 athletes noted above consisted of variables detailing academic testing results for incoming athletes from CNS-VS,

WURS, BADD, SATA, and ImPACT tests, along with Scholastic Aptitude Test (SAT) and ACT (orig. American College Testing) scores. This dataset did not contain an individual-level variable identifying LD/ADHD or medication status. Such data were obtained at the cohort-level from documents in 1) above.

Both data sources identified in 1) and 2) were collected and maintained by UNC's Academic Support for Student Athletes (ASPSA) and/or by the neuropsychologist hired by the athletic department. Testing results were submitted to UNC's Department of Disability Services (DDS) to justify academic accommodations per NCAA regulations.

Conference presentations,³⁵ literacy experts hired by the university,³⁶ and university administrators have relied upon part or all of the dataset of 182 athletes. As an additional verification, this study replicated the Reading Vocabulary (RV), and Writing Mechanics (WM) means and standard deviations calculated in Table 1.1 of the report of Dr. Branum-Martin, one of the literacy experts, using these data and obtained the same results. The replication indicates that this article relies on the same dataset as the experts hired by UNC to investigate athlete literacy rates.

The documentary investigation for this study also included a search of the UNC's Carolina Digital Repository for electronic copies of theses and dissertations within the UNC Department of Exercise and Sports Science (EXSS) with the keywords "concussion or traumatic brain injury" and subsequently searched these results for the keyword "football." The results were then examined to identify the inclusion of UNC football players during this period in the study population and whether LD/ADHD rates and medication prescription rates and usage were disclosed. Where LD/ADHD athlete inclusion in research was discovered, theses or dissertations identifying such inclusion were matched to subsequent publications in peer-reviewed journals to investigate disclosure patterns.

Results

LD/ADHD Diagnosis and Medication Prescription Rates

The publicly-released UNC documents offer a straightforward timeline. According to the end-of-year report submitted by UNC's academic coordinator for football in 2003-2004, approximately 29% of scholarship football students had a learning disability, though no ADHD figures were provided.³⁷ The first testing cohorts with available LD/ADHD screening results were for 2005-06 and 2006-07 incoming freshman football players (n=40). Screening results indicated that, of these 40 athletes, 24 (60%) had either only a specific learning disability (n=6), only ADHD (n=4), or both (n=14). Subsequently, data obtained from a 2007-2008 end-of-year report prepared by the learning specialist who worked with the football team

showed the presence of 21 LD/ADHD athletes on the football team (Figure 2).³⁸ In communications with a former UNC learning specialist, the authors confirmed that only scholarship athletes were generally tested. NCAA rules cap Division I football scholarship rosters at 85 but allow walk-ons in excess of this total. Thus, the 21 LD/ADHD diagnoses out of 85 scholarship players indicate that approximately 25% of the scholarship players on the football team in the 2007-2008 academic year were diagnosed as LD/ADHD.³⁹

Subsequently, a 2009-2010 end-of-year report written by the same learning specialist confirmed the presence of 37 LD/ADHD athletes on the football team. These data (Figure 3) show that 37 out of 85 (44%) scholarship players were diagnosed with LD/ADHD.⁴⁰ The 85 scholarship athlete total excludes the 20 walk-on players from the total of 105 listed in the figure. The 44% result is corroborated in the record by a May 9, 2012 email from the testing neuropsychologist to UNC's Academic Support for Student-Athletes (ASPSA) explaining that:⁴¹

The last year I used CNSVS was 2009. 45% of the athletes we screened had profiles that were consistent with ADHD. In 2010 when I used Impact, the incidence was also 45%.

Additionally, Figure 3 indicates that 16 of the 23 (70%) freshman athletes screened that year were prescribed stimulant medication.

Table 1 shows data from the 2011-2012 end-of-year report submitted by another UNC ASPSA learning specialist indicating that 13 of the 24 (54%) football athletes screened that year were diagnosed LD/ADHD. Across all sports listed in Table 1, 34 of the 57 athletes screened that year (60%) were diagnosed with LD/ADHD.⁴² These included 13 out of 24 incoming football players (54%) in that year. Further,

nine out of the 24 incoming freshmen athletes (38%), all of whom were screened, were prescribed medication.

The UNC learning specialist responsible for coordinating with the neuropsychologist and collecting the data communicated the longitudinal findings from the dataset to UNC administrators in 2013. Her June-August 2013 emails described her review of the academic data for 182 athletes admitted to UNC between 2004 and 2012, noting a "39% incidence of LD and or ADHD."⁴³ A subsequent 2013 UNC document titled *History of Screening/Testing Scholarship Athletes* retrospectively confirmed her concerns, explaining that "there were a very large number of student-athletes diagnosed with ADHD and recommended for medication."⁴⁴

Neuropsychological Test Results for Football Athletes

The publicly released documentation includes a substantial amount of information on the results found for the 137 football athletes on the CNS-VS and ImPACT neuropsychological tests, which constituted part of the total dataset of 182. The CNS-VS test formed part of the overall screening process for 2005-09, while ImPACT was substituted for 2010-12. We compared CNS-VS scores of incoming football players in the 2005-09 cohort to scores from a normal control group (approximate ages 10-29) and a cohort of ADHD patients, both of whom appeared in a 2006 article authored by Thomas Gualtieri and Lyn Johnson in the *Journal of Attention Disorders*.⁴⁵ Several similarities between the 2006 Gualtieri and Johnson study sample and the UNC athlete cohorts allow for comparison between the groups. First, Gualtieri and Johnson also led the NC Neuropsychiatry team that UNC hired to test its athletes from 1997-2007 (Johnson continued in this capacity until

ACADEMIC SUPPORT PROGRAM FOR STUDENT-ATHLETES
END OF YEAR REPORT 2007-2008
Beth Bridger, Learning Specialist, Football

1. TEAMS

Team	# of Students
Football	107
Freshmen	22
LD/ADD	21

****LD/ADD indicates total number of football student-athletes with diagnosed LD/ADD.**

2. ROLES AND RESPONSIBILITIES

LD/ADHD TESTING

Team	# Fall 2007	# Spring 2008	Totals 2007-8
Screening	22	0	22
Full Battery	10	0	10
Meds (new)	2	1	3

Figure 2: UNC Learning Specialist's 2007-2008 End-of-Year Report Detailing Football Team LD/ADHD Incidence and Medication Prescription Rates

ACADEMIC SUPPORT PROGRAM FOR STUDENT-ATHLETES
END OF YEAR REPORT 2009-2010
Beth Bridger
Associate Director/Learning Specialist, Football

1. TEAMS

Team	# of Students
Football	105
LB	16
OL	20
DB	17
QB	3
LD/ADD	37

**LD/ADD indicates total number of football student-athletes with diagnosed LD/ADD.

LD/ADHD TESTING

Team	# Summer 2009	# Fall 2009	# Spring 2010	Totals 2009-10
Screening	20	2	1	23
Full Battery	7	4	1	12
Meds (new)	13	2	1	16

Figure 3: UNC Learning Specialist's 2009-2010 End-of-Year Report Detailing Football Team LD/ADHD Incidence and Medication Prescription Rates

Table 1: UNC Academic Screens, LD/ADHD Testing 2011-2012 – Replication of UNC Learning Specialist’s 2011-2012 End-of-Year Report (correcting error in totals*)

Team	# Screened	# Full Battery	# Diagnosed LD/ADHD	# Prescribed Med.	% Full Battery Diag. LD/ADHD	% of Full Battery Presc. Meds	% of Screened Presc. Meds
UNC Football	24	13	13	9	100%	69%	38%
UNC M Basketball	6	1	1	1	100%	100%	17%
UNC WM Basketball	4	0	0	0			0%
UNC Baseball	11	11	11	8	100%	73%	73%
Other UNC Sports	12	9	9	3	100%	33%	25%
TOTALS	57	34	34	21	100%	62%	37%

Percentage of UNC Athletes Screened Who Were Diagnosed LD/ADHD (34/57) **60%**

Percentage of UNC Athletes Given Full Battery Who Were Diagnosed LD/ADHD (34/34) **100%**

Percentage of UNC Athletes Give Full Battery Who Were Prescribed Medication (21/34) **62%**

**NOTE: The original UNC document contained an apparent mathematical error. The total showed a total of 55 individuals screened instead of 57.*

2013). As with the UNC cohort, the testing for the Gualtieri & Johnson article’s sample was also conducted at NC Neuropsychiatry clinics using the CNS-VS test. Their article relied on 175 patients with ADHD between the ages of 10 and 29, who were compared to 175 age-matched normal controls. UNC athletes would have been approximately 17-20 years old at the time of the testing.

Table 2 presents a comparison of the sub-scale means observed from normal controls, and the ADHD sample from the Gualtieri & Johnson article against those of UNC football players tested or screened during 2004-2009 using CNS-VS (n=76). These UNC football player scores represent the subset of the 137 football players from 2004-2012 whose screening included the CNS-VS test. The remaining 61 athletes, who matriculated beginning in 2010 and whose screening included the ImPACT Test rather than CNS-VS, are analyzed subsequently herein. CNS-VS scores indicate that 41% and 23% of athletes scored two standard deviations below the normal patient cohort mean on complex attention and cognitive flexibility subtests, respectively. These scores were reflected in the Neurocognition Index (NCI), a summary score of the tests in the battery, where approximately a quarter of athletes scored two standard deviations below the normal mean.

In Figure 6, we compare CNS-Vital Signs results from the same UNC data for incoming players from 2004-2009 to scores from a sample of post-concussive patients used by Gualtieri and Johnson in their subsequent 2008 study.⁴⁶ In their 2008 study, Gualtieri and Johnson evaluated the 141 patients (age 18-65) at NC Neuropsychiatry clinics, where UNC athletes were also tested for EIDs. Overall the scores obtained from football players in the UNC data reflect deficits seen in patients with post-concussive syndrome from the 2008 Gualtieri and Johnson study. Approximately 30.1% and 17.6% of athletes scored below the normative mean for TBI level patients (see Fig. 6 footnotes) on complex attention and cognitive flexibility, respectively.

In 2010, UNC’s neuropsychologist began using the ImPACT test as part of the academic screening protocol for football players. Table 4 shows an analysis of the UNC testing data for the Verbal and Visual memory modules of this test for the 2010-2012 incoming football athlete cohorts. Composite scores for the remaining two modules on the ImPACT test, processing speed and reaction time, were not available. None of the individual impulse control (IC) scores reached above the 30-cut-off score used as an invalidity indicator in version 3.0 of the test.⁴⁷

Of additional note, 13% scored below the 25th percentile on both items and 5% scored below the 16th percentile on

Table 2: Comparison of Normal & ADHD Patients and UNC Football Player Scores on CNS-VS

CNS-VS Module	Normal Patient Mean (SD)*	ADHD Patient Mean (SD)*	Incoming UNC Football Players, 2005-2009		
			# Athlete Scores Analyzed	Football Player Mean (SD)	% 2 SD Below Normal Mean
Psychomotor Speed	101.3 (23.7)	92.7 (22.8)	74	98.6 (18.0)	2.7%
Reaction Time	100.8 (15.2)	89.7 (23.6)	71	96.1 (23.3)	11.3%
Memory	98.4 (15.7)	96.8 (19.5)	69	89.1 (17.6)	11.6%
Complex Attention	99.1 (12.5)	84.1 (36.4)	73	69.9 (38.3)	41.1%
Cognitive Flexibility	99.5 (14.0)	88.2 (23.2)	74	85.8 (31.7)	23.0%
Neurocognitive Index	100 (11.4)	90.5 (17.4)	66	87.0 (18.3)	25.8%

* Mean, St. Dev. For Normal & ADHD Patients from Gualtieri & Johnson (2006).

Note: Some athletes did not have scores available on every subdomain.

(Table created by authors with data from UNC)

Table 3: Incoming UNC Football Players Scoring Below TBI Patient Means on CNS-VS Baseline Testing

CNS-VS Module	Normative Means			% UNC Players Below Normative Mean *		
	Post-Concussive Syndrome	TBI - Level 1	TBI - Level 2	Post-Concussive Syndrome	TBI - Level 1	TBI - Level 2
Psychomotor Speed	83.1	57	40.2	13.5%	6.8%	1.4%
Reaction Time	81.6	57.4	37.2	14.1%	8.5%	8.5%
Memory	89.9	76.7	51.9	52.2%	27.5%	0.0%
Complex Attention	85.7	71.1	44.5	50.7%	30.1%	26.0%
Cognitive Flexibility	76.6	64.1	65	33.8%	17.6%	12.2%
Neurocognitive Index	81.6	66.3	46.8	31.8%	15.2%	4.5%

*Mean CNS-VS Scores in Brain Injury Patients from Gualtieri & Johnson (2008)

Note: Neurocognition Index refers to average of the five CNS-VS domain scores above.

TBI Level 1 reflects patients who had severe brain injuries, but who had recovered and were living independently.

TBI Level 2 reflects severe brain injury patients who were unable to live without assistance.

(Table created by authors with data from UNC)

Table 4: Incoming Football Player ImPACT Test Scores (2010-12)

ImPACT Test Item	Mean	% Impaired	% < 25 th percentile	% 16 th percentile
Verbal Memory	95.0	8.2	29.5	18.0
Visual Memory	95.1	0.0	16.4	14.8

(Table created by authors with data from UNC)

both items. We note that the US military Special Operations Command, for example, considers ImPACT symptom scores above 30 and two or more subcomponent scores below the 25th and 16th percentiles to be indicative of simple and complex traumatic brain injury, respectively.⁴⁸

Inclusion of 2004-2012 Football Athlete Cohorts in UNC Concussion Research

The results of matching the 2004-2012 football athlete cohorts discussed above to concussion research conducted at the university are shown in Table 5. A clear pattern emerges by comparing unpublished work by graduate students with subsequent peer-reviewed publications co-authored with UNC researchers, as Table 5 indicates. Several of these studies merit specific emphasis. For example, the 2005 and 2006 incoming football athlete cohorts discussed above were matched to the cohort used in the 2006 thesis of UNC graduate student M.A. McCaffrey.⁴⁹ This thesis was subsequently published in *Neurosurgery* and co-authored with the thesis advisor and members of the thesis committee.⁵⁰ In her thesis, McCaffrey documented the prevalence of attention deficit disorders in “a significant percentage” of the university’s football team and acknowledged LD/ADHD as a confounding factor that should be considered when evaluating the results of computer-based tests of cognitive domains such as the Automated Neuropsychological Assessment Metrics (ANAM). However, the subsequent publication of this thesis in *Neurosurgery*, co-authored with UNC researchers, a) failed to find deficits after high-magnitude impacts; b) found significant improvements between baseline and the high-impact testing condition; and yet c) did not mention either the LD/ADHD characteristics or the medication status of the study population. In her thesis, McCaffrey also identified the incongruity between baseline and post-injury testing conditions, observing that baseline measures were generally taken in the summer when athletes were off prescribed medication, but post-injury testing during the season was done while athletes were medicated and better able to focus. While the McCaffrey thesis acknowledged that the improvements found in the study might have been

explained by such incongruity, the published article in *Neurosurgery* failed to disclose such medication status and attributed improvements to a likely learning effect.

The practice of baseline testing for concussions off-medication while post-injury neuropsychological CNT testing was done while on stimulant medication violated both UNC researchers’ public recommendations and those of the Concussion in Sport Group (CISG), which recommended replication of baseline testing conditions.⁵¹ This research practice also violated the National Athletic Trainers’ Association Position Statement, published in 2004 and co-authored by a UNC concussion researcher and McCaffrey’s thesis advisor. The position statement noted that:⁵²

Other substances to avoid during the acute postconcussion period include those that adversely affect central nervous function...it is well accepted that athletes should be instructed to avoid... central nervous system medications that may interfere with cognitive function.

Central nervous system mediations include stimulants such as methylphenidate (e.g., Ritalin®) and amphetamines (e.g., Adderall®) that are prescribed for ADHD.⁵³ Medicating athletes during post-concussive testing but not at baseline will likely result in improvements caused by medication status that can be mistaken for cognitive recovery. Confirming this observation, UNC EXSS graduate student Ashley Littleton’s unpublished 2011 thesis⁵⁴ and a subsequent co-authored publication appearing in *Archives of Clinical Neuropsychology*⁵⁵ both reported improved performance by medicated ADHD athletes comparable to controls and recommended baseline and post-injury testing occur under equivalent medication status.

Additionally, subsequent unpublished theses under the supervision of UNC concussion researchers by UNC graduate students Gysland (2009)⁵⁶ and Harpham (2013)⁵⁷ appeared as published articles in the *Annals of Biomedical Engineering*.^{58,59} The theses and the published studies that resulted from them relied on football player data during the 2004-2012 period and were co-authored with UNC researchers, who were also the respective thesis advisors. Both published studies failed to quantify the presence of

Table 5: Comparison of Theses and Resulting Published Articles

Author and Thesis	Subsequent Publication	Key Results	Publication Notes/Omissions	Participants	Exclusion Criteria	Key Notes
McCaffrey, Meghan. (2006) Effects of High and Low Impact Magnitudes on Concussion Measures in Collegiate Football Players - M.A. EXSS (Athletic Training)	McCaffrey MA, et al. Measurement of head impacts in collegiate football players: clinical measures of concussion after high- and low- magnitude impacts. Neurosurgery. 2007 Dec; 61(6) :1236-43; discussion 1243.	"Findings suggest that sustaining an impact greater than 90 g does not result in acute observable balance and neurocognitive deficits within 24 hours of sustaining the impact...findings failed to find deficits after high-magnitude impacts." <i>"Significant improvements between baseline and the high testing condition were also noted for Math Processing and Procedural Reaction Time. The improvements in performance observed are difficult to explain."</i>	No discussion of significant presence of ADD that was noted in thesis. 2) No mention of medication - baseline off meds, post- concussion test on meds, which were noted in thesis.	"Forty-three Division I (UNC-Chapel Hill) male collegiate football players (20.74 ± 1.83 years old; 242.64 ± 41.02 kg, 73.41± 2.50 cm) (Table 1) were initially enrolled in this study. Subsequently, 24 players were used in the comparison of scores between impacts greater than 100 g and baseline, while 38 completed testing in the less than 70 g and baseline."	Exclusion criteria included previous head injury within the last six months, or having a current vestibular, visual, or balance disorder.	a) "Another confounding variable to consider when interpreting improvements on the ANAM scores should be the effects of <u>attention deficit disorder (ADD), a learning disorder which was prevalent in a significant percentage of our football team has been diagnosed with.</u> " b) <i>"During the summer a majority of athletes do not take their medication since most are taking a reduced class load, if any. Baseline measures are taken during the summer, generally during that time period that the athlete is not taking the prescribed medication. Thus, when the athlete retakes the test during the season, the athlete is medicated and as a result, is able to better focus."</i>
Gysland, Sonia. (2009) The Relationship Between Subconcussive Impacts and Concussion History on Clinical Measures of Concussion in Collegiate Football Players - M.A. EXSS (Athletic Training)	Gysland SM, et al. The relationship between subconcussive impacts and concussion history on clinical measures of neurologic function in collegiate football players. Ann Biomed Eng. 2012 Jan;40(1):14-22.	"Forty-six male collegiate football players were enrolled in this study (age = 19.65 ± 1.16 years, height = 189.43 ± 7.06 cm, mass = 112.72 ± 20.75 kg)." <i>"Repetitive subconcussive head impacts over a single season do not appear to result in short-term neurologic impairment, but these relationships should be further investigated for a potential dose-response over a player's career."</i>	<i>"There may also be additional variables that we have not accounted for that might help explain changes in our resulting outcome measures. These potential contributing factors, which should be studied in future studies, include motivation or effort of subjects when performing these tests, presence of attention deficit disorder or learning disabilities, and sleep deprivation.</i> These are all possible sources that may influence neurocognitive domains and presence of concussive-like symptoms."	"We enrolled 49 Division I Football Bowl Subdivision (formerly Division I-A) male collegiate football players in this study (2008 season). Inclusion criteria was such that the subjects must be a UNC Division 1 Football Bowl Subdivision collegiate football player and be enrolled in the project entitled, 'Prospective investigation of sport-related concussion: Relationship between biomechanical, neuroanatomical, and clinical factors' (Principal Investigator: Kevin M. Guskiewicz, PhD, ATC)."	No exclusion of subjects with learning disabilities, ADD or ADHD "due to a limited sample population." "All subjects with any conditions listed above or who were taking medications were recorded." Exclusion criteria: football players who had a concussion within three months prior to the scheduled baseline testing (over the course of the summer conditioning session), and anyone with a current vestibular, visual or balance deficit or lower extremity injury that disrupts balance ability.	"Special considerations regarding ADD, ADHD, as well as prescription and nonprescription drug intake were accounted for by self-reported documentation. These conditions have been known to negatively influence performance on neuropsychological and postural stability tests. Therefore, these conditions were taken into consideration when interpreting our data. Due to the nature of our study, we chose to include these athletes in our sample."
Littleton, Ashley. (2011) The Effects of Attention Deficit Hyperactivity Disorder (ADHD) and Stimulant Medication on Clinical Measures of Concussion	Littleton AC, et al. Effects of Attention Deficit Hyperactivity Disorder and Stimulant Medication on Concussion Symptom Reporting and Computerized Neurocognitive Test Performance. Arch Clin Neuropsychol. 2015 Nov;30(7):683-93.	"College-aged participants (22 ADHD and 22 matched controls) were administered a symptom checklist and a computerized neurocognitive test (CNS Vital Signs, CNSVS) 3 times (1 week apart): When unmedicated, the ADHD group performed worse than controls on psychomotor speed [F(1,40) % 15.19, p , 0.001], and worse than when medicated on reaction time [F(1,39) % 6.34, p % 0.02]. The ADHD group performed better and comparable with controls when medicated."		"Sample of thirty-four UNC college athletes. Seventeen participants (nine males and eight females) were in the ADHD group (age: 21.294 ± 2.02 years, previous number of concussions: 0.65 ± 0.70) and seventeen participants (nine males and eight females) were in the matched control group (age: 21.294 ± 2.05 years, previous number of concussions: 0.65 ± 0.70)."	"Individuals reporting a history of three or more previous concussions, known vestibular dysfunction, or any lower extremity injury or concussion in the past six months were excluded."	"Since stimulant medications have been shown to have an effect on scores on measures of concussion, clinicians should ensure that patients' baseline testing and post injury testing occurs under the same or similar medication statuses. ADHD athletes perform similar to controls when under the influence of stimulant medication."

Table 5: Comparison of Theses and Resulting Published Articles (continued)

Author and Thesis	Subsequent Publication	Key Results	Publication Notes/Omissions	Participants	Exclusion Criteria	Key Notes
Harpham, Jacqueline A. (2014) A Study of Visual and Sensory Performance, Collision Anticipation, and Head Impact Biomechanics in College Football Players.	Harpham JA, et al. The effect of visual and sensory performance on head impact biomechanics in college football players. <i>Ann Biomed Eng.</i> 2014 Jan;42(1):1-10.	"38 Division I college football players from the University of North Carolina at Chapel Hill Fall 2012 football team (age =20.4±1.4 years; height=190.2±6.7 cm; mass =109.3±17.8 kg). The findings of our study reveal a link between level of visual and sensory performance and head impact biomechanics in college football players."	LD/ADHD not included in exclusion criteria or incidence in sample. UNC data show 54% (13/24) incoming FB players in 2011-2012 diagnosed LD/ADHD. Of those, 9 were prescribed medication.	"We recruited 38 Division I college football players from the University of North Carolina at Chapel Hill Fall 2012 football team (age =20.4±1.4 years; height=190.2±6.7 cm; mass =109.3±17.8 kg)."	"Exclusion criteria included anyone who has a history of permanent vision loss or is currently symptomatic from a head, neck, or eye injury that would negatively affect scores on visual and sensory performance tasks."	"LD/ADHD not included in exclusion criteria. UNC data show 54% (13/24) incoming FB players in 2011-2012 diagnosed LD/ADHD. Of those, 9 were prescribed medication."
Ocwieja, Karen E. (2011) The Effect of Play Type and Collision Closing Distance on Head Impact Biomechanics.	Ocwieja KE, et al. The effect of play type and collision closing distance on head impact biomechanics. <i>Ann Biomed Eng.</i> 2012 Jan;40(1):90-6.	"We recruited 46 Division I college football players into a prospective cohort study. Data were collected during all home and away games during the 2010 NCAA regular season on one team."	No discussion of LD/ADHD or medication rates among UNC FB players.	A convenience sample of 46 Division I college football players at the University of North Carolina at Chapel Hill were participating in a larger ongoing prospective study assessing the relationship between head impact biomechanics, clinical measures of concussion, and neuroradiology.	No discussion of LD/ADHD or medication rates among UNC FB players.	
Trinidad, Katrina J. (2012) Predicting Clinical Concussion Measures at Baseline and Re-Test Based on Academic Profile and Motivation.	Trinidad KJ, et al. Predicting clinical concussion measures at baseline based on motivation and academic profile. <i>Clin J Sport Med.</i> 2013 Nov;23(6):462-9.	Eighty-eight National Collegiate Athletic Association Division I incoming UNC student-athletes (freshman and transfers).	LD/ADHD excluded	"165 UNC incoming student athletes were tested as a part of a larger sports medicine original baseline testing protocol. 86 met all inclusion criteria and gave consent for academic information release."	LD/ADHD excluded	
Ross, Luke M. (2008) Procedural Reaction Time and Balance Performance during a Dual or Single Task in Healthy Collegiate Students.	Ross LM, et al. Effects of a single-task versus a dual-task paradigm on cognition and balance in healthy subjects. <i>J Sport Rehabil.</i> 2011 Aug;20(3):296-310.	30 healthy, recreationally active college students.	LD/ADHD Excluded	"A sample of 30 healthy, physically active 18-25 year old males and females were recruited from the University of North Carolina at Chapel Hill."	LD/ADHD Excluded	
Schmidt, Julianne D. (2013) The Influence of the Cervical Musculature, Visual Performance, and Anticipation on Head Impact Severity in High School and Collegiate Football.	Schmidt JD, et al. The influence of cervical muscle characteristics on head impact biomechanics in football. <i>Am J Sports Med.</i> 2014 Sep;42(9):2056-66.	Forty-nine high school and collegiate football players, (34 HS, 15 UNC players).	No discussion of LD/ADHD	Forty-nine high school and collegiate football players, (34 HS, 15 UNC players), in 2012 football season.	No discussion of LD/ADHD	

LD/ADHD in the football athlete population, even though the Gysland thesis had noted: "No exclusion of subjects with learning disabilities, ADD or ADHD due to a limited sample who were taking medications were recorded." The Gysland et al. study holds particular relevance as cited in the aforementioned 2013 American Academy of Neurology guideline update for concussion in sport as one of only two Class II studies that did not show a relationship (vs. six that did) between prior concussions and neurobehavioral deficits.¹⁹ Both Class II studies referenced that found no

such relationship were conducted by researchers at UNC using athletes at the university. The same Gysland et al. study has also been cited in the *Handbook of Clinical Neurology, Traumatic Brain Injury Pt. I* (Ch. 4, McKee and Daneshvar⁶⁰). In the same handbook, Guskiewicz and Broglio⁶¹ cite the Collins (1999) study's findings regarding the effects of learning disabilities on concussion risk. Table 5 also includes theses by Trinidad⁶² and Ross,⁶³ both of whom excluded LD/ADHD athletes, and theses by Ocwieja⁶⁴ and Schmidt,⁶⁵ neither of whom excluded or discussed the

prevalence of LD/ADHD among the university's football athletes (corresponding published articles are also included in Table 5).^{66,67,68,69}

Other articles authored by UNC researchers, which did not stem from graduate theses, relied on football athletes at the university during the 2004-2012 period yet failed to disclose the prevalence of LD/ADHD and medication confounding factors. Using UNC football player data over 2004-2006, Guskiewicz et al.⁷⁰ reported on the relationship between instrumentally measured head accelerations and acute clinical symptoms and neuropsychological tests after concussions. From the same population of athletes, Mihalik et al. measured head impacts by football position but also did not mention the prevalence of learning disabilities.⁷¹ A more recent article, again by Mihalik et al. also relied on UNC football player data during the 2004-2012 period and also failed to mention the prevalence of LD/ADHD or medication status.⁷² It is unlikely that UNC concussion researchers were unaware of the LD/ADHD rates and medication usage among the football players during this period. At the very least, they were listed as thesis advisers or as readers on thesis committees in several of the unpublished works referenced above. Furthermore, at least one of the resulting peer-reviewed papers included authors who were UNC staff athletic trainers, Associate Director of Sports medicine and a sports medicine doctor who dealt with and dispensed stimulant medications for athletes.⁷³ Both papers referenced above continue to be widely cited in the literature. Further, articles from this time period that UNC concussion researchers co-authored with others outside the institution specifically noted the exclusion of subjects diagnosed with LD/ADHD from the study sample.^{74,75}

Data using UNC athletes have been used and continue to be used in studies that also include athletes at other universities. Using data collected between 2005 and 2010 from eight collegiate football teams, including UNC, Rowson et al.⁷⁶ used the Symbex Head Impact Telemetry System (HITS) to study the Riddell Revolution and VSR4 helmet models and concluded that their evidence illustrated that helmet design can reduce the incidence of concussions. The study did not indicate control for the modifying factors of ADD or whether other institutions exhibited similar diagnosis rates. Other studies that relied on UNC data and co-authored with UNC researchers include Beckwith et al.,⁷⁷ which examined the association between head impact and diagnosis of concussion, and a more recent 2018 article again by Beckwith et al.⁷⁸ suggesting that finite element head models (FEHM) may provide potentially important information on brain injury mechanisms. Kerr et al.⁷⁹ also relied on UNC athlete cohorts during the period when data indicate a high prevalence of LD/ADHD among the athlete population. Seven of the articles cited above that relied on

UNC football athlete data (McCaffrey et al., Guskiewicz et al., both Mihalik et al. articles, Rowson et al., and both Beckwith et al. articles) resulted from the same Centers for Disease Control (CDC) research grant to UNC.⁸⁰

Discussion

This study documents test results indicating significant cognitive impairments as well as a high prevalence of LD/ADHD diagnoses, greatly exceeding that in the general population of students, among football players at one Tier 1 research university with a top NCAA Division I athletics program. The Nation Center for Education Statistics (NCES) October 2014 report (Table 6.1) found that of the 11.1% of undergraduates in 2011-12 across all reporting institutions that reported any disability, 21.8% reported an attention deficit disorder and 4.8% reported a specific learning disability. These figures indicate a 2.4% ($11.1\% \times 21.8\%$) prevalence of ADD, a 0.5% ($11.1\% \times 0.5\%$) prevalence of LD, and a total prevalence of 2.95% of LD/ADHD. The 39% LD/ADHD prevalence among athletes at UNC during this period exceeds the general undergraduate population prevalence reported by NCES by over an order of magnitude. The 54% LD/ADHD diagnosis rate among football players shown in Table 1 is eighteen times greater than the 2.95% LD/ADHD general undergraduate population figure based on NCES data.⁸¹ In contrast, Putukian et al. (2011)⁸² note that "the prevalence of ADHD in athletes has not been studied, although there is no reason to believe it would differ in the general population." Our study, which relies on direct evidence of test results diagnosis rates from matriculating college athletes rather than on self-reported measures, casts doubt on the assumption that the ADHD diagnosis rate amongst college athletes mirrors that of the general population.

LD/ADHD are associated both with the risk of mTBI and its neurocognitive sequelae. These results serve to highlight comments made by NCAA Chief Medical Officer Brian Hainline, acknowledging that "many athletes arrive in college with a history of injury that will affect both their performance and their well-being."⁸³ Indeed, a recent study by Kelley et al. found a total of 2,125 head impacts during 30 practices among 9 individual athletes whose mean age was 11.1 ± 0.6 years.⁸⁴ The presence of modifying factors documented herein should be disclosed and controlled for in research on concussions, as the literature has observed for nearly two decades. The absence of such controls in the concussion research conducted at UNC raises questions about the validity of such studies and their applicability to other domains where head trauma is also the focus of interest.

Generalizability of Results from UNC-CH Sample

This research indicates a 39% incidence of LD/ADHD among incoming athletes at UNC over the period of 2004-2012 with academic screening results indicating a prevalence of over 50% among football players in some years. Notwithstanding ethical concerns, this study faces the question of generalizability: Is UNC an outlier or are such concussion co-morbidities prevalent among college football players? Two factors indicate that the results obtained from UNC are likely to be common among college football programs and that the issues raised may be far more widespread than recognized in current concussion research model using college athletes.

First, UNC athletes are generally recruited by other schools and choose UNC over rival programs. Thus, no readily ascertainable evidence explains why UNC's diagnosis rates among football players should be any higher or lower than other schools, given that the university's football team both wins and loses such recruiting battles. With respect to confidence in the testing, UNC hired the same neuropsychologist to conduct testing during the entire period. When this neuropsychologist left UNC and established a separate private practice in 2007, UNC moved its testing to the new firm, indicating its confidence in the testing program.

Second, although the NCAA estimates an ADHD prevalence⁸⁵ of between 5% (p.42-43) and 8.7% (p.105) in the college athlete population, limited information from other universities indicates that such high LD/ADHD prevalence figures are not unique to UNC-Chapel Hill. Wolverton reports a 40% incidence of learning disabilities among Louisiana State University (LSU) football players.⁸⁶ An ESPN *Outside-the-Lines* report cited learning disability incidence rates of 35% and 75% among the Florida State University football and basketball players, respectively.⁸⁷ In the academic literature, Merritt found the prevalence of developmental disorders, including ADD/ADHD, of approximately 20% among Pennsylvania State University athletes, though sport-specific breakdowns were not provided.⁸⁸ Despite the prevalence of such testing, researchers often rely on self-reported LD/ADHD diagnoses rather than cross-referencing diagnoses with academic screening and neuropsychological testing of athletes done at matriculation.

Limited External Validity of Concussion Research Using College Athletes

This study's observed prevalence of LD/ADHD among the athlete population calls into question the ability of such results to extrapolate to other populations. The diagnosis and medication prescription rates present in the athlete population discussed in our study do not comport either to

general population figures or to any other readily identifiable group to which such results may be usefully extrapolated. Generalization from college athletes to military servicemembers has been justified partly based on claimed similarities between the two populations. Broglio et al.⁸⁹ offered the following justification for extrapolating concussion research results from college athletes to the military:

...military service members, particularly military service academy students, share similar physical and demographic characteristics with NCAA student athletes. That is, the 'tactical athlete' is typically young (18–25 years), healthy, strives for both mental and physical excellence, and sustains concussions under similar mechanisms as service academy personnel.

These characteristics resemble those offered by NCAA Chief Medical Officer Brian Hainline, who, in 2016, claimed that:⁹⁰

NCAA student-athletes and military servicemembers share many demographics: they are similar in age, athleticism, risk-taking, and the practice of pushing themselves to the edge of excellence.

We could find no analytical support for at least the last three of these claimed similarities. Nor are abstract characteristics such as "pushing to the edge of excellence" or "striving for mental and physical excellence" relevant co-morbidities or modifying factors in concussion research. Representations of age similarities between the two populations also appear questionable, as only 45% of active duty servicemembers and 32.5% of reserve members are age 25 or younger.⁹¹ Most recently, UNC researchers Kerr et al.'s commentary in JAMA⁹² highlighted the limited comparability of control groups such as the general population to former American football players, a contrasting observation to the claims of translational relevance from Broglio and Hainline cited above.

In further contrast to claims of translational relevance from college athletes to the military, a 2006 article by Krauss et al.⁹³ notes that a diagnosis of ADHD was disqualifying for military service at the time if the condition interfered with school or work after age 12. This claim is confirmed by the 2007 U.S. Army Regulation 40-501, which stated that LD/DHD "is disqualifying, unless [the] applicant can demonstrate passing academic performance and there has been no use of medication(s) in the previous 12 months."⁹⁴ Revised as of June 2017, the "is disqualifying" was changed to "does not meet the standard."⁹⁵ Most recently, the *US DoD Instruction 6130.03, Medical Standards for Appointment, Enlistment or Induction into the Military Services*,⁹⁶ effective May 6, 2018, observes that ADHD is disqualifying if accompanied by accommodations or prescribed medication in the previous 24 months. Likewise, learning disorders after the 14th birthday are disqualifying if accompanied by accommodations or a history of comorbid

mental disorders. As such, it is clear that a population that includes a significant prevalence of LD/ADHD with accommodations or stimulant use would differ from the military population with respect to these identified confounding factors.

Such differences notwithstanding, the US military continues to rely on studies of concussion in sports, likely because of such afore-mentioned translational relevance claims made by sports concussion researchers. One example of a study cited by the military⁹⁷ that relied on UNC athletes during the time period covered by this study is Schmidt et al.⁹⁸ The authors, concussion researchers at UNC, relied on preseason baseline testing data for UNC male and female athletes between 2001-2010 to analyze post-concussion impairments and contrast individualized baselines with a normative sample, the latter of which consisted of incoming freshmen and transfers at the university. Of the 1,060 athletes who completed baseline testing, approximately 37% were excluded on the basis of self-reported LD/ADHD or having sustained a previous concussion.

Schmidt et al.'s work is particularly relevant for this study for two reasons: 1) it underscores the importance of separate treatment of LD/ADHD individuals when extrapolating beyond college athletes to other populations, especially the military, and 2) it exposes a major shortcoming in relying on self-reported measures of LD/ADHD. Most LD/ADHD UNC football athletes were first diagnosed with such conditions after EID testing at the university.⁹⁹ If baseline concussion testing predates neuropsychological testing for EIDs among incoming freshman athletes, reliance on self-reported measures would result in substantial under-reporting and over-inclusion of LD/ADHD athletes in concussion research using college athletes, limiting the relevance of such results to other populations. Our research indicates that athletes were often tested for EIDs after the beginning of practice and sometimes after the beginning of the season, meaning that baseline concussion testing would have already occurred. Normative measures obtained from research relying on self-reported measures may be downwardly-biased as a result of such inclusion. Moreover, the 2012 *U.S. Air Force Waiver Guide* cautioned against relying on self-identification of ADD, noting:¹⁰⁰

As it is unlikely that an initial flight applicant or rated aviator would self-identify as suffering from attention deficit disorder, the clinician must have a high index of suspicion for this disorder.

Reliance on self-reported LD/ADHD should be eschewed in favor of diagnoses obtained from medical records and/or academic screening and neuropsychological testing

regularly performed on matriculating college scholarship athletes.

Contrary to the scientific consensus discussed previously herein, we also observe that the majority of recently-published studies from the NCAA-DoD CARE Consortium do not appear to exclude or control for LD/ADHD or stimulant medication status among study participants. With limited exceptions, such studies also commonly fail to disclose the prevalence of these conditions among their study populations. Caccese et al.¹⁰¹ do not include LD/ADHD or medication status among their exclusion criteria and only mention controlling for self-reported learning accommodation status (athletes endorsing 'yes'). Garcia et al.¹⁰² characterize their data with respect to various concussion risk modifiers, yet do not include LD/ADHD or stimulant medication status among them. Stemper et al.,¹⁰³ in a study comparing head impact exposure between concussed athletes and matched controls, do not mention LD/ADHD or medication conditions at all. Katz et al.,¹⁰⁴ whose study's stated purpose was to provide normative data from the CARE Consortium, mention collecting self-reported data but no information on LD/ADHD or medication status. The authors, who found no evidence that college athletes participating in contact sports have "clinically meaningful deficits in preseason cognitive and balance testing" do not list LD/ADHD or medication as exclusion criteria. In fact, they do not acknowledge the presence of these conditions among the college athlete population at all. Neither do Weber et al.^{105,106} or Rowson et al.¹⁰⁷

We find these omissions to be troubling, not only because of previous research identifying such characteristics as modifying factors but also for two additional reasons. First, the CARE Consortium clearly collects self-reported LD/ADHD data. Klein et al. (2019) observed a 13.8% prevalence of ADHD among collision sport athletes who suffered a concussion vs. a 7.5% prevalence in collision sport athletes who did not. ADHD prevalence among non-collision sport control athletes (no concussion) was 6.3%. However, the authors did not note LD/ADHD as control factors or exclusion criteria. Hoffman et al. (2017) excluded athletes if they self-reported LD/ADHD. Second, in recent CARE Consortium article in *Injury Epidemiology*, Van Pelt et al.,¹⁰⁸ some of whom appear as co-authors in the aforementioned studies from the CARE Consortium, studied cadets at U.S. Military Service Academies over a period of three years and found that diagnosed ADD/ADHD increased concussion risk. However, of the studies we reviewed, none of those based on college athlete samples that were published after the Hoffman et al. 2017 study excluded LD/ADHD/medication status or treated them as modifying factors as prescribed in the literature. These findings, along with the documents we present herein detailing the prevalence of these

characteristics among college athletes, lead us to expect that current CARE Consortium studies using college athletes will have limited, if any, translational relevance to the military population.

LD/ADHD, Brain Injury, and Causation

The cumulative effect of concussions and head impacts has been well-recognized.¹⁰⁹ The association of LD/ADHD co-morbidities with head trauma highlights the possibility that the LD/ADHD prevalence in the college athlete population could be explained by brain injury previously sustained during the course of sports participation.¹¹ Previous research supports such a hypothesis. Poole et al.,¹¹⁰ whose study compared 25 high school football players with non-contact-sport controls, found evidence of cumulative effects of head blows despite not pinpointing them to a single causal event. One of the study's co-authors observed that the majority of players had still not fully recovered months after the season's end.¹¹¹ A recent meta-analysis of fifty-seven published papers found an association between traumatic brain injury and subsequent neurologic and psychiatric disease.¹¹² A 2017 study by Montenegro et al.¹¹³ using former high school and college football players was "the first in the literature to demonstrate a threshold dose-response relationship between estimated cumulative head impact exposure from football and later-life risk for cognitive and neurobehavioral impairment." Recently, Iaccarino et al.¹¹⁴ found that a) ADHD was over-represented in athletes with a sports-related concussion (SRC); b) the age of onset predated the SRC; and c) ADHD increased the risk of sustaining an SRC. The study authors conclude that these findings "...suggest that ADHD is an antecedent risk factor for SRC, is a risk factor for sustaining multiple head injuries, and contributes to complicate recovery from SRC." The Iaccarino et al. study also found that 50% (11/22) SRC patients aged <17 years had full ADHD. Using the Taiwan Health Insurance Research Database to analyze children (ages 3-11), adolescents (ages 12-17), and young adults (ages 18-29) between 2001 and 2009 and following up in 2011, Liou et al.¹¹⁵ also found that patients with ADHD had an increased risk of suffering a traumatic brain injury compared to controls.

Brain injuries may result in cognitive impairments such as LD/ADHD, but the diminished impulse control associated with such conditions may also cause athletes to put themselves at increased TBI risk.^{11,116} Recent research indicates that learning disabilities are individually associated with a significantly greater prevalence of previous concussions¹¹⁷ and that mTBI patients with premorbid ADHD diagnoses are significantly more disabled by the injury than those without ADHD.^{118,119} As such, the literature indicates that the determination of a causal model between

LD/ADHD and brain injuries appears complicated by endogeneity.

This limit notwithstanding, lack of control for LD/ADHD as confounding factors in concussion research yields downwardly-biased norms, potentially resulting in either under-diagnosis of concussions (false negatives) among athletes or premature return-to-activity decisions. Normative baselines obtained from samples that include LD/ADHD athletes will be lower, *ceteris paribus*, than what would be obtained from samples that exclude such conditions. Thus, when post-concussive non-LD/ADHD patients are compared to such baselines, they may test in a 'normal' range and be prematurely returned to activity. Han et al. (2019) also observe individuals with ADHD may show no change of neurocognitive function after suffering a concussion.¹²⁰ To the extent that such normative baselines are used as part of a protocol to determine whether the patient suffered a concussion, a concussion diagnosis may be missed. As the aforementioned Peltonen et al. article summarized, clinical decisions may be negatively skewed.²⁷

Further, because deviations from baseline test results are commonly measured using reliable change indices (RCIs)¹²¹ of 80-95%,¹²² these results indicate that athletes with low baselines would have to test in ranges consistent with severe, debilitating brain injury to trigger a significant result. Indeed, Mihalik et al. raise precisely these concerns in a study using UNC athletes, whose results indicated that "small percentages of injured student-athletes displayed reliable and clinically meaningful deficits on the individual measures included in the concussion assessment."¹²³ Mihalik et al. note that: "Too often, computerized neurocognitive testing is viewed as the sole determinant of impairment or improvement following concussive injury." Based on the RCI, athletes may be allowed to return to activity prematurely or concussions may be misdiagnosed as less severe sub-concussive impacts, a concern warranted by limited team-specific concussion figures.

For example, during the 2014 and 2015 seasons, nearly half of the NCAA Football Bowl Subdivision (FBS) college teams (60/128) did not publicly report a single concussion.¹²⁴ Between August 2013 and December 27, 2013, FBS coaching staffs and media only reported 192 concussions among 10,000 players, fewer than two concussions per team, a number questioned even by the head of Datalys, the NCAA's Injury Surveillance Program. Additionally, relying upon the Datalys data, which represent a convenience sample, Kerr et al. (2017) reported an average of 5.63 (+/- 5.36) concussions per football team per season for the 2011/12-2014/15 academic years.¹²⁵ Such a figure remains low, particularly considering the number of head impacts athletes suffer on a consistent basis. The simultaneous co-existence of a high number of head impacts and relatively low number of concussions reported

may indicate that a high prevalence of LD/ADHD in the football athlete population masks the severity of head impacts, resulting in artificially low concussion rates. Piland et al.¹²⁶ cautioned in 2003 that:

Evaluation of concussion resolution depends upon the presence of a representative baseline measure. If baseline measures are confounded by reports of symptoms that are not specific to concussion, injury severity and resolution could be misdiagnosed and underreported.

The fact that substantial percentages of football athletes exhibited test results consistent with patients suffering traumatic brain injury is relevant to an issue raised by Dr. Robert Cantu in the *In re National Hockey League Players' Concussion Injury Litigation* matter. In his declaration, Dr. Cantu noted that:¹²⁷

Another symptom of PCS [post-concussion syndrome], as well as of CTE [chronic traumatic encephalopathy], Alzheimer's, Lewy Body Dementia, and Frontal Lobe Dementia, is a problem with memory and thinking, such as an inability to organize or multitask. Athletes with these problems may believe that they are suffering from Attention-Deficit Disorder (ADD) or Attention-Deficit/Hyperactivity Disorder (ADHD) but in fact, with an appropriate diagnosis of PCS or a neurodegenerative disease, could obtain cognitive therapy. (emphasis added)

Dr. Cantu's comments echo those of McAllister and Arciniegas (2002), who observed that:¹²⁸

the attention deficits of persistently impaired TBI survivors sometimes superficially resemble those of patients with attention-deficit hyperactivity disorder (ADHD) prompting treatment with psychostimulants..."

Even earlier, Gualtieri and Evans (1988) recognized that:¹²⁹

Stimulants improve symptoms of inattention, distractibility, disorganization, hyperactivity, impulsiveness and emotional lability in children and adults with attention-deficit/hyperactivity disorder (AD/HA). Many TBI patients have similar symptoms.

Of particular note, Gualtieri, the aforementioned author, performed neuropsychological testing on UNC athletes from approximately 1997 to 2007. He informed UNC personnel in a January 9, 2007 email, which included an attached paper draft, that:¹³⁰

we screened the last 2 years' entering footballers and last year's women's basketball. The kids were not selected because they were at risk -- everyone was screened. As you can see, 61% of the kids had either ADD or a learning disability (or both), and the large majority were previously undiagnosed.

The combined facts that 1) football athletes in our study sample exhibited depressed neurocognitive testing scores at matriculation; 2) they were diagnosed LD/ADHD at rates multiple times higher than those observed in the undergraduate population; and 3) such high rates were also

observed at least one other major collegiate football program; coupled with 4) observations by Drs. Cantu, McAllister, and Gualtieri, at the very least, raise the possibility that such athletes may have been suffering from neurocognitive sequelae of brain injuries when tested at matriculation. Given research that indicates that concussion patients are at increased risk of additional brain injury, our results warrant the questions of whether sufficient warning was provided to such athletes and whether they should have been permitted to continue playing if doing so placed their safety and welfare at greater risk.

Psychostimulant Prescriptions and Brain Injury

This research also evidences prescriptions of psychostimulants to a significant number of football athletes as a treatment for attention deficit disorders. As data from the 2011-12 end of year report noted, 38% of incoming UNC football players were prescribed medication for LD/ADHD. Prescriptions of pharmacologic treatment consisting of psychostimulants such as methylphenidate (Metadate, Ritalin) can play a role in managing neurocognitive sequelae of TBI.¹³¹ However, such findings warrant concern over whether the use of medication temporarily mitigates the effects of brain injury during post-concussive testing and yields scores incongruous with actual recovery, potentially resulting in a premature return to activity. Further, the use of such stimulants among college athletes is complicated by its prohibition by regulatory bodies such as the World Anti-Doping Agency (WADA) because of potential use as a performance-enhancing drug (PED). The NCAA permits medical use exceptions upon evidence of standard assessment to diagnose ADHD. Nonetheless, concern about the use of such stimulants as PEDs among collegiate athletes is warranted given NCAA surveys of collegiate athletes that show higher percentages of athletes (breakdown by sport was not available) using ADHD medication without a prescription (6.7%, 8.7%, 7.5%) that with a prescription (4.5%, 5.7%, 6.6%) in 2009, 2013, and 2017 surveys, respectively.¹³²

Further, evidence also shows that athletes may not understand the implications of taking psychostimulants for ADHD, such as Adderall. One email from UNC's head of sports medicine states that an athlete suffered heart palpitations after being told "it would help him out with practice" and taking it before his morning run.¹³³ White et al.¹³⁴ identify the risk of heat injury and cardiac arrhythmias as two potential areas of concern among athletes taking stimulant medication of ADHD and observe that young athletes may not recognize the side effects of such medication. This is of particular concern when athletes practice or compete in the heat. Stewman et al.¹³⁵ also note that stimulant use is an independent risk factor for heat

illness. Recently, the independent investigation into the death of University of Maryland student and football athlete Jordan McNair found that McNair was on a prescription of Vyvanse (50mg dose).¹³⁶ While observing that the “general concern among the medical community for student-athletes involved in physical activity while taking stimulant medication” the report also noted that “no records were provided of any counseling or patient education relative to the impact of the drug on exercise tolerance for Jordan McNair.” Such instances highlight the importance that athletes be informed of the risks of participation in sport, particularly when their conditions may place them at greater risk of adverse health outcomes or even death.

Research Ethics and the Belmont Report Guidelines

Our findings indicate that the ethical principles and guidelines set forth by the U.S. Department of Health & Human Services (HHS) *Belmont Report* do not appear to have been followed. For example, the Institutional Review Board (IRB) consent form in the 2005-2006 UNC study (McCaffrey et al. in Table 1, #04-EXSS-366) warned patients not to participate if diagnosed with psychiatric disorders, including somatoform disorders, or other central nervous system (CNS) disorders. However, the IRB consent does not explain what such disorders are, nor are subjects likely to possess sufficient familiarity with the research protocols and complex scientific terminology to understand what, for example, “somatoform disorders” are without more detailed explanation. Further, the IRB makes no mention of LD/ADHD as risk factors despite the acknowledged prevalence of such diagnoses among the institution’s football team. As the *Belmont Report* observes:¹³⁷

...a simple listing of items does not answer the question of what the standard should be for judging how much and what sort of information should be provided... Even when some direct benefit to them is anticipated, the subjects should understand clearly the range of risk and the voluntary nature of participation.

However, the IRB form used in the study above places the onus of comprehension on the participant, not the investigator, stating:

It is important that you understand this information so that you can decide in a free and informed manner whether you want to participate... You are urged to ask the investigators named above, or staff members who may assist them, any questions you have about this study at any time.

This practice appears at odds with the *Belmont Report*, which places the onus of ensuring patient comprehension on the researcher, not the subject:

Because the subject's ability to understand is a function of intelligence, rationality, maturity and language, it is necessary to adapt the presentation of the information to

the subject's capacities. Investigators are responsible for ascertaining that the subject has comprehended the information. While there is always an obligation to ascertain that the information about risk to subjects is complete and adequately comprehended, when the risks are more serious, that obligation increases. On occasion, it may be suitable to give some oral or written tests of comprehension. (emphasis added)

The omission of explanations raises questions regarding the ethics of using collegiate athletes as medical research subjects. College athletes, particularly those early in their academic careers, may not fully comprehend or accurately evaluate the risks associated with such experiments or of continued participation in collision sports. In instances where athletes are subjected to repeated concussive and subconcussive blows to the head, identification of risks and ensuring patients understand co-morbidities that exacerbate such risks are of paramount importance.

Conclusion

A significant strength of this study is its access to and reliance upon publicly released primary documents that are seldom, if ever, available in research studies: de-identified neuropsychological test results and documentation regarding LD/ADHD diagnosis and medication rates among college athletes. The results presented here, which indicate a failure to disclose such modifying factors, raise doubts regarding the validity of results obtained from concussion research conducted on athletes at one major university, as well as research conducted elsewhere that relied on these athlete populations. Papers published from the research program discussed herein should be investigated, compared with unpublished studies, and, where appropriate, retracted. Previously mentioned research indicating elevated LD/ADHD rates among athletes at other universities also merits concern not only for the health and welfare of athletes engaged in collision sports but also for the robustness of sports concussion research that relies on collegiate, or even high school, football players. Failure to disclose or account for LD/ADHD and stimulant medication use in concussion study samples casts doubt on the validity of findings from such research, with potentially grievous implications for athletes and patients whose diagnoses may have been affected by it. Given the prevalence of modifying factors found among college football players in this study, any extrapolation of the results of these published studies to other populations, particularly the U.S. military, appears inappropriate and potentially harmful.

Finally, our results also indicate that self-reported indicators of LD/ADHD may understate the actual prevalence of such cognitive disorders among concussion study samples relying on college athletes. Because baseline concussion testing can occur before neuropsychological

testing for such disorders at colleges and universities, athletes who are diagnosed for the first time may report an absence of LD/ADHD during concussion testing but receive a positive diagnosis after subsequent academic testing. Because post-concussive symptoms may mimic attention deficits, researchers and medical practitioners should ensure that athletes exhibiting LD/ADHD symptoms are not actually suffering acute or potentially cumulative after-effects of brain injuries sustained during sport.

Acknowledgments: The authors gratefully acknowledge the valuable review and comments from Prof. Stephen T. Casper (Clarkson Univ.) and Prof. Daniel Goldberg (Univ. of Colorado Anschutz Medical Campus). The authors also thank Mary

Willingham, a former learning specialist at UNC-Chapel Hill during the period discussed herein, for graciously lending her time to answer questions about the documents and data collection process. We also thank anonymous reviewers for their thoughtful suggestions and encouragement.

Disclosures: Ted Tatos reports no conflicts of interest. Don Comrie previously advised the Morey Objectors on economic and health matters in the National Football League Players' Concussion Injury Litigation, Case No. 12-md-02323-AB, U.S. District Court for the Eastern District of Pennsylvania between August 2013 and April 2015. This study received no external funding.

References

- ¹ DoD Blast Injury Research Program Coordinating Office. International State-of-the-Science Meeting on the Biomedical Basis for Mild Traumatic Brain Injury (mTBI) Environmental Sensor Threshold Values – Literature Review, 4-6 November 2014.
- ² Cochran, WG. Sampling Techniques, 3rd Ed. John Wiley & Sons, 1977.
- ³ Skelly AC, Dettori JR, Brodt ED. Assessing bias: the importance of considering confounding. *Evid Based Spine Care J*. 2012;3(1):9–12. doi:10.1055/s-0031-1298595
- ⁴ Congressionally-Directed Military Research Programs – Psychological Health/Traumatic Brain Injury. Available online at: <https://cdmrp.army.mil/phtbi/default>
- ⁵ Michael McCrea (Chair), Neil Pliskin (Chair, Division 40 Practice Affairs Committee), Jeffrey Barth, David Cox, Joseph Fink, Louis French, Thomas Hammeke, David Hess, Alan Hopewell, Daniel Orme, Matthew Powell, Ron Ruff, Barbara Schrock, Lori Terryberry-Spohr, Rodney Vanderploeg & Ruth Yoash-Gantz (2008) Official Position of the Military TBI Task Force on the Role of Neuropsychology and Rehabilitation Psychology in the Evaluation, Management, and Research of Military Veterans with Traumatic Brain Injury, *The Clinical Neuropsychologist*, 22:1, 10-26
- ⁶ Ridpath, M., Education-Impacting Disabilities and the NCAA Waiver Process, in *NCAA's Mind, Body, and Sport: Understanding and Supporting Student-Athlete Mental Wellness*, Greg Brown, ed. Available online at: <http://www.ncaapublications.com/productdownloads/MindBodySport.pdf>
- ⁷ UNC document release, PR3-036.pdf, February 2016 at 868.
- ⁸ UNC document release, PDF5d-Final-Web.pdf, October 2015 at 2515.
- ⁹ Collins, M., Grindel, S., Lovell, M., Dede, D., Moser, D., Phalin, B., Nogle, S., Wasik, M., Cordry, D., Daugherty, M., Sears, S., Nicolette, G., Indelicato, P., McKeag, D. (1999). Relationship between concussion and neuropsychological performance in college football players. *JAMA*, 282(10): 964-970.
- ¹⁰ Solomon, G. (2013). Vanderbilt Sports Concussion Center: Clinical, Educational, and Research Activities. CE Presentation. Tennessee Psychological Association 2013 Convention.
- ¹¹ Iverson, G., Wojtowicz, M., Brooks, B., Maxwell, B., Atkins, J., Zafonte, R., Berkner, P. (2016). High school athletes with ADHD and learning difficulties have a greater lifetime concussion history. *J Atten Disord*. 2016 Jul 18. pii: 1087054716657410. [Epub ahead of print] PubMed PMID: 27431932.
- ¹² Barker, T., Russo, S., Barker, G., and Craddock, T. (2017). A case matched study examining the reliability of using ImPACT to assess effects of multiple concussions. *BMC Psychology*, 5(1): 14. doi: 10.1186/s40359-017-0184-1. PubMed PMID: 28454588; PubMed Central PMCID: PMC5410025.
- ¹³ Nuwer MR, Nuwer JM, Tsao JW. Student athlete concussions and postconcussion syndrome: ADHD as a risk factor. *Neurol Clin Pract*. 2018 Oct;8(5):377-378. doi: 10.1212/CPJ.0000000000000529.
- ¹⁴ Institute of Medicine (IOM) and National Research Council (NRC). 2014. Sports-related concussions in youth: Improving the science, changing the culture. Washington, DC: The National Academies Press.
- ¹⁵ NCAA Sport Science Institute. Interassociation Consensus: Diagnosis and Management of Sport-Related Concussion Best Practices.
- ¹⁶ McCrory, P., Meeuwisse, W., Aubry, M., Cantu, B., Dvorák, J., Echemendia, R., Engebretsen, L., Johnston, K., Kutcher, J., Raftery, M., Sills, A., Benson, B., Davis, G., Ellenbogen, R., Guskiewicz, K., Herring, S., Iverson, G., Jordan, B., Kissick, J., McCrea, M., McIntosh, A., Maddocks, D., Makdissi, M., Purcell, L., Putukian, M., Schneider, K., Tator, C., and Turner, M. (2012). Consensus statement on concussion in sport: the 4th International Conference on Concussion in Sport held in Zurich, November 2012. *Br J Sports Med*, 47(5): 250-8.

- 17 Elkington, L. and Hughes, D. (2016). Australian Institute of Sport and Australian Medical Association Concussion in Sport Position Statement.
- 18 Harmon, K., Drezner, J., Gammons, M., Guskiewicz, K., Halstead, M., Herring, S., Kutcher, J., Pana, A., Putukian, M., and Roberts, W. (2013). American Medical Society for Sports Medicine Position Statement: Concussion in Sport. *Br J Sports Med* 2013;47:15–26.
- 19 Giza CC, Kutcher JS, Ashwal S, Barth J, Getchius TS, Gioia GA, Gronseth GS, Guskiewicz K, Mandel S, Manley G, McKeag DB, Thurman DJ, Zafonte R. Summary of evidence-based guideline update: evaluation and management of concussion in sports: report of the Guideline Development Subcommittee of the American Academy of Neurology. *Neurology*. 2013 Jun 11;80(24): 2250-7.
- 20 McCrea, M., Guskiewicz, K., Marshall, S., Barr, W., Randolph, C., Cantu, R., Onate, J., Yang, J., Kelly, J. (2003). Acute effects and recovery time following concussion in collegiate football players: the NCAA Concussion Study. *JAMA*, 290(19): 2556-63.
- 21 Guskiewicz KM, Marshall SW, Broglio SP, Cantu RC, Kirkendall DT. No evidence of impaired neurocognitive performance in collegiate soccer players. *Am J Sports Med* 2002;30:157-162.
- 22 Declaration of Christopher Giza, In Re National Football Players Concussion Litigation, No. 2:12-md-02323-AB, MDL No.2323
- 23 Alosco ML, Fedor AF, Gunstad J. Attention deficit hyperactivity disorder as a risk factor for concussions in NCAA division-I athletes. *Brain Inj*. 2014;28(4):472-4.
- 24 Biederman, J., Feinberg, L., Chan, J., Adeyemo, B., Woodworth, K., Panis, W., McGrath, N., Bhatnagar, S., Spencer, T., Uchida, M., Kenworthy, T., Grossman, R., Zafonte, R., and Faraone, S. (2015). Mild traumatic brain injury and attention-deficit hyperactivity disorder in young student athletes. *Nerv Ment Dis*. 203(11): 813-9.
- 25 NFL Sideline Concussion Assessment Tool: Baseline Test. Available online at: <http://static.nfl.com/static/content/public/photo/2014/02/20/0ap2000000327057.pdf>
- 26 Elbin, R., Kontos, A., Kegel, N., Johnson, E., Burkhart, S., and Schatz, P. (2013). Individual and combined effects of LD and ADHD on computerized neurocognitive concussion test performance: evidence for separate norms. *Arch Clin Neuropsychol*, 28(5): 476-84.
- 27 Peltonen K, Vartiainen M, Laitala-Leinonen T, Koskinen S, Luoto T, Pertab J, Hokkanen L. Adolescent athletes with learning disability display atypical maturational trajectories on concussion baseline testing: Implications based on a Finnish sample. *Child Neuropsychol*. 2019 Apr;25(3):336-351. doi: 10.1080/09297049.2018.1474865 .
- 28 Zuckerman, S., Lee Y., Odom, M., Solomon, G., and Sills, A. (2013). Baseline neurocognitive scores in athletes with attention deficit-spectrum disorders and/or learning disability. *J Neurosurg Pediatr*. 12(2): 103-9.
- 29 Salinas, C., Webbe, F. (2012). Sports neuropsychology with diverse athlete populations: contemporary findings and special considerations. *Journal of Clinical Sport Psychology*, 6(4): 363-384.
- 30 Sabini, R., Nutini, D., and Nutini, M. (2014). Phys Sportsmed, Return-to-play guidelines in concussion: revisiting the literature. 42(3): 10-9.
- 31 Iverson, G., Collins, M., Roberge, M., and Lovell, M. (undated). Preseason neurocognitive testing in athletes with academic problems. *Int Neuropsychol Soc*. 2008 Feb; 14(s1):224-225., Available online at: <https://concussionresearch.com/preseason-neurocognitive-testing-in-athletes-with-academic-problems/>
- 32 Majerske, C., Mihalik, J., Ren, D., Collins, M., Reddy, C., Lovell, M., and Wagner, A. (2008). Concussion in sports: postconcussive activity levels, symptoms, and neurocognitive performance. *J Athl Train*, 43(3): 265-74.
- 33 Ganim S., Sayers, D. UNC report finds 18 years of academic fraud to keep athletes playing, CNN Investigations, Oct. 23, 2014, Available online at: <https://www.cnn.com/2014/10/22/us/unc-report-academic-fraud/index.html>
- 34 University of North Carolina at Chapel Hill, University releases batch of records gathered for Weinstein investigation, Oct. 21, 2015, updated June 8, 2017. Available online at: <https://carolinacommittment.unc.edu/university-releases-batch-of-records-gathered-for-weinstein-investigation/>
- 35 Johnson, L. and Willingham, M. (2011). Cognitive/neuropsychological profiles in LD/ADHD and non-disabled collegiate athletes. Poster Presentation B-19. National Academy of Neuropsychology 2011 Conference. (See also: Johnson, L. and Willingham, M. (2011), The Incidence of Learning Disabilities and ADHD in Freshman Student Athletes. Poster Presentation, College Sports Research Institute (CSRI) Conference, April 2013.)
- 36 Dennis Kramer, Review of Incoming Student-Athlete Readiness - Prepared for the University of the North Carolina, Chapel Hill, March 2014 (unpublished); Nathan R. Kuncel, Evaluation and Discussion of Student Athlete Testing Data at the University of North Carolina at Chapel Hill, March 3, 2014 (unpublished); Lee Brannum-Martin, Analysis of Materials Regarding UNC Student Athletes, March 23, 2014 (unpublished).
- 37 UNC document release, PDF-D014, December 2015 at 2856-7. Available online at: <https://s3.amazonaws.com/url-carolinacommittment-storage/PDF-D014.pdf>.
- 38 UNC document release, PDF-D014, December 2015 at 2751. Available online at: <https://s3.amazonaws.com/url-carolinacommittment-storage/PDF-D014.pdf>

- ³⁹ UNC document release, PDF1A-Final-web, October 2015 at 1764. Available online at: <https://s3.amazonaws.com/url-carolinacommithment-storage/PDF1A-Final-web.pdf>
- ⁴⁰ UNC document release, PRR7-05, December 2016 at 4270. Available online at: <https://s3.amazonaws.com/url-carolinacommithment-storage/PRR7-05.pdf>
- ⁴¹ UNC document release, PRR601, August 2016 at 46. Available online at: <https://s3.amazonaws.com/url-carolinacommithment-storage/PRR601.pdf>
- ⁴² UNC document release, PDF3B-Final-Web, October 2015 at 3422-3425. Available online at: <https://s3.amazonaws.com/url-carolinacommithment-storage/PDF3B-Final-web.pdf>
- ⁴³ UNC document release, PR8-Final+Release+03.pdf, June 2017, at 416-417. Available online at: <https://s3.amazonaws.com/url-carolinacommithment-storage/Final+Release+03.pdf>
- ⁴⁴ UNC document release, PR3-045, February 2016 at 302. Available online at: <https://s3.amazonaws.com/url-carolinacommithment-storage/PR3-045.pdf>
- ⁴⁵ Gualtieri, C. and Johnson, L. (2006). Efficient allocation of attentional resources in patients with ADHD: maturational changes from age 10 to 29. *Journal of Attention Disorders*, Feb;9(3):534-42.
- ⁴⁶ Gualtieri, C. and Johnson, L. (2008). A computerized test battery sensitive to mild and severe brain injury. *Medscape J Med*, 10(4): 90.
- ⁴⁷ Lovell, M. ImPACT Administration and Interpretation Manual, 2016. Available online at: <https://pulse-static-files.s3.amazonaws.com/ecb/document/2017/02/07/a05aa3da-93d7-4fff-b9cb-2fb3a89c960f/IMPACT-interpretation-manual.pdf>
- ⁴⁸ Hettich, T., Whitfield, E., Kratz, K., and Frament, C. (2010). Case report: use of the Immediate Post Concussion Assessment and Cognitive Testing (ImPACT) to assist with return to duty determination of special operations soldiers who sustained mild traumatic brain injury. *Journal of Special Operations Medicine*, 10(4): 48-55.
- ⁴⁹ McCaffrey, Meghan. (2006). Effects of High and Low Impact Magnitudes on Concussion Measures in Collegiate Football Players. MA Thesis, University of North Carolina Chapel Hill. Available online at: <https://cdr.lib.unc.edu/concern/dissertations/j6731437r>
- ⁵⁰ McCaffrey, M., Mihalik, J., Crowell, D., Shields, E., Guskiewicz, K. (2007). Measurement of head impacts in collegiate football players: clinical measures of concussion after high- and low-magnitude impacts. *Neurosurgery*, 61(6): 1236-43.
- ⁵¹ McCrory, P., Meeuwisse, W., Dvorak, J., Aubry, M., Bailes, J., Broglio, S., Cantu, R., Cassidy, D., Echemendia, R., Castellani, R., Davis, G., Ellenbogen, R., Emery, C., Engebretsen, L., Feddermann-Demont, N., Giza, C., Guskiewicz, K., Herring, S., Iverson, G., Johnston, K., Kissick, J., Kutcher, J., Leddy, J., Maddocks, D., Makdissi, M., Manley, G., McCrea, M., Meehan, W., Nagahiro, S., Patricios, J., Putukian, M., Schneider, K., Sills, A., Tator, C., Turner, M., and Vos, P. (2016). Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016. *Br J Sports Med*. 2017 Jun;51(11): 838-847.
- ⁵² Guskiewicz, K. M., Bruce, S. L., Cantu, R. C., Ferrara, M. S., Kelly, J. P., McCrea, M., Putukian, M., Valovich McLeod, T. C. (2004). National Athletic Trainers' Association Position Statement: Management of Sport-Related Concussion. *Journal of athletic training*, 39(3): 280-297.
- ⁵³ National Institutes of Health (NIH), Drug Record: Central Nervous System (CNS) Stimulants. Available online at: <https://livertox.nih.gov/CNSStimulants.htm> (accessed 12/30/2018).
- ⁵⁴ Littleton, A. (2011). The effects of attention deficit and hyperactivity disorder (ADHD) on clinical measures of concussion. MA Thesis, University of North Carolina Chapel Hill. Available online at: <https://cdr.lib.unc.edu/record/uuid:c3fb9b92-b250-4e0f-ad09-32f0364f2018>
- ⁵⁵ Littleton A., Schmidt, J., Register-Mihalik, J., Gioia, G., Waicus, K., Mihalik, J., and Guskiewicz, K. (2015). Effects of attention deficit hyperactivity disorder and stimulant medication on concussion symptom reporting and computerized neurocognitive test performance. *Arch Clin Neuropsychol*, 30(7): 683-93.
- ⁵⁶ Gysland, S. (2009). The relationship between subconcussive impacts and concussion history on clinical measures of concussion in collegiate football players. MA Thesis, University of North Carolina Chapel Hill. Available online at <https://cdr.lib.unc.edu/record/uuid:72372317-53c6-499c-9d4c-9cbeb86f8f89>
- ⁵⁷ Harpham, J. (2013). A study of visual and sensory performance, collision anticipation, and head impact biomechanics in college football players. MA Thesis, University of North Carolina Chapel Hill. Available online at: <https://cdr.lib.unc.edu/record/uuid:d1256592-c3d8-4503-bd08-43471d1ca341>
- ⁵⁸ Gysland, S., Mihalik J., Register-Mihalik J., Trulock S., Shields E., and Guskiewicz K. (2012). The relationship between subconcussive impacts and concussion history on clinical measures of neurologic function in collegiate football players. *Ann Biomed Eng*, 40(1): 14-22.
- ⁵⁹ Harpham, J., Mihalik, J., Littleton, A., Frank, B., and Guskiewicz, K. (2014). The effect of visual and sensory performance on head impact biomechanics in college football players. *Ann Biomed Eng*, 42(1): 1-10.
- ⁶⁰ Mckee AC, Daneshvar DH. The neuropathology of traumatic brain injury. *Handbook of Clinical Neurology*. 2015;127: 45-66.
- ⁶¹ Guskiewicz KM, Broglio SP. Acute sports-related traumatic brain injury and repetitive concussion. *Handbook of Clinical Neurology*. 2015;127: 157-72.

- 62 Trinidad, Katrina J. (2012) Predicting Clinical Concussion Measures at Baseline and Re-Test Based on Academic Profile and Motivation. MA Thesis, University of North Carolina Chapel Hill. Available online at: https://cdr.lib.unc.edu/concern/dissertations/5d86p028s?local_e=en
- 63 Ross, Luke M. (2008) Procedural Reaction Time and Balance Performance during a Dual or Single Task in Healthy Collegiate Students. MA Thesis, University of North Carolina Chapel Hill. Available online at: <https://pqdtopen.proquest.com/doc/304548611.html?FMT=ABS>
- 64 Ocwieja KE. The Effect of Play Type and Collision Closing Distance on Head Impact Biomechanics. MA Thesis, University of North Carolina Chapel Hill. Available online at: https://cdr.lib.unc.edu/concern/dissertations/0k225b31k?local_e=en
- 65 Schmidt, Julianne D. (2013) The Influence of the Cervical Musculature, Visual Performance, and Anticipation on Head Impact Severity in High School and Collegiate Football. MA Thesis, University of North Carolina Chapel Hill. Available online at: <https://cdr.lib.unc.edu/concern/dissertations/fj236274d>
- 66 Ocwieja KE, Mihalik JP, Marshall SW, Schmidt JD, Trulock SC, Guskiewicz KM. The effect of play type and collision closing distance on head impact biomechanics. *Ann Biomed Eng*. 2012 Jan;40(1):90-6.
- 67 Trinidad KJ, Schmidt JD, Register-Mihalik JK, Groff D, Goto S, Guskiewicz KM. Predicting clinical concussion measures at baseline based on motivation and academic profile. *Clin J Sport Med*. 2013 Nov;23(6):462-9.
- 68 Ross LM, Register-Mihalik JK, Mihalik JP, McCulloch KL, Prentice WE, Shields EW, Guskiewicz KM. Effects of a single-task versus a dual-task paradigm on cognition and balance in healthy subjects. *J Sport Rehabil*. 2011 Aug;20(3):296-310.
- 69 Schmidt JD, Guskiewicz KM, Blackburn JT, Mihalik JP, Siegmund GP, Marshall SW. The influence of cervical muscle characteristics on head impact biomechanics in football. *Am J Sports Med*. 2014 Sep;42(9):2056-66.
- 70 Guskiewicz K, Mihalik J, Shankar V, Marshall S, Crowell D, Oliaro S, Ciocca M, and Hooker D. (2007). Measurement of head impacts in collegiate football players: relationship between head impact biomechanics and acute clinical outcome after concussion. *Neurosurgery*, 61(6): 1244-52; discussion 1252-3.
- 71 Mihalik J, Bell D, Marshall S, and Guskiewicz K. (2007). Measurement of head impacts in collegiate football players: an investigation of positional and event-type differences. *Neurosurgery*, 61(6): 1229-35; discussion 1235.
- 72 Mihalik JP, Lynall RC, Wasserman EB, Guskiewicz KM, Marshall SW. Evaluating the "Threshold Theory": Can Head Impact Indicators Help? *Med Sci Sports Exerc*. 2017 Feb;49(2): 247-253.
- 73 Email from Mary Willingham dated 9/7/2005 re: "important meds info" to Cynthia Reynolds, Octavus Barnes, Wayne Walden and Emily Yasutomi. UNC Documents, May 2016 release, Part 31 at 1566. Available online at: https://s3.amazonaws.com/url-carolinacommittment-storage/Public_Records_Release_004_Part031.pdf
- 74 Mihalik JP, Stump JE, Collins MW, Lovell MR, Field M, Maroon JC. Posttraumatic migraine characteristics in athletes following sports-related concussion. *J Neurosurg*. 2005 May;102(5): 850-5. PubMed PMID: 15926709.
- 75 Mihalik JP, McCaffrey MA, Rivera EM, Pardini JE, Guskiewicz KM, Collins MW, Lovell MR. Effectiveness of mouthguards in reducing neurocognitive deficits following sports-related cerebral concussion. *Dent Traumatol*. 2007 Feb;23(1): 14-20. PubMed PMID: 17227375.
- 76 Rowson S, Duma S, Greenwald R, Beckwith J, Chu J, Guskiewicz K, Mihalik J, Crisco J, Wilcox B, McAllister T, Maerlender A, Broglio S, Schnebel B, Anderson S, Brolinson P. (2014). Can helmet design reduce the risk of concussion in football? *J Neurosurg*, 120(4): 919-22.
- 77 Beckwith J, Greenwald R, Chu J, Crisco J, Rowson S, Duma S, Broglio S, McAllister T, Guskiewicz K, Mihalik J, Anderson S, Schnebel B, Brolinson P, and Collins M. (2013). Head impact exposure sustained by football players on days of diagnosed concussion. *Medicine and science in sports and exercise*, 45(4): 737-746.
- 78 Beckwith JG, Zhao W, Ji S, Ajamil AG, Bolander RP, Chu JJ, McAllister TW, Crisco JJ, Duma SM, Rowson S, Broglio SP, Guskiewicz KM, Mihalik JP, Anderson S, Schnebel B, Gunnar Brolinson P, Collins MW, Greenwald RM. Estimated Brain Tissue Response Following Impacts Associated With and Without Diagnosed Concussion. *Ann Biomed Eng*. 2018 Jun;46(6): 819-830.
- 79 Kerr Z, Register-Mihalik J, Kroshus E, Baugh C, Marshall S. (2016). Motivations associated with nondisclosure of self-reported concussions in former collegiate athletes. *Am J Sports Med*, 44(1): 220-5.
- 80 National Institutes of Health Project Reporter, Project Number 5R49CE000196-05. Available online at: https://projectreporter.nih.gov/project_info_results.cfm?aid=7485806&icde=32340364
- 81 National Center of Education Statistics (NCES). Profiles of Undergraduate Students, 2007-2008, 2011-2012. Available online at: <https://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2015167>
- 82 Putukian M, Kreher JB, Coppel DB, Glazer JL, McKeag DB, White RD. Attention deficit hyperactivity disorder and the athlete: an American Medical Society for Sports Medicine position statement. *Clin J Sport Med*. 2011;21: 392-401.
- 83 The Coalition on Intercollegiate Athletics. (2014). Report on the COIA 2014 Annual Meeting February 28 –March 2, University of South Florida, Executive Summary.

- 84 Kelley ME, Kane JM, Espeland MA, Miller LE, Powers AK, Stitzel JD, Urban JE. Head impact exposure measured in a single youth football team during practice drills. *J Neurosurg Pediatr*. 2017 Nov;20(5):489-497.
- 85 NCAA. Mind, Body, Sport – Understanding and Supporting Student-Athlete Mental Illness (Gary T. Brown, ed.). October 2014.
- 86 Wolverton, Brad. The Hottest Hire in Athletics? Learning Specialists. *The Chronicle of Higher Education*. February 28, 2016. Available online at <http://www.chronicle.com/article/The-Hottest-Hire-in-Athletics-/235513>
- 87 Farrey, Tom. Seminoles helped by 'LD' diagnoses. *ESPN*. Dec. 18, 2009. Available online at: <http://www.espn.com/espn/otl/news/story?id=4737281>
- 88 Merritt, V. and Arnett, P. (2014) Premorbid predictors of postconcussion symptoms in collegiate athletes, *Journal of Clinical and Experimental Neuropsychology*, 36:10: 1098-1111.
- 89 Broglio SP, McCrea M, McAllister T, Harezlak J, Katz B, Hack D, Hainline B; CARE Consortium Investigators. A National Study on the Effects of Concussion in Collegiate Athletes and US Military Service Academy Members: The NCAA-DoD Concussion Assessment, Research and Education (CARE) Consortium Structure and Methods. *Sports Med*. 2017 Jul;47(7): 1437-1451.
- 90 Hainline, BW. Concussion and the NCAA: Report from the Chief Medical Officer, in *The Bridge – Concussion: A National Challenge*, National Academy of Engineering, Spring 2016.
- 91 United States Department of Defense. 2017 Demographics – Profile of the Military Community. Available online at: <http://download.militaryonesource.mil/12038/MOS/Reports/2017-demographics-report.pdf>
- 92 Kerr ZY, Chandran A, DeFreese JD. Considerations for Present and Future Research on Former Athlete Health and Well-being. *JAMA Netw Open*. 2019;2(5):e194222.
- 93 Krauss MR, Russell RK, Powers TE, Li Y. Accession standards for attention-deficit/hyperactivity disorder: a survival analysis of military recruits, 1995-2000. *Mil Med*. 2006 Feb;171(2): 99-102.
- 94 United States Army. Regulation 40-501, Standards of Medical Fitness. Rapid Action Revision (RAR) Issue Date: 10 September 2008. Available online at: <https://www.gmo.amedd.army.mil/asthma/ArmyReg.pdf>
- 95 United States Army. Regulation 40-501, Standards of Medical Fitness. Rapid Action Revision (RAR) Issue Date: 14 June 2017. Available online at: https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/ARN3801_AR40-501_Web_FINAL.pdf
- 96 US Department of Defense. DoD Instruction 6130.03 – Medical Standards for Appointment, Enlistment, or Induction into the Military Services. Effective date May 6, 2018. Available online at: <https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/613003p.pdf?ver=2018-05-04-113917-883>
- 97 Dickey, NW. (2016). Review of the Scientific Evidence of Using Population Normative Values for Post-Concussive Computerized Neurocognitive Assessments. Defense Health Agency/Defense Health Board Falls Church United States. URL: <http://www.dtic.mil/dtic/tr/fulltext/u2/1017708.pdf>
- 98 Schmidt, J., Register-Mihalik, J., Mihalik, J., Kerr, Z., and Guskiewicz, K. (2012). Identifying impairments after concussion: normative data versus individualized baselines. *Med Sci Sports Exerc*, 44(9),1621-8.
- 99 UNC document release, PDF1A-Final-Web.pdf at 15706. URL: <https://s3.amazonaws.com/url-carolinacomment-storage/PDF1A-Final-web.pdf>
- 100 United States Air Force Waiver Guide, June 2012.
- 101 Caccese JB, DeWolf RM, Kaminski TW, Broglio SP, McAllister TW, McCrea M, Buckley TA; CARE Consortium Investigators. Estimated Age of First Exposure to American Football and Neurocognitive Performance Amongst NCAA Male Student-Athletes: A Cohort Study. *Sports Med*. 2019 Mar;49(3):477-487. doi: 10.1007/s40279-019-01069-x.
- 102 Garcia GP, Broglio SP, Lavieri MS, McCrea M, McAllister T; CARE Consortium Investigators. Quantifying the Value of Multidimensional Assessment Models for Acute Concussion: An Analysis of Data from the NCAA-DoD Care Consortium. *Sports Med*. 2018 Jul;48(7):1739-1749. doi: 10.1007/s40279-018-0880-x.
- 103 Stemper BD, Shah AS, Harezlak J, Rowson S, Mihalik JP, Duma SM, Rigen LD, Brooks A, Cameron KL, Campbell D, DiFiori JP, Giza CC, Guskiewicz KM, Jackson J, McGinty GT, Svoboda SJ, McAllister TW, Broglio SP, McCrea M; CARE Consortium Investigators. Comparison of Head Impact Exposure Between Concussed Football Athletes and Matched Controls: Evidence for a Possible Second Mechanism of Sport-Related Concussion. *Ann Biomed Eng*. 2018 Oct 22. doi: 10.1007/s10439-018-02136-6.
- 104 Katz BP, Kudela M, Harezlak J, McCrea M, McAllister T, Broglio SP; CARE Consortium Investigators. Baseline Performance of NCAA Athletes on a Concussion Assessment Battery: A Report from the CARE Consortium. *Sports Med*. 2018 Aug;48(8):1971-1985.
- 105 Weber, M.L., Lynall, R.C., Hoffman, N.L. et al. Health-Related Quality of Life Following Concussion in Collegiate Student-Athletes With and Without Concussion History. *Ann Biomed Eng* (2018).
- 106 Weber ML, Dean JL, Hoffman NL, Broglio SP, McCrea M, McAllister TW, Schmidt JD; CARE Consortium Investigators, Hoy AR, Hazzard JB, Kelly LA, Ortega JD, Port N, Putukian M, Langford TD, Tierney R, Campbell DE, McGinty G, O'Donnell P, Svoboda SJ, DiFiori JP, Giza CC, Benjamin HJ, Buckley T, Kaminski TW, Clugston JR, Feigenbaum LA, Eckner JT,

- Guskiewicz K, Mihalik JP, Miles JD, Anderson S, Master CL, Collins M, Kontos AP, Bazarian JJ, Chrisman SPD, Brooks A, Duma S, Bullers CT, Miles CM, Dykhuizen BH. Influences of Mental Illness, Current Psychological State, and Concussion History on Baseline Concussion Assessment Performance. *Am J Sports Med*. 2018 Jun;46(7):1742-1751.
- ¹⁰⁷ Rowson S, Duma SM, Stemper BD, Shah A, Mihalik JP, Harezlak J, Riggan LD, Giza CC, DiFiori JP, Brooks A, Guskiewicz K, Campbell D, McGinty G, Svoboda SJ, Cameron KL, Broglio SP, McAllister TW, McCrea M. Correlation of Concussion Symptom Profile with Head Impact Biomechanics: A Case for Individual-Specific Injury Tolerance. *J Neurotrauma*. 2018 Feb 15;35(4): 681-690.
- ¹⁰⁸ Van Pelt KL, Allred D, Cameron KL, Campbell DE, D'Lauro CJ, He X, Houston MN, Johnson BR, Kelly TF, McGinty G, Meehan S, O'Donnell PG, Peck KY, Svoboda SJ, Pasquina P, McAllister T, McCrea M, Broglio SP. A cohort study to identify and evaluate concussion risk factors across multiple injury settings: findings from the CARE Consortium. *Inj Epidemiol*. 2019 Jan 14;6(1): 1. doi: 10.1186/s40621-018-0178-3.
- ¹⁰⁹ Gronwall, D., and P. Wrightson. "Cumulative effect of concussion." *The Lancet* 306, no. 7943 (1975): 995-997.
- ¹¹⁰ Poole, V., Breedlove, E., Shenk, T., Abbas, K., Robinson, M., Leverenz, L., Nauman, E., Dydak, U., and Talavage, T. (2015). Sub-concussive hit characteristics predict deviant brain metabolism in football athletes. *Dev Neuropsychol*, 40(1): 12-7.
- ¹¹¹ Venere, E. (2015). Deviant brain metabolism' found in high school football players. *Purdue University News*. Available online at: <http://www.purdue.edu/newsroom/releases/2015/Q3/deviant-brain-metabolism-found-in-high-school-football-players.html#>
- ¹¹² Perry, D., Sturm, V., Peterson, M., Pieper, C., Bullock, T., Boeve, B., Miller, B., Guskiewicz, K., Berger, M., Kramer, J., and Welsh-Bohmer, K. (2016). Association of traumatic brain injury with subsequent neurological and psychiatric disease: a meta-analysis. *J Neurosurg*, 124(2): 511-26.
- ¹¹³ Montenegro PH, Alosco ML, Martin BM, Daneshvar DH, Mez J, Chaisson CE, Nowinski CJ, Au R, McKee AC, Cantu RC, McClean MD, Stern RA, Tripodis Y. Cumulative Head Impact Exposure Predicts Later-Life Depression, Apathy, Executive Dysfunction, and Cognitive Impairment in Former High School and College Football Players. *J Neurotrauma*. 2017 Jan 15;34(2):328-340. doi: 10.1089/neu.2016.4413.
- ¹¹⁴ Iaccarino MA, Fitzgerald M, Pulli A, Woodworth KY, Spencer TJ, Zafonte R, Biederman J. Sport concussion and attention deficit hyperactivity disorder in student athletes: A cohort study. *Neurol Clin Pract*. 2018 Oct;8(5): 403-411. doi: 10.1212/CPJ.0000000000000525.
- ¹¹⁵ Liou YJ, Wei HT, Chen MH, et al. Risk of traumatic brain injury among children, adolescents, and young adults with attention-deficit hyperactivity disorder in Taiwan. *J Adolesc Health* 2018;63(2): 233-238.
- ¹¹⁶ McKee, A., Daneshvar, D., Alvarez, V., and Stein, T. (2014). The neuropathology of sport. *Acta neuropathol*, 127(1): 29-51.
- ¹¹⁷ Nelson, L., Guskiewicz, K., Marshall, S., Hammeke, T., Barr, W., Randolph, C., and McCrea, M. (2016). Multiple self-reported concussions are more prevalent in athletes with ADHD and learning disability. *Clin J Sport Med*, 26(2): 120-7.
- ¹¹⁸ Bonfield, C., Lam, S., Lin, Y., and Greene, S. (2013). The impact of attention deficit hyperactivity disorder on recovery from mild traumatic brain injury. *J Neurosurg Pediatr*, 12(2): 97-102.
- ¹¹⁹ Webbe, Frank (ed). (2011). *The Handbook of Sport Neuropsychology*, Springer Publishing Co.
- ¹²⁰ Han DH, McDuff D, Thompson D, Hitchcock ME, Reardon CL, Hainline B. Attention-deficit/hyperactivity disorder in elite athletes: a narrative review. *Br J Sports Med*. Jun;53(12): 741-745. doi: 10.1136/bjsports-2019-100713. Epub 2019 May 16.
- ¹²¹ Broglio, S., Macciocchi, S., and Ferrara, M.S. Sensitivity of the concussion assessment battery. *Neurosurgery*, 2007 Jun;60(6): 1050-7; discussion 1057-8.
- ¹²² Lynall, R., Schmidt, J., Mihalik, J., and Guskiewicz, K. (2016). The clinical utility of a concussion rebaseline protocol after concussion recovery. *Clin J Sport Med*, 26(4): 285-90.
- ¹²³ Register-Mihalik JK, Guskiewicz KM, Mihalik JP, Schmidt JD, Kerr ZY, McCrea MA. Reliable change, sensitivity, and specificity of a multidimensional concussion assessment battery: implications for caution in clinical practice. *J Head Trauma Rehabil*. 2013 Jul-Aug;28(4): 274-83.
- ¹²⁴ Bella, T. (2015). What have we learned from 500 concussions in 3 years of college football? *Aljazeera America*. Available online at: <http://america.aljazeera.com/watch/shows/america-tonight/articles/2015/12/30/500-concussions-ncaa-college-football-reporting.html>
- ¹²⁵ Kerr, Z., Roos, K., Djoko, A., Dalton, S., Broglio, S., Marshall, S., and Dompier, T. (2017). Epidemiologic measures for quantifying the incidence of concussion in National Collegiate Athletic Association sports. *J Athl Train*, 52(3): 167-174.
- ¹²⁶ Piland SG, Motl RW, Ferrara MS, Peterson CL. Evidence for the Factorial and Construct Validity of a Self-Report Concussion Symptoms Scale. *J Athl Train*. 2003 Jun;38(2): 104-112.
- ¹²⁷ Declaration of Robert C. Cantu, In Re National Hockey League Players' Concussion Injury Litigation, MDL No. 14-2551 (SRN/JSM)
- ¹²⁸ McAllister TW, Arciniegas D. Evaluation and treatment of postconcussive symptoms. *NeuroRehabilitation*. 2002;17(4): 265-83.
- ¹²⁹ Gualtieri CT, Evans RW. Stimulant treatment for the neurobehavioural sequelae of traumatic brain injury. *Brain Inj*. 1988 Oct-Dec;2(4): 273-90.
- ¹³⁰ Email from Thomas Gualtieri (NC Neuropsychiatry) to John Blanchard, Lyn Johnson, and Mary Willingham (Subj: student

athlete screening paper). UNC document release, PDF1A-Final-web, October 2015 at 15706. Available online at: <https://s3.amazonaws.com/url-carolinacommittment-storage/PDF1A-Final-web.pdf>

- ¹³¹ Talsky, A., Pacione, L., Shaw, T., Wasserman, L., Lenny, A., et al. Pharmacological interventions for traumatic brain injury, *BCMJJ*, January, February 2010; 53(1): 26-31.
- ¹³² NCAA Research. NCAA National Study on Substance Use Habits of College Student-Athletes, June 2018. Available online at: <http://www.ncaa.org/about/resources/research/ncaa-student-athlete-substance-use-study>
- ¹³³ Email from Mario Ciocca to Lyn Johnson (neuropsychiatrist), Mary Willingham, and Scott Oilaro RE: medlist. Date redacted. UNC-CH Public Records Request ID 160111, Closed 9/19/2016 at p. 6513.
- ¹³⁴ White RD, Harris GD, Gibson ME. Attention deficit hyperactivity disorder and athletes. *Sports Health*. 2014 Mar;6(2): 149-56. doi: 10.1177/1941738113484679.
- ¹³⁵ Stewman CG, Liebman C, Fink L, Sandella B. Attention Deficit Hyperactivity Disorder: Unique Considerations in Athletes. *Sports Health*. 2018 Jan/Feb;10(1): 40-46. doi: 10.1177/1941738117742906.
- ¹³⁶ Walters, Inc. An Independent Evaluation of Procedures and Protocols Related to the June 2018 death of a University of Maryland Football Student-athlete, September 21, 2018. Available online at: <https://www.usmd.edu/newsroom/Walters-Report-to-USM-Board-of-Regents.pdf>
- ¹³⁷ Belmont Report (1979). The Belmont Report: Ethical principles and guidelines for the protection of human subjects of research. National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research. (1978). The Belmont report: Ethical principles and guidelines for the protection of human subjects of research. [Bethesda, Md.]: The Commission.