RETROSPECTIVE ANALYSIS OF CONTACT SPORT PARTICIPATION ON COGNITIVE FUNCTION IN HEALTHY ATHLETES

By

Lisa Martinez, ATC

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Committee Membership

Dr. Justus Ortega, Committee Chair

Dr. Sheila Alicea, Committee Member

Elizabeth Larson, Committee Member

Dr. Sheila Alicea, Program Graduate Coordinator

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ABSTRACT

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This study explored the effects of contact and limited contact sport participation on neurocognitive function in non-concussed collegiate and adolescent athletes over time. Athletes participating in contact and limited contact sports have an increased risk of sustaining neurocognitive injuries, known as subconcussive blows, compared to non-contact sport athletes. We hypothesized that athletes participating in contact and limited contact sports, would exhibit a deficit in neurocognitive function following multiple seasons of play when compared to athletes participating in non-contact sports. Using a mixed repeated measures MANOVA statistical design, we analyzed computerized neurocognitive baseline ImPACT composite scores (verbal memory, visual memory, visual motor processing speed, reaction time, and total symptoms scores) over a four-year period in contact sport athletes (n=1791), limited contact sport athletes (n=364) and non-contact sport athletes (n=116). Over a four-year period, contact and limited contact sport athletes did not significantly differ in overall neurocognitive function compared to non-contact sport athletes over time (p = .0894). However, athletes participating in contact sports and limited contact sports exhibit slower visual motor processing speed and reaction time compared to non-contact sport athletes. Although subconcussive blows

may lead to more long-term impairment of brain function, the effect of contact sport participation on brain function is less evident over a shorter three to four-year period.

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INTRODUCTION

The most common sports-related head injuries are concussions and approximately 1.6-3.3 million sports-related concussions (SRCs) occur each year in the United States (Bailes & Omalu, 2017; Schatz & Sandel, 2013). During 2001-20015, children ages 5-18 years old accounted for 2.4 million sport related emergency room visits and 135,000 of those were SRCs (Bailes & Omalu, 2017). SRCs and traumatic brain injuries (TBIs) have been associated with a decrease in neurocognitive function over long periods of time (Baugh et al., 2012; Broglio, Martini, Kasper, Eckner, & Kutcher, 2013; Gavett, Stern, Cantu, Nowinski, & McKee, 2010; Vargas, Rabinowitz, Meyer, & Arnett, 2015). SRCs are TBIs induced by biomechanical forces caused by either a direct blow to head or direct blow to the body with an impulsive force transmitted to the head (McCrory et al., 2017). Typically, SRCs will result in a rapid onset of short-lived neurocognitive impairment that lead to an alteration of consciousness, disturbance of vision, and equilibrium imbalances that will resolve spontaneously (Daneshvar, Nowinski, McKee, & Cantu, 2011; McCrory et al., 2017). Moreover, possible long-term effects of SRCs include decreased neurocognitive function and an increase in mental illnesses. Little is known about the effects of non-concussive mild head impacts, also known as subconcussive blows. Subconcussive blows are referred to as head impacts that do not cause observable symptoms, but are thought to result in serious long term neurocognitive deficits (Belanger, Vanderploeg, & McAllister, 2016). Most head impacts received during games and practices are subconcussive (Broglio et al., 2013; McCuen et al., 2015). Despite our knowledge of neurological deficits in concussed athletes, there is little information regarding the effects of repetitive subconcussive blows on neurocognitive function across multiple seasons of contact sport participation.

Subconcussive Blows

Athletes in contact sports often experience subconcussive blows that, by definition, do not elicit observable symptoms or meet the criteria of a clinically-diagnosed concussion (Belanger et al., 2016; Broglio, Eckner, Paulson, & Kutcher, 2012; McCuen et al., 2015). However, repetitive subconcussive blows have been hypothesized to have long-term effects on brain function (Belanger et al., 2016; Broglio, Williams, O'Connor, & Goldstick, 2016). Recent studies showed that subconcussive blows in contact sports can cause neurophysiological changes, such as a disruption to the integrity of brain white matter, blood flow changes and altered neural electrical activity, that can accumulate from one season to the next (Abbas, Shenk, Poole, Breedlove, et al., 2015; J. E. Bailes, Petraglia, Omalu, Nauman, & Talavage, 2013; K. M. Breedlove et al., 2014; Davenport et al., 2016; McCuen et al., 2015). In another study, results suggested that subconcussive blows may lead to functional changes in the brain that disrupt memory and thought processes, and can lead to depression, as well as increase risk of neurodegenerative diseases such as dementia or Parkinson’s Disease (Davenport et al., 2016). Overall, the long-term neurocognitive effects for healthy athletes exposed to subconcussive blows in contact sports remains unknown, especially among adolescent and collegiate level athletes.

Long-Term Effects of Concussions

In the last decade, the field of neuroscience has made tremendous discoveries related to the long-term effects concussions on brain functions. In one such study, concussion history (number of prior concussions) was directly related to cognitive impairment and depression later in life (Broglio et al., 2013). Similarly, concussions have also been associated with depression, suicidality, and chronic memory impairments, including increased risk of Alzheimer's disease (Baugh et al., 2012). Recently, researchers observed an increase in depression among collegiate athletes’ following a concussion injury; a condition known as post-concussion depression symptoms (PCDS; Gavett et al., 2010; Vargas et al., 2015). PCDS are often characterized by anger, frustration, experience of functional loss and limitations (Vargas et al., 2015). PCDS may also be a symptom or precursor to the neurodegenerative disease known as Chronic Traumatic Encephalopathy, CTE; (Baugh et al., 2012; Breedlove et al., 2012).

CTE is characterized by a progressive decline of memory and cognition as well as depression, suicidal behavior, poor impulse control, aggressiveness, and other neurodegenerative illnesses (Stern et al., 2011). The earliest evidence of concussions being associated with CTE was observed in professional boxers who, after being frequently punched, exhibited acute impairment of motor control known as “Punch Drunk” (Baugh et al., 2012; Gavett, Stern, & McKee, 2011). Although most closely associated with concussions, neuropathological findings have also shown CTE to be present in football players with no history of diagnosed concussions (e.g. offensive linemen and linebackers), and in athletes as young as 17. While researchers have been unable to identify the precise cause of CTE, findings suggest that repetitive subconcussive blows may lead to the development of this neurodegenerative disease (Baugh et al., 2012; Breedlove et al., 2014).

The long-term effects of subconcussive blows on neurocognitive function and their relation to CTE have primarily been identified in football, and other sports such as baseball, MMA, and wrestling (McCuen et al., 2015). Athletic participation is a daily activity for many youth, adolescents, and young adults, placing them at risk for SRCs. Receiving multiple SRCs have been shown to result in impaired neurocognitive functioning post-injury (Collins, Lovell, & McKeag, 1999), decreased performance on future neurocognitive baseline tests (Moser & Schatz, 2002; Moser, Schatz, & Jordan, 2005), and an increased risk for more severe concussion-related symptoms, such as loss of consciousness, anterograde amnesia, and confusion (Collins et al., 2002).

Cumulative Head Impacts

In general, contact sport athletes collide with high forces, increasing their chances of SRCs. These subconcussive blows tend to be more frequent during games compared to practices (Broglio et al., 2013). During competition, college football players sustain an average of three subconcussive blows to the head per game (Broglio et al., 2011; Broglio et al., 2013; Stern et al., 2011; Tsushima, Geling, Arnold, & Oshiro, 2016). In another study, researchers investigated exposure to subconcussive head blows in high school football athletes. The 42 participants sustained a combined 32,510 impacts in a single season, with an average of 774 impacts per player during the 15-week season; approximately 50 impacts per week (Broglio et al., 2013; Daneshvar, Baugh, et al., 2011).

Similar to football players, soccer players are exposed to subconcussive blows during both practice and games. Yard and colleagues (2008) showed that, over a two-year span, 32 soccer players were exposed to over 630,000 subconcussive blows, an average of ~ 9,800 exposure per player per season (Yard et al., 2008). Other investigators showed that high school female soccer athletes received approximately 2.85 head impacts per game and collegiate female soccer athletes received approximately 6.98 head impacts per game (McCuen et al., 2015).

High school athletes who sustain numerous subconcussive blows have been shown to have an impaired ability to learn and exhibit permanent brain tissue damage (Abbas, Shenk, Poole, Robinson, et al., 2015; Tsushima et al., 2016). In a recent study, neuroimages (Functional MRIs) were obtained from healthy high school football athletes over the course of one athletic season to observe neurocognitive functional connectivity. Based on these neuroimages and other baseline measures, the study concluded that majority of non-concussed athletes who sustained subconcussive blows to the head had altered brain function when compared to non-collision sport athletes (Abbas, Shenk, Poole, Robinson, et al., 2015). Abbas and colleages concluded that exposure to subconcussive blows may lead to neurological damage that could alter learning ability, motor control and other cognitive functions (Abbas et al., 2015). In a similar study, Tsushima et al. (2016) showed that participation in contact sports with a high exposure to subconcussive blows negatively affects neuropsychological function in young athletes. In this same study, as well as another, adolescent contact sport athletes took longer than collegiate athletes to recover and may experience altered neurological development (Broglio et al., 2014; Tsushima et al., 2016). More specifically, high school contact sport athletes had more white matter damage and worse neurocognitive functioning compared with older collegiate contact sport athletes (Tsushima et al., 2016).

Assessing Cognitive Function

Due to the nature of concussion injury, tests of cognitive function have become a key component in the clinical assessment of concussion injury (Aubry et al., 2002; McCrory et al., 2017; Schatz, Pardini, Lovell, Collins, & Podell, 2006). Most tests of cognitive function for concussion assessment involve a computerized neurocognitive test that is administered typically prior to the season as a baseline measure, and again following any suspected concussion injury. The most widely used computerized neurocognitive test is the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT, Pittsburg, PA). ImPACT is designed to measure athletes' symptoms, verbal memory, visual memory, visual motor processing speed, and reaction time. ImPACT is widely accepted by researchers as a valid and reliable assessment tool for measuring cognitive function in people age ten years and older, and recently received FDA approval as a diagnostic tool for concussions (Schatz et al., 2006; Schatz & Sandel, 2013; Swanik, Covassin, Stearne, & Schatz, 2007).

In fact, sensitivity and specificity analyses indicates that ImPACT can correctly classify ~85% of concussion-related injuries (Schatz et al., 2006). Because ImPACT is typically administered to athletes yearly to obtain a baseline measure of cognitive function, Schatz et al. (2006) provided an opportunity to investigate the effects of sports participation on cognitive function over multiple years.

Limitations in Literature

Various studies have associated subconcussive head blows with brain tissue damage and impaired brain function, but only following a single season of play (Abbas, Shenk, Poole, Breedlove, et al., 2015; Abbas, Shenk, Poole, Robinson, et al., 2015; J. E. Bailes et al., 2013; K. M. Breedlove et al., 2014; Broglio et al., 2012; Davenport et al., 2016; Merchant-Borna et al., 2016; Poole et al., 2015; Tsushima et al., 2016). Moreover, some of these studies have been conducted in contact sports with a high incidence of subconcussive blows, such as football and soccer, without comparison to sports with less exposure to subconcussive blows. Given these inconsistencies across various studies, it has been suggested that future studies assess the effect of subconcussive blows on brain function in larger groups, over longer periods of time, using consistent protocols and across a wide range of sports and ages (Belanger et al., 2016).

Purpose and Hypothesis

The purpose of this study was to quantify the effects of contact sport participation on neurocognitive function in collegiate and adolescent athletes over multiples seasons of play. Primarily, we hypothesized that athletes participating in contact and limited contact sports would exhibit a deficit in neurocognitive function when compared to athletes participating in non-contact sports. Secondly, we hypothesized that contact and limited contact sports athletes would exhibit a decrease in neurocognitive function following multiple seasons of play.

METHODS

Subjects

Subjects for this study consisted of 2,271 combined male (n=1,392) and female (n=879) high school and collegiate athletes (mean age, 15.8 ± 2.1 years) who completed computerized neurocognitive baseline testing as part of their institution's concussion testing program and who had not experienced a diagnosed concussion during the four years investigated. Data for this retrospective analysis was collected for a four-year period from a de-identified North Coast Concussion Program (NCCP) database and included adolescent and collegiate athletes (13-26 years). Participants were categorized into three groups based on their level of contact sport participation (Table 1.): contact (N=1791, mean age, 17± 2 years), limited contact (N=364, mean age 17 ± 2 years) and non-contact (N=116, mean age 17 ± 2 years). *Contact sports* refer to sports where athletes routinely make contact with each other or with inanimate objects (Rice, American Academy of Pediatrics Council on Sports, & Fitness, 2008). *Limited contact sports* refer to sports where athletes make contact with other athletes or inanimate objects infrequently. *Non-contact sport* athletes do not make contact with others or inanimate objects (Rice et al., 2008). All subjects provided informed consent and parental permission, if needed, prior to participation in this study. The Humboldt State University Institutional Review Board approved this study prior to data collection.

Table 1. Level of Contact in Sport Participation

Contact (n=1791)	Limited Contact (n=364)	Non-Contact (n=116)
Football (n=816)	Softball (n=67)	Golf (n=13)
Soccer (n=469)	Baseball (n=31)	Cross Country (n=39)
Rugby (n=88)	Volleyball (n=267)	Track & Field (n=29)
Wrestling (n=36)		Tennis (n=29)
Basketball (n=207)		Rowing (n=6)
Ultimate Frisbee (n=13)		
Lacrosse (n=21)		
Cheerleading (n=140)		

Procedures and Measures

For this study, we analyzed four years of baseline ImPACT composite scores that had been collected from subjects prior to the start of their athletic season. These composite scores consist of verbal memory, visual memory, visual motor processing speed, reaction time and symptoms. As part of their preseason testing, every athlete completed a ~30-minute ImPACT baseline test. Athletes were encouraged to utilize their best performance to prevent invalid scores. During the data organization, participants were categorized and cleaned up for missing demographic information. Subjects with consistent invalid baseline scores were included in this study. Invalid ImPACT baseline scores are represented on a general sex and age algorithm, this does not mean that scores are not valid but low for the subjects age and sex group.   For this study we compared the ImPACT composite scores among the three levels of contact (contact, limited contact and non-contact) over a four-year period.

Statistical Analysis

We used a mixed repeated measures MANOVA ($p < .05$) and repeated measures ANOVA to determine the differences in baseline ImPACT composite scores due to contact sport participation (independent variable: contact, limited contact and non-contact) and time (independent variable: 1-4 years). The five dependent variables were analyzed from the ImPACT baseline composite scores including verbal memory, visual memory, visual motor processing speed, reaction time, and total symptoms scores. To efficiently run this analysis with a large sample we analyzed the collected data using the "R" software (R, Version. 3.2.3, Auckland, New Zealand). Assumptions that violated of sphericity and normality were adjusted by log transformation.

RESULTS

According to our statistical mixed repeated measures MANOVA analysis, there was a difference among the three levels of contact sport participation ($p < 0.001$) and a significant change over the four years ($p < 0.001$). However, there was no interaction effect between contact sport participation and time ($p = .0894$).

Contact vs Non-Contact

Over the four seasons of testing contact sport athletes scored significantly 3.8% worse on visual motor processing speed ($p < 0.001$) and 2.5% slower on reaction time ($p < 0.001$) when compared to non-contact sport athletes (*Figure 1 & Figure 2*). However, there was no difference between contact and non-contact sport athletes in verbal memory, visual memory or reported symptoms ($p > .05$; *Figure 3, Figure 4 and Figure 5*).

Contact vs Limited Contact

Similar to the differences from non-contact sport athletes, contact sport athletes had ~5% worse visual motor processing speed ($p < 0.001$) and 1% worse reaction time ($p < 0.001$) compared to the limited contact sport athletes. Otherwise, contact sport and limited contact sport athletes did not differ in verbal memory or visual memory. Limited contact sport athletes reported 41% more symptoms compared to contact sports ($p < 0.001$; *Figure 5*).

Limited Contact vs Non-Contact

The results of our investigation showed that limited contact sport athletes scored similarly well as non-contact sport athletes over the four years tested except in the measure of reaction time. Limited contact sport athletes scored 1.1% slower on reaction time ($p < 0.001$) compared to non-contact sport athletes (*Figure 2*).

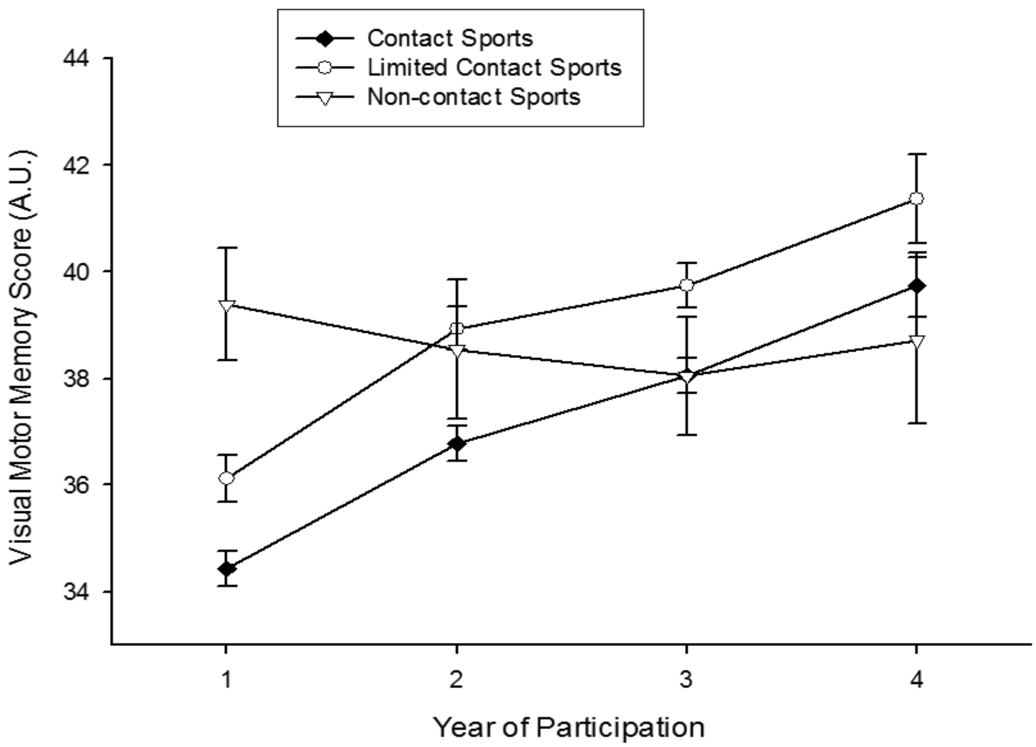

Figure 1. Average baseline Visual Motor Processing Speed composite score from ImPACT assessment over four seasons of play for contact (◆), limited contact (O) and non-contact (▽) sport athletes. Error bars represent standard error of mean.

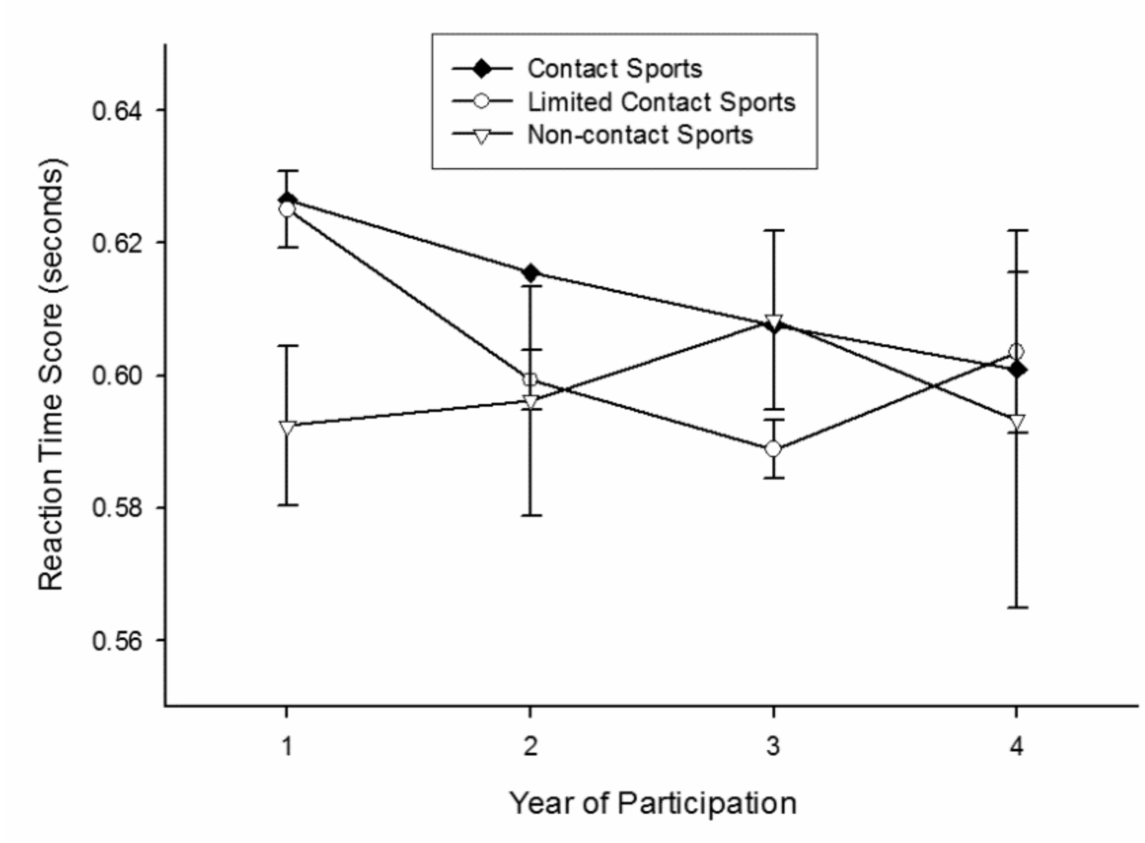

Figure 2. Average baseline Reaction Time composite score from ImPACT assessment over four seasons of play for contact (◆), limited contact (O) and non-contact (▽) sport athletes. Error bars represent standard error of mean.

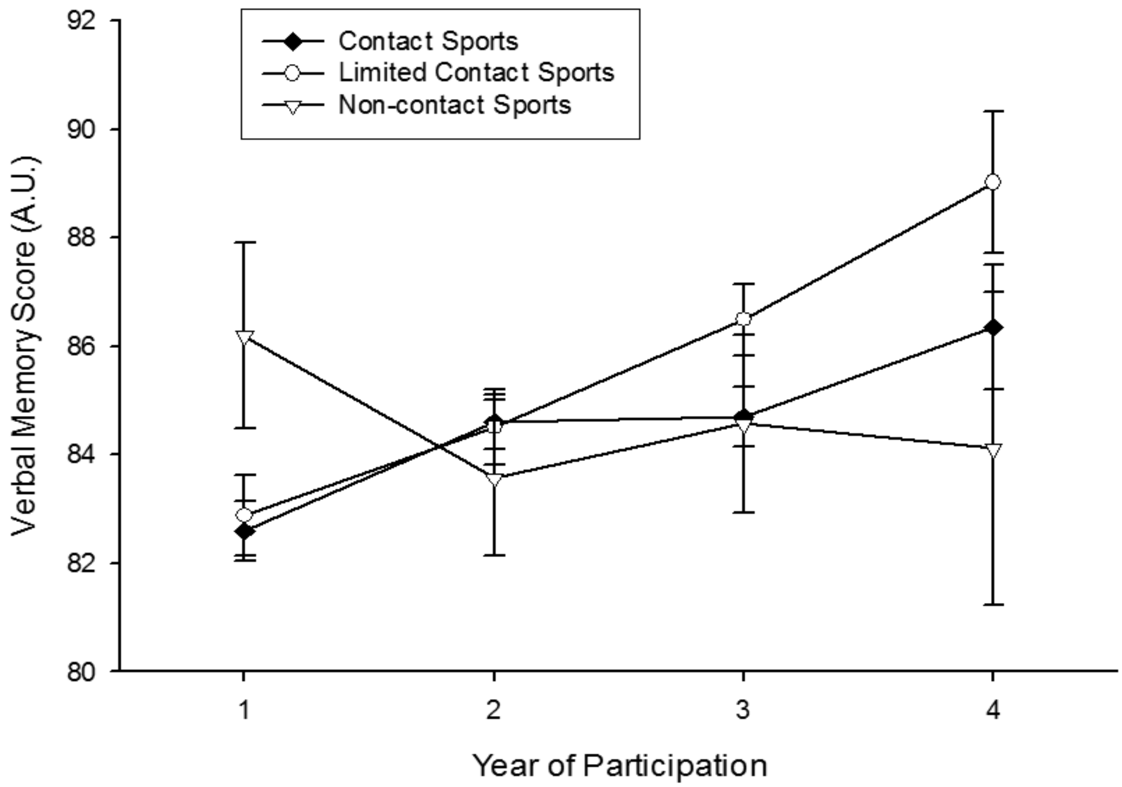

Figure 3. Average baseline Verbal Memory composite score from ImPACT assessment over four seasons of play for contact (◆), limited contact (O) and non-contact (▽) sport athletes. Error bars represent standard error of mean.

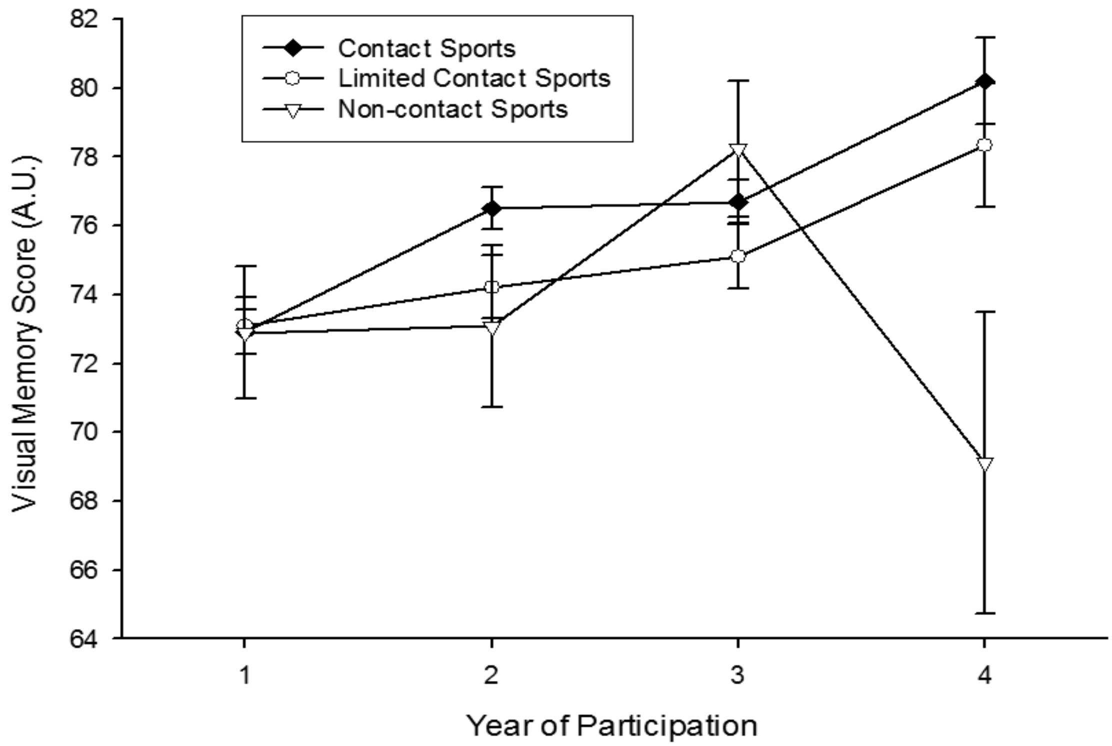

Figure 4. Average baseline Visual Memory composite score from ImPACT assessment over four seasons of play for contact (◆), limited contact (O) and non-contact (▽) sport athletes. Error bars represent standard error of mean.

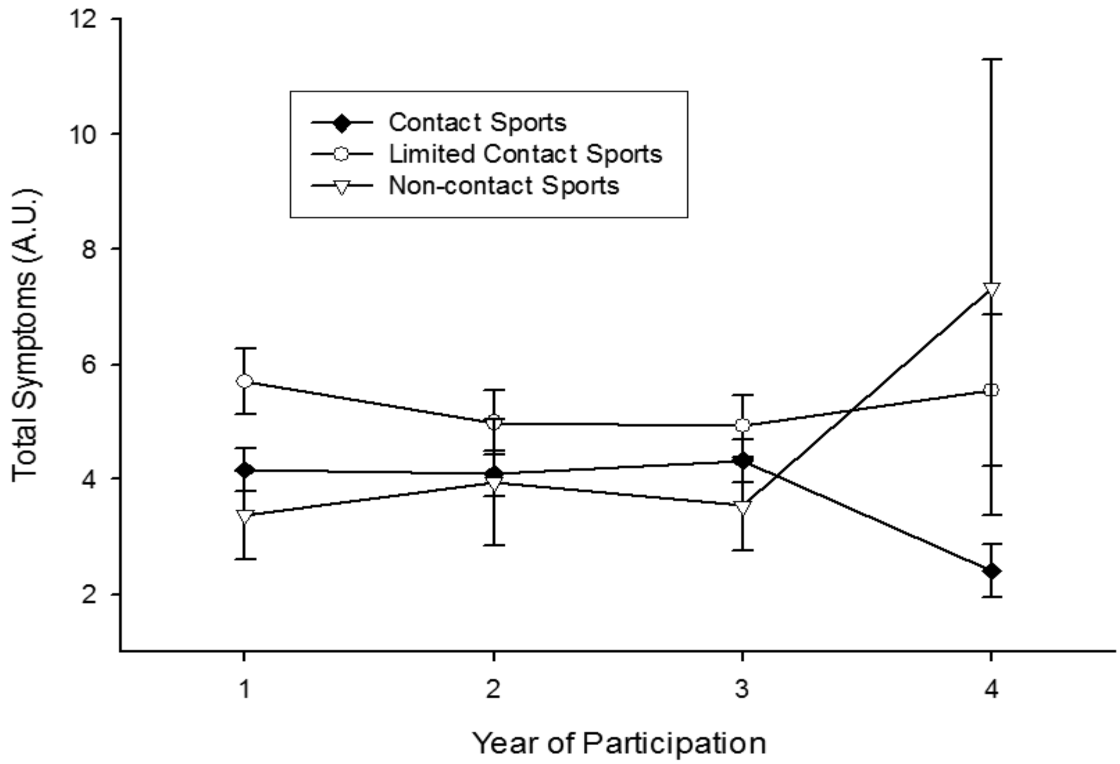

Figure 5. Average baseline number of Symptoms reported from ImPACT assessment over four seasons of play for contact (◆), limited contact (O) and non-contact (▽) sport athletes. Error bars represent standard error of mean.

DISCUSSION

In support of our primary hypothesis, neurocognitive function as assessed by the ImPACT assessment, was worse in athletes who participate in contact or limited contact sports as compared to non-contact sport athletes. While there was essentially no difference in visual memory or verbal memory between the groups, both contact and limited contact sport athletes performed worse in reaction time and visual motor processing speed. In contrast to our secondary hypothesis, neurocognitive function in contact and limited contact sport athletes did not get worse over the four years of testing. Rather, all groups tended to perform better on the ImPACT assessments over the four-year period.

Practice-Learning Effect

Regarding contact sports versus non-contact groups, only two of the five domains of cognitive performance, visual motor processing speed ($p < 0.001$), and reaction time ($p < 0.001$) supported the theme of neurocognitive deficits in contact sport athletes. Although some of the other composite scores, such as verbal memory and visual memory tended to be worse in the contact and limited contact sport athletes compared to the non-contact sport athletes, thus supporting our primary hypothesis, there was not enough significant evidence to accept it. Moreover, we did not observe any worsening in any contact sport athletes over the four seasons of play. One possible explanation for this lack of difference in verbal memory and visual memory may be that some individuals improved their scores as a result of learning (practice effect). In fact, visual and verbal memory composite scores have been shown to improve as a result of practice effect out to at least four test administrations (Maerlender et al., 2016). This learning effect is most prevalent in verbal memory and visual memory but not as prevalent with visual motor speed and reaction time composite scores (Broglio et al., 2016; Maerlender et al., 2016). Thus, it is also possible the reason we did not observe a worsening in ImPACT scores over time in the contact and limited contact sport athletes, is that a learning effect with improved scores has offset any worsening due to exposure to subconcussive blows.

Reporting Symptoms

In contrast to what might be expected, contact sport athletes consistently reported the fewest number of concussion symptoms as compared to the other two groups. Several studies suggest that contact sport athletes live within a sport culture that encourages risk-taking and playing through injury, which may negatively influence an athlete's willingness to report concussion symptoms (Broglio et al., 2014; Jarem, Vosloo, & Scriber, 2013; Kirkendall, 2001). Based on this research, it is possible that the contact sport athletes in our study simply did not report all the symptoms they were experiencing.

Processing Speed and Reaction Time

While learning effects and the internal pressures to not report symptoms may explain the lack of differences in verbal memory, visual memory and total symptom scores, contact and limited contact sport athletes did exhibit slower visual motor processing speed and reaction time as compared to the non-contact sport athletes. Results from Maerlender et al. (2016), demonstrated that the practice effects for both the visual motor speed and reaction time composite scores are minor (Maerlender et al., 2016). Moreover, an ImPACT sensitivity and specificity study reported visual motor processing speed composite scores to be effectively classified during a post injury assessment (Schatz et al., 2006). Furthermore, Eckner and colleagues, reported that reaction times are one of the most sensitive domains of neurocognitive change following injury and prolonged reaction time is common following SRCs (Eckner et al., 2014).

Limitations

Adolescent Brain Development

This study is not without limitations that might have influenced our ability to test our hypotheses. First, adolescent athletes were included in our sample. Several studies have shown that the brain continues to develop until the age of ~25 years (Abbas et al., 2015; Chun et al., 2015; Dahl, 2004; Field et al., 2003; Giedd et al., 1999; Moser & Schatz, 2002; Moser et al., 2005; Newsome et al., 2016; Pujol et al., 1993; Rice et al., 2008). A recent study showed that repetitive subconcussive blows in young athletes leads to delayed neurological development (Tsushima et al., 2016). Other research on both animals and humans suggest that immature adolescent brains are more susceptible to brain injury and recovery is slower and often more complicated compared to mature adult brains (Field et al., 2003; Newsome et al., 2016; Tsushima et al., 2016). Thus, younger adolescent contact sport athletes may sustain more impairment of neurocognitive functioning from subconcussive blows compared to older contact sport athletes (Tsushima et al., 2016). Future research should investigate the interaction of age and exposure to subconcussive blows on neurocognitive function.

Exposure Rate of Subconcussive Blows

A second limitation of our study was that we did not collect the exposure rate to subconcussive blows among our contact and limited contact sport athletes. In many of the these sports an individual may only play a small portion of a game or practice, whereas other athletes in the same sport may play considerably more and thus have a much greater exposure to subconcussive blows. Such a diversity in exposure within contact and limited contact sports may have further influenced our ability to identify differences among the levels of contact sport participation. Moreover, our methodology did not control for player status classification (e.g. starter versus redshirt) or the number of minutes each athlete played, although such information could be used to further classify rates of subconcussive exposure (Broglio et al., 2013). This limitation may have been further exacerbated by the fact that we did not assess which athletes play multiple sports throughout each year. Although this would be a challenging measure to obtain, to better understand the influence of exposure over time on neurocognitive function, future studies should obtain and relate subconcussive blow exposure rates to neurocognitive function over multiple seasons.

Sample Size and Demographics

Another limitation of our study was the relatively small sample of limited and non-contact sports athletes. These large differences in sample sizes between groups may have influenced our statistical ability to identify differences among our groups. However, when assumptions of sphericity or normality of distribution were violated, we adjusted our statistical analysis accordingly. Nonetheless, greater samples sizes for limited contact and non-contact sports athletes would have strengthened our ability to interpret our results. There was also limited control of test conditions because the data was previously collected. We can only speculate that the reason for some of the insignificant findings may have been a result of prior collected baseline scores that were invalid, mislabeled, missing demographic information and uneven sample sizes.

Future Research

Certainly, replication with other samples would be highly desirable. Further research should consider focusing on two levels of contact as opposed to three (e.g. contact versus non-contact) to help control for outside factors with other levels of contact sports. Sports that are listed as limited contact are not as reliable of a measure because most injuries are not necessarily due to intentional contact. When controlling for these limitations in further research, more conclusive results would be expected.

Practical Implications

Overall our analysis indicates that the commonly accepted neurocognitive assessment demonstrated less than optimal reliability for clinical utility. Ultimately, while some of these measures individually meet the reliability standards set for clinical utility, there is evidence that it provides a high level of sensitivity to observe changes in cognitive functions when comparing baseline performance to post concussion injury performances. Currently there are no concussion assessment tools that meet or exceed the accepted threshold for clinical utility. It is recommended that clinicians continue self-education with current concussion consensus and research in order to provide the most effective evidence based practices.

CONCLUSIONS

The purpose of this study was to quantify the effects of contact sport participation on neurocognitive function in collegiate and adolescent athletes over multiple seasons of play. Although neurocognitive function does not worsen over four years of play among contact sport athletes, contact sport and limited contact sport athletes do exhibit slower visual motor processing speed and reaction times compared to non-contact sport athletes. While the influence of subconcussive blows on neurocognitive function over times remains unclear, the results of this study clearly show that future studies of this important issue should more accurately measure and relate the influence of subconcussive exposures and age to neurocognitive function over time. Nonetheless, the results of this study provide key information in developing clinical recommendations regarding the play of contact sports and its impact on brain function through our lifespan.

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APPENDIX A

Operational Definitions

1. Subconcussive blows- forces from impacts to head or body that cause minor disturbances on brain with inducing no readily observable concussive like symptoms (Davenport et al., 2016).
2. ImPACT- This computerized neurocognitive test is designed to measure athletes' symptoms, measure verbal and visual memory, processing speed, and reaction time (Schatz & Sandel, 2013).
3. Baseline assessment- An assessment administered during preseason prior to the athletic season to compare with other assessments in the event of an injury (Abbas, Shenk, Poole, Breedlove, et al., 2015).
4. Neurocognitive- cognitive functions that are closely linked to the function of neural pathways within the brain (Bailes & Omalu, 2017).

APPENDIX B

Assumptions

1. Participants were fully rested prior to baseline assessment.
2. All participants completed baseline testing during preseason (prior to the start of season practices or games).
3. All participants were honest in the subjective information they provided.
4. Non-contact sport participants have minimal risks receiving subconcussive blows.