The effect of subconcussive head impact exposure and jugular vein compression on behavioral and cognitive outcomes after a single season of high-school football: A prospective longitudinal trial.

Megan E. Narad, PhD*, Division of Behavioral Medicine & Clinical Psychology, Cincinnati Children's Hospital Medical Center; Department of Pediatrics, University of Cincinnati College of Medicine; 3333 Burnet Ave, MLC 10006, Cincinnati, OH 45229-3039, Phone: 513-803-8902; Fax: 513-636-0755; Email: megan.narad@cchmc.org;

Jeffery N. Epstein, PhD, Division of Behavioral Medicine & Clinical Psychology, Cincinnati Children's Hospital Medical Center; Department of Pediatrics, University of Cincinnati College of Medicine; 3333 Burnet Ave, MLC 10006, Cincinnati, OH 45229-3039, Phone: 513-636-8296; Fax: 513-636-0755; Email: jeff.epstein@cchmc.org

James Peugh, PhD, Division of Behavioral Medicine & Clinical Psychology, Cincinnati Children's Hospital Medical Center; Department of Pediatrics, University of Cincinnati College of Medicine; 3333 Burnet Ave, Cincinnati, OH 45229-3039, Phone: 513-803-5170, email: James.peugh@cchmc.org

Kim D. Barber Foss, M.S., Emory Sports Performance And Research Center; 4450 Falcon Parkway, Flowery Branch, Georgia, 30542; Phone number: 404-544-1287; Fax: 404-544-1278; Email: Kim.BarberFoss@emory.edu

Jed A. Diekfuss, PhD, Emory Sport Performance and Research Center; 4450 Falcon Parkway, Flowery Branch, Georgia, 30542; Phone number: 404-544-1287; Fax: 404-544-1278; Email: Jed.a.diekfuss@emory.edu

Scott Bonnette, PhD, The SPORT Center, Division of Sports Medicine, Cincinnati Children's Hospital Medical Center; 3333 Burnet Ave, MLC 10001, Cincinnati, OH 45229; phone: 513-803-2517; fax: 513-636-6374; email: Scott.bonnette@cchmc.org

Sarah Orban, PhD, Department of Psychology, University of Tampa, Tampa, FL; 401 W. Kennedy Blvd, Tampa, FL 33606; Phone: 813-257-3081; Email: Sorban@ut.edu

Weihong Yuan, PhD; Division of Radiology, Pediatric Neuroimaging Research Consortium, Cincinnati Children's Hospital Medical Center; Department of Radiology, University of Cincinnati College of Medicine; 3333 Burnet Ave, Cincinnati, OH 45229-3039; phone: 5130636-2862; email: Weihong.yuan@cchmc.org

Jonathan A. Dudley, PhD; Department of Radiology, University of Cincinnati College of Medicine; 3230 Eden Ave, Cincinnati, OH 45267; Phone: 513-803-8984; email: Jonathan.dudley@cchmc.org

Christopher A. DiCesare, PhD, Department of Mechanical Engineering, University of Michigan; 1305 George G. Brown Laboratories, 2350 Hayward St., Ann Arbor, MI 48109-2125; Phone: 740-296-4196; email: dicesaca@umich.edu

Danielle L. Reddington, BA; The SPORT Center, Division of Sports Medicine, Cincinnati Children's Hospital Medical Center; 3333 Burnet Ave, MLC 10001, Cincinnati, OH 45229; phone: 513-803-4878; fax: 513-636-6374; email: reddindl@mail.uc.edu

Wen Zhong, BA; The SPORT Center, Division of Sports Medicine, Cincinnati Children's Hospital Medical Center; 3333 Burnet Ave, MLC 10001, Cincinnati, OH 45229; phone: 513-803-4878; fax: 513-636-6374; email: zhongwn@mail.uc.edu

Katharine S. Nissen, BS; The SPORT Center, Division of Sports Medicine, Cincinnati Children's Hospital Medical Center; 3333 Burnet Ave, MLC 10001, Cincinnati, OH 45229; phone: 513-803-4878; fax: 513-636-6374; email: k.schuyler.nissen@gmail.com

Jessica L. Shafer, BA; The SPORT Center, Division of Sports Medicine, Cincinnati Children's Hospital Medical Center; 3333 Burnet Ave, MLC 10001, Cincinnati, OH 45229; phone: 513-803-4878; fax: 513-636-6374; email: Jessica.shafer@cchmc.org

Jason M. Avedesian, PhD; Sports Performance and Research Center, Department of Orthopaedics, Emory University School of Medicine, 4450 Falcon Pkwy, Flowery Branch, GA 30542; Phone number: 404-544-1287; Fax: 404-544-1278; Email: Jason.avedesian@emory.edu

Alexis B. Slutsky-Ganesh, PhD; The SPORT Center, Division of Sports Medicine, Cincinnati Children's Hospital Medical Center; 3333 Burnet Ave, MLC 10001, Cincinnati, OH 45229; phone: 513-803-4878; fax: 513-636-6374; email: abslutsk@uncg.edu

Rhodri S. Lloyd, PhD; Youth Physical Development Centre, School of Sport and Health Sciences, Cardiff Metropolitan University, Cardiff, UK; Sport Performance Research Institute, New Zealand (SPRINZ), AUT University, Auckland, New Zealand; Centre for Sport Science and Human Performance, Waikato Institute of Technology, Hamilton, New Zealand; Cyncoed Campus, Cyncoed Rd, Cardiff, Wales, CF23 6XD; phone: 029 2041 7062; email: rlloyd@cardiffmet.ac.uk

David Howell, PhD; Sport Medicine Center, Children's Hospital Colorado, Aurora, Colorado; Department of Orthopedics, University of Colorado, Arora, Colorado; 13123 East 16th Ave, Box 060, Aurora, CO 80045; phone: 720-777-1502; fax: 720-777-7268; email: David.howell@cuanschutz.edu

Gregory D. Myer, PhD; Emory Sport Performance and Research Center, Emory Sports Medicine Center, Department of Orthopaedics, Emory University School of Medicine, The Micheli Center for Sports Injury Prevention, Waltham, MA; 4450 Falcon Pkwy, Flowery Branch, GA 30542; phone: 513-404-5382; fax: 404-544-1278; Email: greg.myer@emory.edu

* Corresponding Author

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Abstract

This prospective longitudinal trial aimed to 1) determine the role of head impact exposure on behavioral/cognitive outcomes, and 2) assess the protective effect(s) of a jugular vein compression (JVC) collar on behavioral/cognitive outcomes following one season of high-school football. Participants included 284 male high-school football players aged 13-18 years enrolled from seven midwestern high-schools. Schools were allocated to the JVC collar intervention(four teams, 140 players) or non-collar/no intervention control (three teams, 144 players) condition. Head impact exposure was measured throughout the season using CSx accelerometers. Outcome measures included post season parent and adolescent report on Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale *(*SWAN) and Post-Concussion Symptom Inventory (PCSI), as well as adolescent performance on Attention Network Task (ANT), digital Trail Making Task (dTMT), and Cued Switching task. No significant effect of head impact exposure or JVC collar use on post-season SWAN or PCSI scores or performance on dTMT and Cued Switching task were noted. There was no effect of head impact exposure on ANT performance; however, the JVC collar group had greater post-season Alerting network scores than the non-collar group (*p*=.026, *d*=.22). Findings provide preliminary evidence that the JVC collar may provide some protection to the alerting attention system. These findings should be interpreted cautiously as a greater understanding of the long-term sequalae of head impact exposure and the role of cumulative head impact exposure behavioral/cognitive outcomes is required.

Introduction

Over 1 million high-school students play football annually, making it one of the most popular high-school sports in the United States.[1] Despite recent declines in participation,[2] football remains a leading cause of sport-related emergency room visits[3] and concussions.[3-5] While there has been a focus on understanding the mechanisms[6,7] and prevention[8] of sports-related concussion, there is mounting concern that repetitive sub-concussive head impacts (i.e., head impacts not resulting in a clinical diagnosis of concussion[9-13] may result in subtle cognitive or neurological changes that do not immediately cause observable clinical symptoms.

Repetitive head impact exposure during adolescence has been associated with poor long-term cognitive, behavioral, and psychiatric functioning in adulthood;[14-16] however, findings regarding short-term impairments during adolescence are mixed. Some have documented detrimental short-term effects of repetitive sub-concussive head impacts on neurophysiology,[17-19] white matter integrity,[20,21] functional connectivity,[11] metabolic functioning,[22] and neurocognitive functioning[23-25] among young football players. Yet others report minimal, if any, short-term effects of head impact exposure on white matter integrity,[26] neurophysiology,[27] neurocognitive outcomes,[27-31] postural stability[31-33] or oculomotor performance.[31,33] Given these inconsistencies, it remains critically important to better understand the influence of repetitive head impacts in young athletes, particularly as adolescence is a critical period of neurodevelopment.[34-37]

Despite inconsistencies in the literature, strategies to reduce/mitigate short- and long-term effects of head impact exposure are needed. However, the strategies that have been employed to date (e.g., rule changes, improving personal protective equipment such as helmets) have had limited effectiveness for mitigating concussion risk.[8] An emerging line of research has investigated the use of an external jugular vein compression (JVC) collar for the protection of the brain against head impacts through absorption of “slosh” energy.[38-40] Preliminary evidence indicates that the JVC collar may lessen structural and functional alterations associated with repetitive head impacts,[41-46] including the attenuation of pre- to post-season brain activation changes in functional activation during a working memory task.[45,46] However, it remains unknown whether the JVC collar mitigates behavioral/neurocognitive outcomes.

The present study used select measures hypothesized to be sensitive to the subtle short-term behavioral/neurocognitive effects of head impact exposure, with an emphasis on multidimensional aspects of attention and executive functioning.[47-51] The goals of this study were to 1) determine the role of head impact exposure on behavioral/cognitive functioning, and 2) assess the mitigative effect(s) of JVC collar use on behavioral/cognitive outcomes following a single season of high-school football.

Materials and Methods

Participants

284 male high-school football players between the ages of 13-18 (Mean ± *SD*=15.8±1.0) were enrolled from seven midwestern high-schools. Parental consent and player assent were obtained prior to data collection. Exclusion criteria included history of neurological deficits, cerebral infarction or recent or severe head trauma, medical contraindications to JVC collar use (glaucoma, hydrocephalus, carotid hypersensitivity, known increased intracranial pressure, central vein thrombosis, any airway obstructions, recognized seizure disorder, prothrombotic or hyperthrombotic condition, cerebral cavernous malformation), or not medically cleared to play sports. This study was approved by an institutional review board and was registered with clinicaltrials.gov (NCT# 04068883).

Procedure

Recruitment occurred between April and June of 2018. Athletes were administered a behavioral and neurocognitive battery at pre- and post-season. Pre-season study visits occurred prior to the start of any practice or games. Post-season study visits occurred at the end of the regular season and before the start of any playoff games. Notably, while assessors were not made aware of participants' group assignments, they were also not officially blinded from condition.

Prior to the start of the season, schools were allocated at the team level to the JVC collar intervention group (four teams, 140 players) or non-collar/no intervention control group (three teams, 144 players). Athletes allocated to the collar group were individually fitted with the JVC collar. The collar was positioned around the neck to apply mild bilateral JVC to increase venous dilation, implying backfill into the venous capacitance vessels of the brain. The details of collar fitting and physiological response has been documented via ultrasound studies[41,42] and real time MRI,[52] and the effect is reported to be less than the physiologic response to a Valsalva maneuver, sneeze, or cough.[41] Athletes wore the collar during every practice and game; attendance and compliance with collar use were recorded daily. Collars were visually inspected after each practice/game, and any collar that appeared to be altered or manipulated in anyway was replaced with a new collar of the same size. There were no adverse events reported due to collar wear.

During the season, athletes wore an accelerometer device (CSx System Ltd., Auckland, New Zealand) attached to their left mastoid process at all practices and games to quantify head impact exposure.

Outcome Measures

Post Concussive Symptom Inventory (PCSI,).[53] The PCSI is a 20-item parent- and self-report questionnaire assessing for concussion symptom severity. Symptoms are rated from 0 (“not a problem”) to 6 (“severe problem”). In addition to a total symptom score created by summing all 20 items, four factor scores are derived from summing items on each factor: Physical (8-items; e.g. “complains of headaches”), Fatigue (3-items; e.g., “sleeping more than usual”), Emotional (“4-items; e.g., “acts irritable”), and Cognitive (5-items; e.g., “has difficulty concentrating”) problems. At the pre-season assessment, athletes were instructed to rate symptom severity during the past three months in order to establish a baseline level of symptoms. This previous three-month time range, rather than *current* symptom severity, was also used at the post-season assessment.

Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale (SWAN).[54] The SWAN is a parent and self-report measure of the 18 ADHD symptoms from the Diagnostic and Statistical Manual 5 (DSM-5). Items measure attention, and appropriate level of activity and impulse control. Each symptom was rated from 1("far below average") to 7 ("far above average"). Inattention score (mean rating of 9 inattention symptoms), hyperactive/impulsive score (mean rating of 9 hyperactivity/impulsivity symptoms), and total score (mean rating of all 18 symptoms) were used as dependent variables. Higher scores indicate better functioning.

Attention Network Task (ANT). The ANT is a computerized attention task designed to assess three components of attention (i.e., alerting, orienting, and executive/conflict).[55] Each trial began with a central fixation cross, followed by a cue, and then a target stimulus. There were four warning cue conditions that each appeared in 25% of trials: 1) a center cue (asterisk in place of fixation cross), 2) a double cue (asterisks above and below fixation cross), 3) a spatial cue (single asterisk in position of upcoming stimulus), or 4) no cue. The stimulus array is a set of one to five arrows presented horizontally that appears either in the upper portion of the screen (50%) or lower portion of the screen (50%). The task included three types of stimuli: congruent trials (33%; central target arrow facing same direction as flanking arrows), incongruent trials (33%; central target arrow facing opposite direction as flanking arrows), and neutral trials (33%; no flanking arrows). Participants indicated the direction the central arrow was pointing by pressing the left or right mouse key. After responding, they received auditory and visual feedback indicating accuracy. Following a 24-trial practice block, participants completed one experimental block of 96 trials. Reaction times (RT), and attention network scores for alerting (median RT for no cue trials - median RT for double cue trials), orienting (median RT for central cue trials - median RT for spatial cue trials), and conflict (median RT for incongruent trials - median RT for congruent trials) were computed.

Digital Trail Making Test (dTMT). A digital version of the Trail Making Test was used that was identical to the paper and pencil version.[56] Parts A and B of the dTMT consisted of circles distributed over a tablet screen. In Part A, the circles were numbered 1-25, and participants were instructed to draw lines to connect the numbers in ascending order. In Part B, the circles included both numbers (1-12) and letters (A-L). The participants were required to draw lines to connect the circles in an ascending pattern with the added task of alternating between the numbers and letters (i.e., 1-A-2-B-3-C, etc.). Participants were instructed to connect the circles as quickly as possible without lifting the stylus from the tablet screen. The time to complete Part A was subtracted from Part B to denote speed of executive functioning and cognitive flexibility.

Cued Task Switching Task. This task was designed to assess the ability to switch between competing tasks or stimuli (e.g., shape and color) response sets. Participants were instructed to match a stimulus presented in the upper center of the screen to one of two stimuli in the lower left and right corners of the screen. Participants completed two task-homogeneous (i.e., single task) blocks or repeat blocks where they matched the upper stimulus to shape (Task A); two blocks where they matched to color (Task B); and two task-heterogeneous (i.e. switch) blocks where they switched between Tasks A and B in a pseudo-random fashion. Participants were instructed on which type of task they were to complete prior to each block. Each block contained 12 trials. Dependent variables used were switching-cost (the difference in RT and error rate between repeat *trials* and switch *trials* within switch blocks) and mixing-cost (the difference in RT and error rate between repeat *blocks* and switch *blocks*).

Head Impact Exposure Tracking

A CSx accelerometer device (CSx System Ltd., Auckland, New Zealand) was used to quantify head impact exposure. The CSx sensor is comprised of a triaxial accelerometer and gyroscope, which quantifies linear and rotational accelerations at 2300 Hz and 1000 Hz, respectively. Recording of impact data was triggered when the sensor placed below the left mastoid exceeded a 10g acceleration threshold. For each recorded impact, 50 ms of data were transmitted – 5 ms before and 45ms after the time of the impact. The magnitude of each impact was quantified by finding the peak *g* forces recorded during the 45 ms time period after the impact occurred.

To minimize the potential for false positive recordings we implemented an additional 'hit run' filtering method. A 'hit run' was defined as an instance where the accelerometer data indicated an athlete received three or more hits >20 *g* spaced $\leq$ 10 seconds apart within a 30 second time interval (which is considered unlikely for actual football participation). These events occurred disproportionately at the end of the sessions, potentially due to athletes removing the accelerometers and placing them on a table. Hit-run filtering resulted in the removal of 28.5% of the total head impacts accumulated across the cohort. After the 'hit run' filter was applied, the total number of impacts and *g* forces were summed across the regular season, and the number of impacts >90 *g* was used as an indicator of head impact exposure. The threshold of 90 *g*s was used to eliminate the potential for spurious head impact recordings. Notably, there is no consensus on the 'threshold' of significant *g*-force, and this 90g threshold was selected to be congruent with existing literature that 90g is the force of impact that may potentially put athletes at neurological risk.[57,58]

Data Analysis

An independent t-test was used to compare the total number of head impacts >90 *g* between the collar and no collar groups.

Separate analyses of covariance (ANCOVA) models were run for each outcome to assess for group (collar (intervention) vs. non-collar (control)) differences and head impact exposure on post-season performance. Models included nesting at the school level and controlled for pre-season performance. Due to the known influence of ADHD on rating scales[59] and task performance,[60] we controlled for ADHD status (defined by parent report of diagnosis, history of stimulant medication, or $\geq$ 5 symptoms of inattention rated as “far below average” or “below average” on baseline parent-rating) and ADHD medication status at the time of each assessment. The number of participants with ADHD did not differ between collar (n=23) and non-collar (n=23) groups (X^2 (1)=.01, p=.92). Censoring was used in models examining the PCSI outcomes to handle the overabundance of ‘0’ ratings on this measure. Because this was not a concussed sample, a high number of ‘0’ ratings was expected. Due to the number of analyses completed, a false discovery rate correction[61] was used, and only corrected p-values were reported.

Results

Head Impact Exposure

Mean number of previously played season of football was 7.33 (SD=4.17) seasons for the collar group and 6.88 (SD=3.56) seasons for the non-collar group. There was no difference in number of seasons played between the two groups (t(282)=.74,p=.46). Mean number of hits (>90*g*s) per athlete was 22.54 (SD=15.47; range=0-92), and did not differ between the collar and no-collar groups (t(280)=1.15, p=249). Descriptives for each outcome variable are reported in Table 1.

Behavioral/Cognitive Outcomes

No significant effect of head impact exposure or JVC collar intervention was observed on any of the adolescent- or parent-report PCSI or SWAN factor scores (Table 1). Similarly, no effects of the head impact exposure or the collar intervention were observed on any of the dTMT or cued switching task outcomes. Table 1 reports the regression coefficients for all models. Positive coefficients indicate a positive relationship between the independent variable and post-season dependent variable (e.g., greater number of hits >90gs associated with greater post-season score on dependent variable), while negative coefficients indicate a negative relationship between the independent variable and post-season dependent variable (e.g., greater number of hits >90gs associated with lower post-season score on dependent variable).

While no effects of head impact exposure or the JVC collar intervention were observed on most of the ANT outcomes, a significant, albeit small, effect of the collar was noted on the altering network score (FDR-corrected *p*=.026, *d*=.22). Specifically, those in the collar group had better post-season alerting network scores than the no collar group.

Discussion

This prospective longitudinal study examined the effects of head impact exposure on behavioral/cognitive outcomes and the potential protective effect of wearing a JVC collar during a single season of high-school football. Head impact exposure did not affect any assessed outcome. Although the JVC collar did not impact the majority of behavioral outcomes, collar-wear result in better post-season ANT alerting network scores compared to the non-collar group, although the effect size was small.

While there are some studies that have reported a decline in behavioral functioning following a season of contact sport; these previous studies have some important methodological differences from the present study which may account for the differences in findings. First, a number of these studies used collegiate athletes;[23,24,62,63] therefore, it is possible that deficits observed among college athletes may be due to greater cumulative lifetime exposure or greater exposure to higher g forces during collegiate-level sports compared to high-school level sports. Some studies have also demonstrated declines in functioning after a season of play on neurocognitive constructs (e.g., visual/spatial memory[10,62]) that were not assessed in the present study. Finally, some studies have demonstrated declines in cognitive functioning using more proximal testing to the time of exposure. For example, Espinoza et al.[63] reported a decline in reaction time on a complex choice task when athletes were tested on the sideline immediately following an impact. Notably, these decrements in performance immediately after impact were not assessed as change over the course of a season.[63]

Our finding of the absence of effect of head impact exposure on behavioral/neurocognitive functioning following a season of high-school football is congruent with several studies.[27-31] The current study had one of the largest samples to date and is further strengthened by the measurement of concurrent head impact exposure. While the absence of any effect of head impact exposure on functioning is promising, quantification of head impact exposure is difficult. There is no consensus on the 'threshold' of significant *g*-force, and while use of a 90*g* threshold is congruent with literature suggesting this represents the force of impacts that may potentially put athletes at neurological risk and elicit behavioral decrements,[57] the exact threshold for head impacts is unknown. Thus, we can only conclude that head impact exposure *as measured in our study* did not impact behavioral or neurocognitive outcomes.

Changes in neurophysiology[9,11,17,18] and/or white matter integrity[20,21] following a season of contact sport have also been reported. Further, these changes in neurophysiology often occur in the absence of symptoms of concussion or altered cognitive or behavioral functioning[9,64-66] and may persist long after the season has ended and possibly contribute to cumulative brain changes over time.[21,65] Further, these neurophysiological changes are thought to be responsible for the maintenance of apparently normal behavioral and cognitive performance. Hyperconnectivity, for example, is a neurophysiological alteration often associated with head impact exposure.[11] Repeated head impact exposure may result in continued recruitment/use of alternative collateral neural pathways in order to maintain apparently normal behavioral/cognitive functioning. Overtime these alternate pathways are strengthened which manifests as hyperconnectivity.[11] Therefore it is possible that neural plasticity may be acting as a compensatory mechanism for head impact related damage.[11] Another explanation for our limited findings may be that a single season of play may contribute to changes in physiology that are not yet observable at the behavioral/neurocognitive level. Notably, neurophysiological changes have been observed in athletes prior to the start of a season and long after the season ends[11,21,65] suggesting that there may be some degree of reorganization because of continued recruitment of alternate pathways with no return to neurophysiological baseline,[11] contributing to cumulative brain changes over time.[21,65] In sum it is possible that our neurobehavioral tests are not sensitive enough to detect these changes, or possibly, these neurocognitive changes are inconsequential or take time to develop after neurophysiological change.

Previously, the JVC collar had been shown to prevent alterations in white matter integrity associated with head impact exposure,[41-44] and prevent pre- to post-season changes in functional activation.[45] Yuan et al[45] reported a similar lack of effect of the JVC collar on working memory task performance despite an increase in functional activation in the non-collar group. As discussed above, this hyperactivation in the non-collar group may reflect a compensatory mechanism allowing for comparable task performance. Therefore, it is possible that our measures were not sufficiently demanding to override these compensatory mechanisms to detect subtle behavioral/cognitive changes. In contrast, athletes in the collar group showed better post-season alerting attention than the non-collar group, meaning that at the post-season assessment, those in the collar group were more responsive to cuing than those in the non-collar group. This may indicate that a single season of high-school football may impact the alerting attention system, and the JVC collar may provide some protection to this system. Moreover, the ANT may be sufficiently demanding to strain the compensatory mechanisms of the no-collar group, allowing for detection of subtle group differences.

Study limitations should be considered. First, measurement of head impact exposure relied on a 90*g* threshold. Previous studies have noted the importance of the directionality (e.g., linear vs rotational) in understanding their effect on neural injury.[17] Therefore, a better understanding of the effects of quality, periodicity, and magnitude of head impact exposure is required before we have confidence that head impacts do not alter behavioral/cognitive outcomes. In addition, previous research[45,46] reported change in functional activation in the absence of change in behavioral/cognitive performance, indicating a greater level of cognitive resources were used to maintain performance. It is possible that our measures were not demanding enough to override these compensatory mechanisms to detect subtle behavioral/cognitive changes. Future research would benefit from the inclusion of dynamic motor tasks or dual (cognition and motor) tasks sensitive to subtle concussion-related deficits.[67-69] While analyses controlled for ADHD status and medication usage, we did not conduct an ADHD diagnostic assessment. Future studies would benefit from including a diagnostic assessment to identify groups who may be at greater risk for deficit from head impact exposure. In addition, we did find that the JVC collar may prevent some decline in the functioning of the alerting system; however, the mechanism for this remains unknown. In light of the literature supporting the neuro-biological correlates of attention networks,[70] coupled with preliminary studies indicating that the JVC collar may mitigate head impact related changes in white matter integrity and functional activation,[41-43,45] future studies should include neuroimaging during task completion. This would allow for examination of congruent task-specific alterations in neurophysiology. Notably, due to logistic limitations, players were not individually randomized to the collar or no collar group, but rather participants were allocated to group at the team/school level. While the groups did not differ demographically or on any pre-season performance measure, future studies would benefit from a randomized controlled trial to eliminate this source of potential bias. Finally, the current study presents findings following a single season of play, and it is possible that changes in behavioral/cognitive functioning are downstream effects of cumulative head impact exposure. Future studies would benefit from following players across multiple seasons to further explore whether declines in functioning become apparent with increasing cumulative head impact exposure, and exploration of the protective role of the JVC collar across multiple seasons and/or cumulative impact is required.

Conclusion

Despite the promising results of limited negative effects of head impacts during a season of high-school football, previous literature documents pathophysiological changes in the absence of concomitant behavioral change. Therefore, concluding that a single season of head impact exposure does not impact functioning should be considered cautiously. A better understanding of measuring and quantifying subtle behavioral/cognitive changes is required, and monitoring throughout development will be important to better understand long-term sequalae of head impact exposure, and the role of cumulative exposure on athletes.

Author Disclosure Statement

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No additional competing interests exist

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Table 1. Mean (standard deviations) and model results for all dependent variables.

	No Collar Group		Collar Group		Group (Collar vs. No Collar)		Number of hits >90gs	
Outcome Variable	Baseline	Post-season	Baseline	Post-season				
Adolescent Report	N = 144	N = 141	N = 140	N = 135	Coefficient	*p*-value	Coefficient	*p*-value
PCSI - Cognitive	2.88 (4.63)	3.19 (4.74)	2.17 (3.50)	2.68 (5.07)	5.954	.96	0.041	.46
PCSI-Emotional	2.64 (3.71)	2.35 (3.58)	1.81 (2.47)	1.99 (3.17)	4.166	.96	0.04	.30
PCSI – Fatigue	2.81 (3.03)	2.55 (3.25)	3.00 (3.24)	2.64 (3.29)	4.414	.96	0.032	.30
PCSI - Physical	4.11 (5.15)	3.98 (5.49)	3.32 (4.15)	3.36 (5.28)	0.868	.96	0.02	.71
PCSI - Total	11.95 (13.70)	11.57 (14.12O	10.25 (10.20)	10.21 (13.72)	9.514	.96	0.121	.30
SWAN - Inattention	.97 (.77)	.97 (.85)	1.07 (.80)	1.11 (.85)	-0.016	.96	0.004	.51
SWAN - Hyperactivity/Impulsivity	.81 (1.03)	.89 (1.00)	.97 (1.00)	1.07 (1.02)	-0.446	.96	0.005	.30
SWAN - Total	.89 (.82)	.93 (.85)	1.02 (.80)	1.09 (.87)	-0.228	.96	0.005	.30
Parent Report	N = 137	N = 129	N = 129	N = 117	Coefficient	*p*-value	Coefficient	*p*-value
PCSI - Cognitive	.99 (2.25)	.96 (2.36)	1.12 (2.96)	1.14 (2.94)	-2.712	.96	-0.06	.52
PCSI-Emotional	1.24 (2.07)	1.16 (2.45)	1.00 (1.81)	1.39 (2.37)	1.261	.96	-0.016	.78
PCSI - Fatigue	1.04 (1.84)	1.29 (2.24)	1.33 (2.53)	2.00 (3.08)	-0.944	.96	-0.006	.89
PCSI - Physical	1.54 (2.36)	1.91 (3.93)	1.64 (2.42)	2.33 (4.19)	-4.785	.96	0.016	.85
PCSI - Total	4.66 (6.21)	5.19 (8.51)	4.98 (7.32)	6.67 (10.14)	-5.605	.96	-0.039	.78
SWAN - Inattention	.68 (1.07)	.87 (.96)	.72 (1.05)	.92 (1.05)	-0.363	.96	0.003	.63
SWAN - Hyperactivity/Impulsivity	1.05 (1.01)	1.08 (.94)	1.07 (1.02)	1.09 (1.16)	-0.593	.96	-0.001	.90

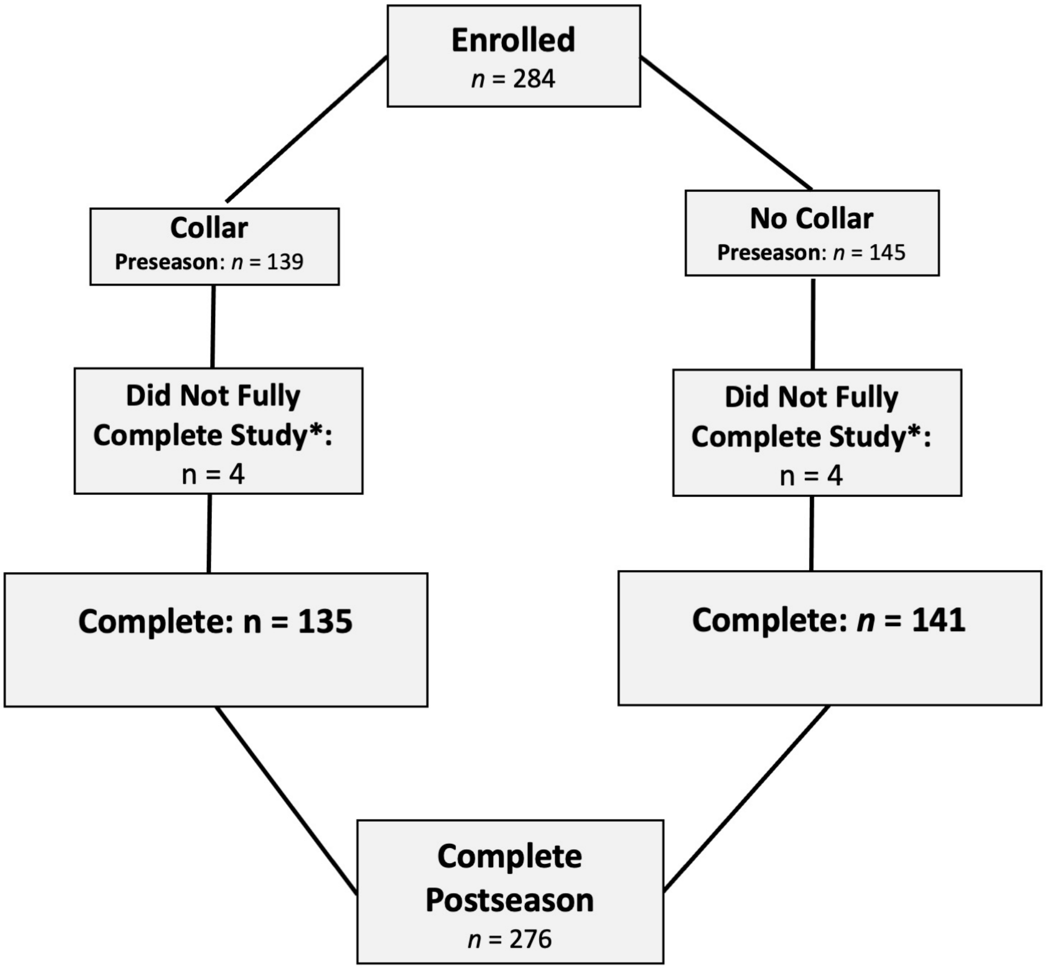
SWAN - Total	.86 (.95)	.97 (.88)	.90 (.98)	1.01 (1.07)	-0.467	.96	0.001	.89
Flanker	N = 143	N = 140	N = 140	N = 136	Coefficient	*p*-value	Coefficient	*p*-value
Alerting Network	17.59 (31.66)	26.30 (29.11)	16.13 (34.39)	29.20 (26.94)	**29.480***	**.03**	0.13	.52
Conflict Network	89.17 (46.84)	66.76 (35.35)	91.60 (52.37)	70.38 (29.47)	3.694	.96	-0.058	.78
Orienting Network	34.01 (29.75)	24.45 (33.32)	28.11 (33.63)	22.30 (27.07)	-5.682	.96	-0.191	.30
Mean Reaction Time	515.16 (65.10)	466.96 (63.94)	504.87 (67.40)	459.28 (50.84)	2.601	.96	-0.229	.64
Std Dev of Reaction Time	106.60 (39.05)	91.23 (36.16)	101.18 (37.65)	89.77 (27.88)	4.375	.96	-0.244	.30
Trail Making Task	N = 144	N = 138	N = 136	N = 133	Coefficient	*p*-value	Coefficient	*p*-value
Time B - Time A	21.90 (11.05)	20.60 (12.09)	21.67 (10.86)	22.02 (12.34)	3.361	.96	0.005	.92
Cued Task Switching	N = 144	N = 140	N = 140	N = 136	Coefficient	*p*-value	Coefficient	*p*-value
Mixing cost error rate	-.08 (.08)	-.07 (.08)	-.07 (.09)	-.05 (.09)	0.003	.96	0	.78
Mixing cost reaction time	126.84 (75.09)	114.56 (65.03)	112.30 (73.54)	86.63 (67.15)	-15.076	.96	-0.151	.78
Switching cost error rate	-.02 (.13)	-.03 (.12)	-.03 (.12)	-.02 (.12)	-0.006	.96	0.001	.30
Switching cost reaction time	-1.49 (68.97)	-3.76 (65.42)	-10.17 (62.96)	-6.45 (65.02)	-29.398	.96	0.098	.87

Note: PCSI = Post Concussive Symptom Inventory; SWAN = Strengths and Weakness of ADHD Symptoms and Normal Behavior Scale.

All p-values are FDR corrected p-values

* =FDR corrected p<.05

Figure 1.



<u>*Reasons for Collar Group:</u>
Dropped out of School (*n* = 1)
Quit Team (*n* = 1)
Early Season-Ending Injury (*n* = 1)
Withdrew (*n* =1)
Total (*n* = 4)

<u>*Reasons for Non-Collar Group:</u>
Quit Team (*n* = 1)
Early Season-Ending Injury (*n* = 1)
Scheduling Conflict for Postseason Visit (*n* = 1)
Quit sports due to incidental finding (*n* = 1)
Total (*n* = 4)