Convergence Insufficiency Identifies Athletes at Risk of Prolonged Recovery From Sport-Related Concussion

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Background: Sensitive and specific screening methods are needed to identify athletes at risk of prolonged recovery after sport-related concussion (SRC). Convergence insufficiency (CI) is a common finding in concussed athletes.

Purpose: To assess the relationship between CI and recovery after SRC at the initial office visit.

Study Design: Case-control study; Level of evidence, 3.

Methods: In this retrospective cohort study, 270 athletes (147 male, 123 female), mean ± SD age 14.7 ± 2.0 years (range, 10-21 years), with the diagnosis of SRC who presented for initial office visit between January 2014 and January 2016 were evaluated for near point of convergence (NPC). The athletes were categorized into 2 groups: normal near point of convergence (NPC ≤6 cm), and convergence insufficiency (NPC >6 cm). These athletes were then followed to determine recovery time.

Results: Athletes presented for initial office visit at a mean of 5.2 ± 4.2 days (range, 1-21 days) after SRC. Half of the athletes had CI after SRC (50.4%; n = 136). Athletes with CI (NPC 12.3 ± 4.7 cm) took significantly longer to recover after SRC, requiring 51.6 ± 53.9 days, compared with athletes with normal NPC (4.1 ± 1.3 cm), who required 19.2 ± 14.7 days ($P < .001$). After controlling for potential confounding variables, CI significantly increased the odds of prolonged recovery (≥28 days from injury) by 12.3-fold ($P < .001$; 95% confidence interval, 6.6-23.0). CI screening correctly classified 75.2% of our sample with 84.2% sensitivity and 70.0% specificity. The positive predictive value for CI and prolonged recovery was 62.5%, and the negative predictive value was 88.1%.

Conclusion: CI at the initial office visit identified athletes at increased risk of prolonged recovery after SCR. Clinicians should consider measuring NPC in concussed athletes as a quick and inexpensive prognostic screening method.

Keywords: head injuries/concussion; eye injuries; clinical assessment/grading scales; pediatric sports medicine

Concussion, a form of mild traumatic brain injury (TBI), continues to gain recognition as a growing public health concern.[32] An estimated 1.4 to 3.8 million sport-related concussions (SRCs) occur annually in the United States, with as many as 50% going unreported.[15,18] Concussions, while not inherently life threatening, have been associated with significant long-term sequelae.[18,24]

Postconcussion syndrome (PCS), defined as prolonged symptoms after concussion beyond the generally accepted time frame for recovery,[21] is a common phenomenon.[2,5,9,11,13,20,23] Although the time frame to define standard recovery from concussion has not been scientifically established, many researchers have used 4 or more weeks of concussion-related symptoms in athletes to define PCS.[8,11,27] A recent study of 247 athletes age 5 to 18 years found that 73% of athletes were symptomatic at 4 weeks after SRC.[8] Previous research has identified risk factors for prolonged recovery after SRC, including female sex, younger age, prior history of concussion, mood disorders, learning disabilities, attention-deficit disorder/attention-deficit hyperactivity disorder (ADD/ADHD), and migraine headaches.[2,4,5,9,11,13,19,23] While these variables are predetermined, further studies are needed to identify modifiable factors associated with prolonged recovery from SRC.

With approximately 50% of the brain circuitry related to vision, it is not surprising that an increasing amount of literature has shown an association between concussion and

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eye movement.[32,34] The link between oculomotor function and concussion is deeply rooted in pathophysiological processes, as eye movement requires sophisticated interplay between both cortical and subcortical structures in the brain.[32,35] Among people with concussion, an estimated 50% to 90% will show symptoms related to visual complications, such as blurred vision and diplopia. These symptoms may result in impaired academic and occupational performance, decreased quality of life, and delayed recovery by decreasing the effectiveness of cognitive rehabilitation.[33]

Near point of convergence (NPC) is the distance nearest the eye at which an object will be clearly focused. Convergence insufficiency (CI), as measured by an abnormal NPC, is a common ocular complication after SRC.[7,22,26] Reports estimate that CI occurs in 47% to 64% of people with concussion and only 5% of the general population.[7,26,29,35] As CI represents abnormal oculomotor function, it comes as no surprise that many of the signs and symptoms of concussion are the same as CI, including double vision, eyestrain, headaches, blurred vision, and difficulty reading.[7,32,35] Recent research has shown that CI testing, when included as part of a comprehensive vestibular and oculomotor impairment screen, is a consistent and sensitive method to identify patients with concussions; the authors reported that CI increased the likelihood of correctly identifying athletes with concussions by 38%.[25]

Currently, most clinical tests do not appear to have useful predictive values for determining an athlete's risk for developing prolonged postconcussion symptoms.[3] With a growing body of evidence regarding diagnosis and sequelae of concussions, there is a need for more accurate and informative testing to better appreciate short-term prognosis and the likely time of recovery after initial incident. Once athletes at increased risk of prolonged recovery are identified, clinicians could implement therapies in a more efficient manner, modify academic and/or occupational accommodations, and provide appropriate anticipatory guidance. If prolonged recovery is anticipated, the athlete could benefit by making more informed decisions regarding future academic, occupational, sporting, and other general life events.

Testing for NPC and diagnosing CI can be done affordably without clinical expertise or expensive equipment in the outpatient setting.[26] To our knowledge, no studies have evaluated the association between CI and risk of prolonged recovery after SRC. The purpose of this study is to determine the prognostic value of CI screening in athletes with SRC.

METHODS

Participants

We conducted a retrospective cohort study of 270 athletes (147 male, 123 female), 10 to 21 years of age (mean ± SD, 14.6 ± 2.0 years), seen at a sports medicine office for initial evaluation of SRC within 21 days of injury from January 2014 to January 2016. Diagnosis of SRC was made by 2 sports medicine physicians with extensive training in concussion management within the same clinic. To standardize our findings, we defined *concussion* using the Consensus Statement on Concussion in Sport from the 4th International Conference on Concussion in Sport[24]: a complex pathophysiological process affecting the brain, induced by biomechanical forces that may present with a range of domains including clinical symptoms, physical signs, cognitive impairment, neurobehavioral features, and sleep disturbance. The sports medicine physicians used the validated 22-item symptom checklist from the Sideline Concussion Assessment Tool 3 (SCAT3),[24] as well as patient history and physical examination involving cognitive, neurological, musculoskeletal, vestibular, and ocular assessment, including NPC, to aid in diagnosing concussion. Clinicians evaluated all participants, with the mechanism of injury clearly defined, and recorded the sport in which each participated. An a priori sample size of 186 participants was calculated to obtain a minimum power of 80% to detect a statistically significant difference between groups.[28] Participants were excluded if they were lost to follow-up or had any of the following preexisting conditions: strabismus, amblyopia, ocular surgery, intracranial hemorrhage, neurologic or ocular surgery, vestibular disorder, substance abuse, migraine headache, learning disability (including ADD/ADHD), psychiatric or mood disorder (not including depression and anxiety), and NPC greater than 15 cm at time of recovery measured in the office following SRC.

Measurement

Convergence was defined as the simultaneous adduction of the eyes to maintain binocular fusion (the coordination of separate images of the same object in both eyes into one image) on near targets.[36] NPC was defined as the point to which the lines of sight are directed when convergence is at its maximum.[7] NPC can be assessed by moving a target toward the bridge of the patient's nose and measuring the distance at which the patient can no longer maintain fusion or the distance at which a patient develops exophoria (eye deviation outward from the midline).[36]

To obtain NPC in our study, we used methods described by Ellis et al,[12] which were shown to be reliable to detect CI in athletes after SRC. Participants were asked whether they required glasses or contact lenses and were tested in their best corrected vision. The patient fixated both eyes on the physician's finger while the finger was slowly moved toward the patient at a rate of 3 to 5 cm/s. The physician's finger was stopped when the patient reported blurred or double vision or the physician observed exophoria. Consistent with previous studies, the physician then measured NPC in centimeters from the bridge of the participant's nose to the physician's finger.[1,14]

Convergence insufficiency was defined as a binocular vision disorder characterized by exophoria greater at near than at distance, a remote NPC, and a decreased positive fusional convergence at near vision.[6] As in previous literature, we classified CI as an NPC measurement greater than 6 cm, while normal NPC was defined as 6 cm or less.[8,12,16,22] These values were obtained from age-related normative values reported in the literature for children and adolescents.[16]

Interrater reliability for the 2 physicians was assessed by use of measurements from 20 volunteers without SRC. Informed consent was obtained from each participant. NPC was measured independently by each of the 2 physicians. Measurements for 9 of these 20 participants (45%) were the same between physicians, while measurements for 17 of 20 (85%) were within 1 cm between physicians. Interrater reliability was tested using a kappa statistic. The kappa statistic for NPC was 0.32 ($P < .001$) indicating fair agreement.[37]

Procedures

All participants completed the SCAT3 symptom checklist at the initial office visit.[24] The sports medicine physicians performed a detailed history and physical examination, including NPC measurements at initial office visit and subsequent weekly office visits to determine recovery. Recovery was defined as the time interval from date of injury to the date the physician cleared the athlete to begin the return to play (RTP) protocol, which was overseen by the respective school's certified athletic trainer (ATC) as outlined in the Consensus Statement on Concussion in Sport.[24] Athletes were required to meet the following criteria to be cleared to start the RTP protocol: symptom free (assessed by history and SCAT3 symptom checklist),[24] normal physical examination, returned to school for full days with no restrictions, and neurocognitive test results returned to baseline, if available. The physician was contacted by the ATC if the athlete developed any symptoms and/or was not able to complete the protocol. The athlete was then reevaluated in the office. If the athlete chose not to return to sport, he or she was required to meet all aforementioned criteria to determine clearance.

Prolonged recovery was defined as 28 days or more to recovery, while standard recovery was defined as fewer than 28 days to recovery.[8,11,27] All procedures were administered individually in clinical examination rooms by the 2 sports medicine physicians. This study was approved by the institutional review board.

Statistical Analysis

Recovery and SCAT3 values (continuous variables) were compared across normal NPC and CI groups by use of unpaired Student t test. Logistic regression was used to compute adjusted and unadjusted odds ratios to estimate the association between measures of prolonged recovery and convergence insufficiency. Adjusted odds ratios controlled for age (continuous), sex (binary), previous concussion (binary), and participation in a collision sport (football, men's lacrosse, ice hockey), contact sport (basketball, soccer, wrestling, women's lacrosse, field hockey), limited contact sport (baseball, softball, tennis, volleyball), or noncontact sport (swimming, track and field, and cross-country) (binary). Stata's "rocfit" and "estat classification" syntax was used to assess the testing characteristics of convergence insufficiency in predicting prolonged recovery. We used a level of statistical significance set at $\alpha = .05$, recognizing that tests of statistical significance are approximations that serve as aids to interpretation and inference. Intercooled Stata statistical software was used for the analysis (Release 11; StataCorp LP).

RESULTS

A total of 270 athletes (147 male, 123 female) were included in our analysis, with a mean ± SD age of 14.7 ± 2.0 years (range, 10-21 years). Athletes presented for initial office visit a mean 5.2 ± 4.2 days (range, 1-21 days) after SRC. Mean total number of visits per participant was 5.1 ± 3.4.

Our sample was divided into 2 groups: athletes with normal NPC (≤6 cm) and those with CI (NPC >6 cm). Athletes with CI presented for initial office visit a mean 1.2 days later and complained of more symptoms and increased total symptom severity on SCAT3 compared with those with normal NPC. Groups were similar in age, sex, history of concussion, and type of sport played (collision, contact, limited contact, and noncontact). Athlete demographics are shown in Table 1.

At the initial office visit, 136 athletes (50.4%) had CI and 134 (49.6%) had normal NPC. Athletes with CI (mean NPC 12.3 ± 4.7 cm) took significantly longer to recover from SRC, with a mean of 51.6 ± 53.9 days, compared with athletes with normal NPC (mean NPC 4.1 ± 1.3 cm), who required 19.2 ± 14.7 days ($P < .001$), as shown in Table 2.

Logistic regression analysis demonstrated that CI significantly increased the odds of prolonged recovery by 12.3-fold ($P < .001$; 95% confidence interval, 6.6-23.0) after adjustment for the following potential confounding variables: age, sex, previous concussion, and type of sport played.

CI screening at initial office visit correctly classified 75.2% of our sample with 84.2% sensitivity and 70.0% specificity based on a CI cutoff measurement of 6 cm. The positive predictive value for CI and prolonged recovery was 62.5%, and the negative predictive value was 88.1%.

DISCUSSION

Our findings indicate that detecting CI at the initial office visit was useful in identifying athletes at increased risk of prolonged recovery after SRC. Logistic regression analysis demonstrated that individuals with CI at presentation had a 12.3 times increased odds of prolonged recovery, requiring a mean of 51.6 days to recover, as opposed to individuals with normal NPC, who required a mean of 19.2 days to recover. To our knowledge, this was the first study to evaluate NPC measurement as a prognostic screening method in athletes after SRC.

The results observed are consistent with current literature highlighting the importance of oculomotor function in concussion. This connection is increasingly recognized as more refined eye examinations are being linked to the diagnosis of concussion. One such examination that is gaining use is the King-Devick (KD) test, an objective examination that uses eye movement to diagnose concussion with a sensitivity

TABLE 1
Athlete Demographics[a]

	Normal NPC (n = 134)	CI (n = 136)	*P* Value
Age, y, mean ± SD	14.9 ± 2.0	14.4 ± 2.0	.41
Days to initial evaluation, mean ± SD	4.6 ± 3.3	5.8 ± 4.9	.015
Female, n (%)	60 (44.8)	63 (46.3)	.65
Previous concussion, n (%)	29 (21.6)	32 (23.5)	.71
SCAT3 number of symptoms, mean ± SD	7.8 ± 3.3	15.1 ± 4.2	<.001
SCAT3 total symptom severity, mean ± SD	14.5 ± 4.6	43.1 ± 9.5	<.001
Type of sport played, n (%)			
Collision	43 (32)	42 (31)	.63
Contact	74 (55)	77 (57)	.63
Limited contact	12 (9.0)	14 (10)	.71
Noncontact	5 (4.0)	3 (2.0)	.46

[a]CI, convergence insufficiency; NPC, near point of convergence; SCAT3, Sideline Concussion Assessment Tool 3.

TABLE 2
Outcome Measures[a]

	Normal NPC (n = 134)	CI (n = 136)	*P* Value
Recovery, d, mean ± SD	19.2 ± 14.7	51.8 ± 53.9	<.001
NPC at initial office visit, cm, mean ± SD	4.1 ± 1.3	12.3 ± 4.7	<.001
Prolonged recovery (>28 days), n (%)	16 (11.9)	85 (62.5)	<.001

[a]CI, convergence insufficiency; NPC, near point of convergence.

and specificity of 86% and 90%, respectively.[35] Although affordable, KD testing requires a baseline examination for reliability, access to the testing material, and approximately 2 minutes to complete.

The Vestibular/Ocular Motor Screening (VOMS) assessment is another recently developed screening tool that uses NPC in addition to other visual testing such as smooth pursuits, saccades, vestibulo-ocular reflex (VOR), and visual motion sensitivity (VMS) to evaluate patients after SRC.[17] Mucha et al[25] found that VOMS was sensitive in identifying patients with concussion and that it demonstrated internal consistency. The authors noted that their study highlights the importance of the oculomotor components of VOMS—most importantly, NPC measurement.[25] Further research is needed to determine whether the KD test and VOMS assessment have prognostic value in determining recovery time.

Our findings suggest that NPC screening is comparable with computer-based ImPACT (Immediate Post-concussion Assessment and Cognitive Testing) scores to predict protracted recovery after SRC. Lau et al[19] examined 109 male high school football players with SRC to show that ImPACT neurocognitive scores (verbal memory, visual memory, reaction time, and processing speed) within 2.23 days of injury identified athletes at risk of prolonged recovery with a sensitivity of 53.2%; specificity, 75.4%; positive predictive value, 64.1%; and negative predictive value, 66.2%. We found that CI screening identified athletes at risk of prolonged recovery with a sensitivity of 84.2%; specificity, 70.0%; positive predictive value, 62.5%; and negative predictive value, 88.1%.

Current commonly used concussion assessment tools, such as the SAC (Standardized Assessment of Concussion), ImPACT, and BESS (Balance Error Scoring System), do not include an ocular screening component.[24] With approximately half of the brain circuitry related to vision, and 50% to 90% of concussed patients reporting visual symptoms, our results confirm the importance of including visual screening when evaluating a concussion athlete.[32-34] We found that NPC screening correctly stratified more than 75% of athletes for standard and prolonged recovery times. Thus, we suggest that NPC screening should be included as part of a thorough examination of a concussed athlete.

Strengths and Limitations

This study is unique in that it provides a practical, cost-efficient method for screening athletes for prolonged recovery after SRC. NPC testing takes seconds to conduct, can be adequately performed without specialized training, and provides a wealth of information that can be used for both prognostic significance and guidance of future treatment. Additionally, NPC testing can be used without a baseline examination for the athlete.

This study had several limitations. First was standardization of NPC measurements. At this time, no consensus exists as to the optimal method to measure NPC.[7] Our study used methods for NPC measurement reported by Ellis et al.[12] We attempted to minimize variance in measurements by using only 2 sports medicine physicians with extensive training in concussion management. A kappa statistic was used to determine interrater reliability

and showed fair agreement.[37] Physicians used their index fingers moving at a rate of 3 to 5 cm/s to obtain NPC measurements, while other studies used pens or other objects. Of importance, previous literature suggests no difference in NPC measurement with different types of targets.[31] Further studies would be beneficial to show whether slowing the speed of finger movement and using a standardized measurement tool would lead to more accurate NPC measurements.

Second, our findings are limited to athletes without preexisting vestibulo-ocular disorders. CI has been reported to occur in 5% of the population at baseline. Other possible causes of CI include wide interpupillary distance, toxemia, anxiety neurosis, poorly developed accommodation or convergence, presbyopia, and endocrine disorders.[10] We attempted to control for baseline CI by excluding individuals with NPC measurement of greater than 15 cm at time of recovery. Further studies are needed to determine whether baseline CI affects recovery from SRC.

Third, the potential for observer bias exists. Physicians performing NPC measurements at initial office visit were not blinded to history (including SCAT3 data) and other physical examination elements. However, physicians were blinded to the main outcome measured—recovery time.

Fourth, we assumed that symptoms reported by the patients were accurate. This applies to both concussive symptoms and ocular symptoms during NPC testing.

Future Directions

The practicality of NPC testing in an outpatient setting cannot be understated and should support future studies in this field. The significant evidence linking mild TBI and oculomotor function has led to a stronger push not only for outpatient ocular testing but also for prescreening of athletes to obtain baseline results.[17] Clinicians could potentially use baseline NPC values for athletes who sustain SRC as part of a comprehensive evaluation to determine recovery. Further studies should be aimed at evaluating the significance of returning to baseline NPC after SRC as an indicator for recovery. These findings could be compared with commonly used tools for concussion assessment, such as ImPACT and KD testing.

Referral for vestibulo-ocular therapy may be beneficial for athletes with CI after SRC. Previous studies in children and adolescents with baseline symptomatic CI have shown that vestibulo-ocular rehabilitation improved NPC from a mean of 13.7 cm to 4.5 cm ($P < .001$) and improved symptoms significantly.[30] Further studies are needed to examine the role of vestibulo-ocular rehabilitation and recovery in athletes with CI after concussion.

CONCLUSION

Convergence insufficiency at the initial office visit was useful in identifying athletes at increased risk of prolonged recovery after SRC. Clinicians should consider measuring NPC in athletes with SRC as a quick and inexpensive prognostic screening method. These findings may help clinicians to provide appropriate anticipatory guidance, tailor academic and/or occupational accommodations, and promote treatment recommendations such as referral for vestibulo-ocular therapy for athletes with CI.

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