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Prevalence of Undiagnosed Concussion in Adolescent Athletes Based on Neuropsychological Declines

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Abstract

Prevalence of Undiagnosed Concussion in Adolescent Athletes Based on Neuropsychological Declines

By Mackenzie M. Herzog

Background: The effect of repeated impacts to the head during athletics, especially those at a subclinical level, is not well understood. We define undiagnosed concussion as traumatic brain injury that is not detected or reported. Reliable Change Index (RCI) for ImPACT can be used to identify athletes who have sustained a probable undiagnosed concussion, based on score declines in composite scores or symptom scale that indicate clinically significant change.

Hypothesis/Purpose: The purpose is to determine the prevalence of undiagnosed concussion based on neuropsychological score declines among adolescent athletes without diagnosis or report of a clinical concussion. In addition, we will compare the prevalence of undiagnosed concussions amongst sports.

Study Design: Cohort Study

Methods: Adolescent athletes, who had 2 baseline ImPACT tests 8 months to 2 years apart, without diagnosis or report of concussion, were retrospectively identified and included in this IRB-approved study. Athletes were aged 12-18 years and underwent initial baseline ImPACT test between 2010-2012. Athletes with impulse control composite scores >30 were excluded. Sports included football, boys' lacrosse, boys' soccer, girls' soccer, and wrestling. Clinically significant change was assessed using previously published 95% RCIs for high school athletes. Athletes who showed declines in test scores >95% RCI from test to retest were considered to have a potential undiagnosed concussion.

Results: Of 290 athletes, 42 (14.5%) showed cognitive function declines indicative of undiagnosed concussion. Football players had almost 2 times the risk of having undiagnosed concussion as participants in all other sports, when controlling for history of ADD/ADHD (RR=1.84; 95%CI: 1.11,3.06; p=0.004). Time between tests, age, hours of sleep, or years active in sport were not associated with undiagnosed concussion.

Conclusion: This study found that 14.5% of included adolescent athletes sustained a potential undiagnosed concussion, with football players having double the risk of other athletes. To our knowledge, this study is the first to attempt to identify the prevalence of undiagnosed concussion among adolescent athletes by assessing declines in neuropsychological test scores in the absence of clinically detected concussion. Findings demonstrate that the burden of sports-related concussion among adolescent athletes is potentially greater than the reported incidence rates.

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Table of Contents

INTRODUCTION

Approximately 40% of all childhood brain injury is related to athletic activity (1). Recent studies estimate an overall incidence rate of 2.5 concussions per 10,000 athlete-exposures in high school sports, defined as one athletic competition or practice (2, 3). Additionally, reported concussion rates in athletics increased by a factor of 4.2 (95%CI 3.4-5.2) from 1998 to 2008 (2). The incidence of concussion among high school athletes is concerning; however, the incidence of undiagnosed head injury is potentially more alarming due to the potential for long-term cognitive deficits and the inability to appropriately treat the head injuries that are not recognized.

All athletic activity poses an inherent risk for head trauma, and yet the effect of repeated impacts to the head, especially those at a subclinical level, is not well understood. Clinical studies have demonstrated the potential detrimental effects of a single concussion, and repetitive mild injury to the brain has also been implicated in both short-term and long-term neurocognitive impairment (4). In addition, a study of 21 adolescent male football players that measured head collisions throughout one season found that athletes who exhibited no clinical concussion symptoms demonstrated measurable neurocognitive impairments, indicating a risk for undiagnosed concussion in this population (5). For the purposes of this paper we define undiagnosed concussion as traumatic brain injury that is not detected or reported by athletes, coaches, or medical professionals.

Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT), is a popular computerized neuropsychological screening tool used by high school and collegiate sports medicine professionals to assess cognitive function among adolescent

athletes. ImPACT measures aspects of attention, memory, reaction time, and processing speed using six different test modules and produces four composite scores in the following areas: verbal memory, visual memory, reaction time, and processing speed (6). In addition, the Post-Concussion Scale is embedded in ImPACT and calculates a total symptom score for 22 common concussion symptoms (6). Athletes are commonly tested prior to participation in athletics to determine baseline neurocognitive function, and baseline tests are used to assess post-concussion functioning. Subsequently, ImPACT allows for athletes to act as their own controls, should they sustain a concussion. This type of neuropsychological testing is an effective tool to monitor recovery following concussion and has become standard of care for assessing neurocognitive recovery (7, 8).

Moreover, ImPACT, in particular, has been shown to be a reliable and valid tool for concussion assessment (8-11). Two recent studies evaluated the test-retest reliability of computerized ImPACT among athletes and found little variation between baseline assessments, indicating stability of the test over a long-term period. Elbin, Schatz, and Covassin performed an analysis of the one-year test-retest reliability among high school athletes and found Pearson *r* correlations of .40 to .74 for the four composite scores and the symptom scale (8). Additionally, Schatz performed a similar analysis of two-year test-retest reliability among college athletes and found similar Pearson *r* correlations of .27 to .60 (11).

In addition to determining the reliability of ImPACT, the previous two studies also calculated the Reliable Change Indices (RCI) for the composite scores and symptom scale of the test in order to determine the stability of the test (8, 11). Jacobson and Truax first proposed RCI in 1991 as a statistical tool for measuring the magnitude of change

that has occurred between test and retest in clinical practice (12). RCI indicates whether the difference between test and retest is reflective of clinically significant change versus change related to expected variation in scores resulting from practice effects, neurodevelopment, or normal variation (12). RCI is used by ImPACT to detect clinically significant change from baseline testing to post-injury testing (13). The ImPACT Clinical Interpretation Manual notes that, "The magnitude of changes from baseline testing is assessed via the use of *Reliable Change Index (RCI)* scores for the ImPACT composites. If an athlete demonstrates a change in scores that falls outside of the range of normal score variation, the ImPACT report notes these changes in test performance (13)." This change in test performance can then be clinically interpreted in order to assist physicians in making return to play and return to school decisions following injury.

In the previously mentioned studies, Elbin, Schatz, and Covassin found that a small percentage of high school athletes showed absolute value changes outside of the RCI between initial ImPACT baseline and retest; 8-13% showed clinically meaningful change at the 80% confidence interval and 5-8% at the 95% confidence interval (8). Schatz also found that 7-13% and 4-9% of the collegiate athletes tested showed meaningful changes in ImPACT at the 80% and 95% confidence intervals, respectively (11). The authors used these findings to conclude that ImPACT is a stable test over a long-term period; however, the significance related to those athletes showing clinically significant change, given that athletes who sustained a concussion between tests were excluded, was not discussed.

The recent increased interest in sports concussion has resulted in renewed discussions of sports safety and risk for injury. Concussion education and legislation have

made sports concussion reporting commonplace and, in some cases, mandatory, resulting in better care for athletes who sustain an injury. However, the risk for undiagnosed concussion remains a concern.

We propose that RCI for ImPACT can be used to identify athletes who have sustained a probable undiagnosed concussion, based on absolute value changes that indicate clinically significant change in composite scores or symptom scale from initial baseline to retest. The ability to assess the prevalence and risk factors for potential undiagnosed concussion will allow for better understanding of the risk for injury among athletes, which could in turn improve identification of adolescent athletes who are at risk for such injuries. A better understanding of concussion and the ability to identify athletes at risk may improve concussion screening and lead to future injury prevention activities. To our knowledge, no previous study has assessed neurocognitive function declines among adolescent athletes to attempt to elucidate the prevalence of undiagnosed concussion. The broad, long-term goal of this research is to improve understanding of the risk for brain injury in adolescent athletes. The primary, specific aims of this study are to determine the prevalence of undiagnosed concussion based on neuropsychological score declines among adolescent athletes without diagnosis or report of a clinical concussion. In addition, we will compare the prevalence of undiagnosed concussions amongst the sports, hypothesizing that the rates of undiagnosed concussion will follow a similar trend as the reported concussion incidence rates.

MATERIALS AND METHODS

Participants

Adolescent athletes who participated in any sport and were under the care of our institution's sports medicine team were retrospectively identified and included in this Institutional Review Board approved study. Initial inclusion criteria were any athlete between the ages of 12 to 18 years who underwent baseline ImPACT test between 2010 and 2012 and did not have a clinically detected or self-reported concussion prior to testing. Athletes who are under the care of our sports medicine staff undergo baseline ImPACT prior to participation in organized athletics as standard of care. Baseline ImPACT is repeated every two years, at minimum, as suggested in the ImPACT manual and past studies emphasizing the need to provide current baseline measures on neurocognitive performance (8, 11, 13).

Following initial identification of athletes who had baseline ImPACT, the database was reviewed to identify athletes who underwent a second baseline ImPACT test as part of routine pre-participation screening, in the absence of a clinically detected or self-reported concussion after the initial baseline. Retest occurred at a minimum of eight months and a maximum of two years following the initial baseline. A minimum of eight months was selected to allow for at least one season of athletic participation between the two tests. A maximum of two years was selected to ensure stability of the baseline test (8, 11). Exclusion criteria included an impulse control composite score greater than 30 because the validity of these tests is considered questionable (13, 14) and any athlete who had two baseline tests within one month of each other because this suggested a potential error in testing protocol or invalid responses by the test-taker, resulting in difficulty determining true, valid baseline scores. Additionally, athletes who participated in non-contact sports, including volleyball, girls lacrosse, cheerleading, and

baseball were excluded due to the fact that during the included time period (2010-2012) only collision and contact athletes were routinely baseline ImPACT tested by our sports medicine staff. Non-contact athletes were only baseline tested if they had sustained a prior head injury or were at increased risk for head injury due to some other reason, which could lead to selection bias of non-contact sport athletes.

A total of 381 athletes had two baseline ImPACT tests with no history of concussion. Ninety-one athletes (24%) were excluded for the following reasons: 4 (1%) had two baseline tests within one month of each other, 24 (6%) had impulse control composite scores greater than 30, 35 (9%) did not have a retest between eight months and two years, and 28 (7%) played a non-contact sport that did not undergo baseline ImPACT as standard of care. Two hundred and ninety athletes were available for assessment of undiagnosed concussion. There were 38 females and 252 males. The mean age at time of initial baseline ImPACT was 15.3 years (range: 12.2-17.5 years).

For analysis of association between sport and undiagnosed concussion, only athletes who listed the same primary sport on both the initial baseline test and the retest were analyzed. Of the 290 athletes included in the prevalence analysis, 20 listed different primary sports on the two tests and were excluded from the final sport analysis, leaving 270 athletes for statistical analysis of sport with undiagnosed concussion. Sports analyzed included football, boys' lacrosse, boys' soccer, girls' soccer, and wrestling.

Materials

The online Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT) versions 2.0 and 2.1 were used for this analysis (ImPACT Applications, Inc.,

Pittsburgh, PA, 2014). Data from the verbal memory, visual memory, reaction time, and processing speed composite scores, in addition to the total symptom scale, were used to analyze change between initial baseline test and retest. High scores on the verbal memory, visual memory, and processing speed composites indicate better performance, whereas low scores on the reaction time composite and the symptom scale indicate better performance (15). Clinically significant change was assessed using previously published 95% RCIs for high school athletes (8). Absolute value changes required for clinically meaningful change are listed in Table 1 (8).

Given that RCI is used to detect clinically significant change, change that is greater than that which would be expected due to variation in scores from practice effects, neurodevelopment, or normal variation (12), we concluded that athletes who had a decline in test scores greater than the absolute point change required for reliable change at 95% could represent those athletes who sustained undiagnosed concussions. More specifically, we concluded that those athletes who showed clinically significant declines in test scores from initial baseline to retest likely represented athletes who sustained undiagnosed concussions. Ninety-five percent RCI was selected over 80% RCI in order to use a strict criterion for identifying possible undiagnosed concussion. Consequently, we identified all athletes who had a clinically significant decline greater than the absolute value that would be required for 95% RCI on at least one of the composite scores and/or the symptom scale as athletes who sustained undiagnosed concussions.

Statistical Analyses

Change in ImPACT score was calculated as [Test 1 Score – Test 2 Score]. Subsequently, negative values for the verbal memory, visual memory, and processing speed composites were indicative of neurocognitive improvement from initial baseline to retest, whereas positive values were indicative of neurocognitive decline. For reaction time composite score and symptom scale, positive values were indicative of improvement and negative values were indicative of decline.

All statistical analyses were performed using SAS 9.3 (Cary, NC, 2002-2010). Stratified analysis was used to assess the association between undiagnosed concussion and sport. Several variables were considered as possible confounders, including age, gender, education level, years active in the sport, hours of sleep prior to test, history of ADD/ADHD, history of dyslexia, and history of autism. Only gender, history of ADD/ADHD, and history of autism were considered to be associated with both the exposure (sport) and outcome (decline of test score/undiagnosed concussion) and were considered confounders. Gender was controlled for in the division of sports by gender. This choice was made to account for the fact that some gender comparable sports (such as boys' and girls' soccer) have different published incidence rates for concussion. In addition, while lacrosse is a sport played by both genders, only boys' lacrosse is considered a contact sport, and therefore only boys' lacrosse met the inclusion criteria for this study. This leaves history of ADD/ADHD and history of autism as the only two variables to be controlled for in the analysis. No athletes reported a history of autism, and consequently, this variable was dropped from the analysis, leaving only history of ADD/ADHD for stratified analysis. Risk ratios and 95% confidence intervals were

computed to identify the association between sport and undiagnosed concussion. Significance was assessed at the 95% level.

Two-tailed t-tests were used to assess a difference in means for several variables between the outcome group (decline of test score/undiagnosed concussion) compared to the group without the outcome. The variables assessed were: time between tests, age at test one, hours of sleep at test one, hours of sleep at test two, change in hours of sleep ([Test 1-Test 2]), and years active in the sport at test one. Significance was assessed at the 95% level.

RESULTS

The percentages of athletes with clinically significant change, assessed using an absolute point change greater than that required for reliable change at 95% based on the previously published RCIs from Elbin, Schatz, and Covassin (8), are listed in Table 1. Of the 290 included athletes, 42 (14.5%) showed cognitive function declines indicative of an undiagnosed concussion. Of the 42 athletes who showed cognitive function declines, 35 declined greater than 95% RCI on one composite score or symptom scale, five declined on two composite scores and/or symptom scale, one declined on three composite scores and/or symptom scale, and one declined on all five composites scores and symptom scale. The number of undiagnosed concussions by sport is listed in Table 2.

Football players had almost two times the risk of having an undiagnosed concussion than all other sports combined, when controlling for history of ADD/ADHD (RR=1.84; 95%CI: 1.11, 3.06; p=0.004). The risk ratios for all other sports compared to football, controlling for history of ADD/ADHD, are listed in Table 2.

There was no difference between those athletes with an undiagnosed concussion compared to those without evidence of concussion for any of the following variables: time between tests, age at test one, hours of sleep, or years active in sport at test one (Table 3).

DISCUSSION

This study found that 14.5% of adolescent athletes who participate in football, boys' lacrosse, boys' soccer, girls' soccer, and wrestling, and who were not known to have a head injury, sustained a potential undiagnosed concussion. Undiagnosed concussions were identified using the Reliable Change Index (RCI) to detect clinically significant declines in cognitive functioning over an eight-month to two-year period. In addition, football players had almost double the risk of having an undiagnosed concussion than all other sports combined (RR=1.84; 95%CI: 1.11, 3.06; p=0.004). To our knowledge, this study is the first to attempt to identify the prevalence of undiagnosed concussion among adolescent athletes by assessing declines in neuropsychological test scores in the absence of clinically detected concussion. Findings demonstrate that the burden of sports-related concussion among adolescent athletes is potentially greater than the reported concussion incidence rates.

It is well documented that football players have the highest rates of clinically detected concussion among high school athletics, with published incidence rates around six concussions per 10,000 athletic exposures (2, 3, 16-18). A limitation of the present study is that incidence rates could not be calculated due to the fact that the undiagnosed concussions identified in this study were prevalent cases, not incident cases. Since we

were unable to observe the actual concussion event and we were not able to estimate the timing of the injury event, but rather identified the event on routine ImPACT retest, the cases were considered prevalent rather than incident. Although we were unable to calculate incidence rates, this study showed similar trends in rates of undiagnosed concussion (Table 2). Football players were more likely than all other sports combined to have neurocognitive declines from test to retest indicating a potential undiagnosed concussion. Following football, the risk of undiagnosed concussion was greatest among girls' soccer athletes, which is also consistent with the published incidence rates (2, 3). Interestingly, wrestling athletes actually had a slightly greater risk of having an undiagnosed concussion than football athletes. This could indicate that wrestlers are more likely to have concussive injuries that are not reported or detected by athletes, coaches, parents, and medical staff. One hypothesis for this finding is that wrestlers may be more likely to sustain repetitive mild head impacts versus a single concussive event, due to the nature of the sport; however, these results may also be affected by the small sample size of wrestlers in our study group.

It is important to recognize that there may be other explanations for the significant decline in test scores from test to retest, aside from potential undiagnosed concussion. In fact, the use of the 95% significance level in calculating the RCI indicates that we would expect to see 5% change, based on the definition of RCI. There are several other explanations for the change in score from test to retest. First, the brain of the athlete is cognitively maturing during adolescence, which could result in score changes on neuropsychological testing tools such as ImPACT. One unpublished study found that large improvements in neuropsychological test scores occurred between the ages of 9 to

15 years, consistent with cognitive maturation (19, 20). Cognitive maturation could explain changes outside of the 95% RCI from ImPACT test to retest; however, one would expect to see significant increases in scores from initial baseline to retest in the presence of cognitive maturation. This may explain the percentage of athletes who showed increases in score from test to retest, but we hypothesize that this explanation does not hold for significant declines from test to retest.

Practice effects have also been implicated in observed changes in test scores from test to retest (21), but in the same manner, one would expect to see significant increases in scores due to practice effects rather than declines. ImPACT has been found to be a stable, reliable, and valid neuropsychological assessment tool, which should minimize practice effects (8, 11). Additionally, RCI is a statistical tool purported to report clinically significant change greater than that which would be expected from practice effects, neurodevelopment, or other normal variation (12). Other explanations for significant declines in test scores include testing environment or test taker characteristics that could affect scores, such as hours of sleep, stress, or other distractions. These variables may affect crude test to retest changes in scores and could potentially explain the percentage of athletes who had significant declines in test scores; however, these variables should not be associated with the exposure (sport) in this study, therefore they should not confound the association between sport and undiagnosed concussion. In addition, we analyzed differences in several variables, including hours of sleep, times between tests, and age to determine if there were any significant differences between the group with undiagnosed concussion and the group without evidence of concussion that could explain the significant decline in test score. There was no statistically significant difference for

any of these variables (Table 3). Consequently, we feel that a significant decline in ImPACT score from initial baseline test to retest is likely to represent undiagnosed concussion.

Another important aspect of this study to discuss is the use of neuropsychological testing as a means to identify potential undiagnosed concussions. Concussions are complex injuries that involve a wide domain of symptoms and clinical indicators, and many different tools can be used for clinical examination (22). These tools include symptom presentation, physical signs of concussion, and assessment of behavioral changes (22). Neuropsychological testing is merely one tool used to detect concussion, and furthermore, not all athletes with a concussion show changes on neurocognitive testing (13). Therefore, there are other methods that may be equally or more effective in identifying undiagnosed concussion, such as postural stability testing or symptom assessment (22). Likely the best method for evaluating athletes for potential undiagnosed concussion would be a combination of these things. However, a benefit to using ImPACT to identify potential undiagnosed concussions is that ImPACT is commonly used in a variety of settings to evaluate both adolescent and adults athletes for concussion. The widespread use of this tool lends to its ability to be used as a screening tool for undiagnosed concussion.

There are also conceivable criticisms for the use of RCI as a statistical tool for identifying potential undiagnosed concussion. All RCI models share a common equation structure, but there are potential differences in how predicted retest scores and standard errors are calculated (23). One study found that different RCI models yield varying results, particularly in concussed athletes (23). The study concluded that the choice of

RCI model might affect the determination of clinically significant change (23). For the present study, we used previously published RCI data from a population with similar characteristics as our study population. Consequently, we assume that the RCIs used are reliable and sensitive in our study population. The possibility remains that RCI is not the best method for identifying clinically significant change. However, this method of RCI is currently used by ImPACT to identify significant changes in test score from baseline to post-injury (13), meaning this same method is used to make decisions about recovery following concussion injury. Therefore it is logical that it could also be used to identify potential undiagnosed concussions.

For the purposes of this study, 95% RCI was selected over 80% RCI in order to use a strict criterion for identifying possible undiagnosed concussion. We feel a strict criterion increases the sensitivity and specificity of RCI in detecting potential undiagnosed concussion. It is possible that the burden of undiagnosed concussion is even larger that this study reports, and including a broader definition for undiagnosed concussion, such as 80% RCI, may have identified more potential cases; however, we feel that a broader definition would also have resulted in an increased number of false-positive cases. Nevertheless, it is important to note that the prevalence of undiagnosed concussion may vary based on the definition of a used.

Recently there has been a surge in concussion research that has shed light on the potential detrimental effects of sports concussion. Consequently, we have gained a better understanding of the epidemiology of sports concussion, and more emphasis has been placed on early identification and treatment of sports concussions. The International Consensus Conferences on Concussion in Sport has been convening since 2001 to

examine sports-related concussion identification and management issues and provide consensus statements regarding appropriate evaluation, diagnosis, and management of these injuries (22). In the 2012 consensus statement, the committee noted the importance of obtaining an accurate concussion history during preparticipation examinations (22). At the same time, the committee recognized that concussion injuries often go unrecognized or unreported (22). Accordingly, the ability to recognize cognitive declines between initial baseline neuropsychological test and retest that may indicate undiagnosed concussion provides examiners another tool for recognizing and understanding an athlete's risk for future injury. With increased recognition comes the benefit of potential educational opportunities as well as potential for modifying participation to maximize protection for the athlete.

There are several strengths to this study. To our knowledge, this study is the first to attempt to identify the prevalence of undiagnosed concussion among adolescent athletes. While the hypothesis exists that the true prevalence of concussion is larger than that which is currently reported in the literature, this is the first study to attempt to quantify the burden of undiagnosed concussion. The use of RCI provides a statistical tool for analyzing the burden of undiagnosed concussion. RCI is currently used in determining recovery after a concussion, which supports the use of RCI for the purposes of this study. In addition, this is a relatively large cohort of adolescent athletes who underwent two baseline ImPACT tests in the absence of clinically detected or reported concussion. The sample was identified from the ImPACT database of a large healthcare system and represents a diverse population, lending to the external validity of the study. In addition, the study included five different high-risk sports.

On the other hand, there are also limitations to this study, including those previously discussed. An additional limitation is the lack of data on other sports, including noncontact sports. We hypothesize that the risk for undiagnosed concussion follows a similar pattern as the reported incidence rates for concussion; however, we were unable to fully test this hypothesis due to lack of data on other sports. Nevertheless, the trend that was observed in this study supports our assumption that clinically significant decline in test score may represent undiagnosed concussion. Another limitation is that we defined undiagnosed concussion as score decline greater than 95% RCI from test to retest on at least one composite score or symptom scale. It is unclear whether declines on certain composite scores and/or the symptom scale may be more accurate in identifying potential undiagnosed concussion, or if declines on multiple composite scores and/or symptom scale may be more precise in identifying potential undiagnosed concussion. Again, the prevalence of undiagnosed concussion is likely to vary based on the definition used for undiagnosed concussion. More research is necessary to understand the true burden of undiagnosed concussion. The limitation of only two testing periods also exists in our study. Given that the average time to recovery from the effects of concussion is 10 days (22), it is likely that more athletes sustained an undiagnosed concussion that resulted in neurocognitive declines after the initial baseline test, but recovered prior to the retest. Assuming this possibility, the risk of undiagnosed concussion could be even greater than we report. Along these same lines, another limitation of the study is the cross-sectional nature of the test points. It is impossible to determine whether those athletes who had an undiagnosed concussion had neurocognitive declines that improved over time following the retest, or if the neurocognitive declines

persisted over time. Finally, recently there have been considerations for effort in testing. It is possible that as athletes become more aware of baseline testing for concussion, they are influenced by a desire to continue playing and purposefully perform lower ("sandbag") on the baseline ImPACT as a result. While we would not expect a decline from initial baseline to retest due to this purposeful "sandbagging", there is a possibility that the baseline ImPACT test is not valid in some cases. More research is necessary to answer these important questions.

SIGNIFICANCE

An understanding of the risk for potential undiagnosed concussion will allow for identification of adolescent athletes who are at risk for such injuries, which can drive targeted education and improve concussion screening. In addition, this knowledge can guide future injury prevention activities and recommendations for improving safety in both boys' and girls' athletics.

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Table 1. Rates of Clinically Meaningful Change Using 95% Reliable Change Index (RCI) (N=290)

Variable	Δ95%RCI[a]	Improve	Decline	Total
Verbal Memory	19	8.3%	2.8%	11.1%
Visual Memory	25	5.5%	4.8%	10.3%
Motor Speed	9.5	8.6%	0.7%	9.3%
Reaction Time	.13	8.6%	6.9%	15.5%
Symptom Scale	18	3.8%	3.1%	6.9%

[a]Absolute point change required for reliable change at 95% based on Elbin et al (8)

Table 2. Prevalence and Risk Ratio Results for Undiagnosed Concussion (Reference=Football) (N=270)

Sport	N	Undiagnosed Concussion	RR	95% CI
Football	126	25 (19.8%)	Ref.	Ref.
Boys Lacrosse	62	3 (4.8%)	0.71	(0.59, 0.85)
Boys Soccer	38	2 (5.3%)	0.79	(0.67, 0.92)
Girls Soccer	36	4 (11.1%)	0.87	(0.73, 1.05)
Wrestling	8	2 (25.0%)	1.02	(0.89, 1.15)

Table 3. Comparison of Outcome Groups on Potential Biasing Variables for ImPACT Test Scores (N=290)

Variable	Outcome[a]		No Outcome[a]		p-value
	N	mean (std)	N	mean (std)	
Time Between Tests (years)	42	1.30 (0.43)	248	1.38 (0.47)	p=0.295
Age at Test 1 (years)	42	15.3 (0.84)	248	15.4 (0.95)	p=0.493
Hours of Sleep at Test 1	14	8.54 (1.31)	133	8.03 (1.40)	p=0.195
Hours of Sleep at Test 2	14	7.75 (1.31)	133	7.88 (1.68)	p=0.780
Change in Hours of Sleep (Test 1-Test 2)	14	0.79 (1.96)	133	0.15 (2.04)	p=0.266
Years Active in Sport at Test 1	42	1.95 (2.67)	240	1.57 (2.24)	p=0.324

[a]The outcome was undiagnosed concussion, defined as decline in test score from test to retest that was greater than the absolute value change required for 95%RCI