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Incidence of Remote Near-Point of Convergence in University Athletes After Sport-Related Concussion

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Abstract

Objective: Near-point of convergence (NPC) testing is an attractive screening tool in the sport setting because it is rapid, requires few resources, and is easy to administer. Remote NPC has been reported after sport-related concussion (SRC), although the incidence among a university-aged population is not well defined. The purpose of the study was to examine the incidence of remote NPC after SRC in a cohort of Canadian interuniversity athletes. **Design:** Cross-sequential. **Setting:** University. **Participants:** One hundred thirty-two university athletes [SRC, n = 68; musculoskeletal (MSK) injury, n = 64] were tested before the beginning of their competitive season and again after their injury. **Independent Variables:** Healthy athletes measured preseason were compared with athletes after SRC or MSK injury using both longitudinal and cross-sectional designs. **Main Outcome Measures:** Remote NPC (pass/fail), measured at 6 cm or greater, repeated 3 times. **Results:** After SRC, 22% of athletes failed their test postinjury (95% CI, 14%-33%). Comparatively, in the MSK group, 3% of athletes failed their test postinjury (95% CI, 1%-7%). A direct comparison of both injury groups yielded a mean 19% higher prevalence of failed NPC tests after SRC versus MSK injury (95% CI, 10%-30%). There seems to be no relationship between reported symptom burden and NPC performance after SRC. **Conclusion:** Remote NPC occurs in approximately 1 of 5 athletes after SRC and is rarely observed after MSK injury.

Key Words: sport-related concussion, near point convergence, Bayesian modeling, mild traumatic brain injury, musculoskeletal injury

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INTRODUCTION

Visual disturbances are a common occurrence after sport-related concussion (SRC). Approximately 50% to 80% of individuals with concussion experience at least one symptom of visual impairment or disruption to their oculomotor function after injury.[1–3] The visual system comprises various structures such as the retina, hypothalamus, midbrain, cerebral cortex, and pons, along with various nerves, tracts, and pathways; it is believed that at least 40% of the brain's pathways are directly involved in vision.[3–6] The stress and strain from concussive impact and the consequent neurometabolic alterations may disrupt different areas of the visual system, potentially manifesting as abnormalities in convergence, accommodation, and saccadic eye movements.[7,8] As a result, individuals with SRC may experience symptoms related to visual impairment including blurred vision, sensitivity to light, headache, and dizziness.[3,5,9]

Numerous tests have been used to identify visual abnormalities after concussion, including the Vestibular/Ocular Motor Screen,[10] King-Devick Test,[11,12] and near point of convergence (NPC).[13–15] Of these, NPC is particularly attractive because it requires few resources and is easy to administer. NPC is a test that examines the ability of both eyes, while turned inwards, to fixate on a moving object brought toward the individual. Remote NPC may indicate vergence or accommodative-related deficits of consequence; affected individuals may have trouble in daily activities such as reading, writing, and focusing.[14,16]

Prior studies have found large variability in the incidence of athletes with remote NPC after concussion, ranging from 26% to 55%.[13–15,17,18] However, these studies were primarily conducted in adolescent populations ranging from 8 to 18 years old; in studies looking at older individuals such as a university-aged population, the incidence was not quantitated and thus remains unknown.[10,19] Furthermore, as athletes are at risk for both concussion and musculoskeletal (MSK) injuries, allowing for comparison between injury types is an effective methodological approach to evaluate the relative contribution of brain versus general injury effects, accounting for similar factors between injury groups such as psychosocial reactions, pain, and removal from play.[20,21] One would expect to see more NPC effects in the former due to anatomical vulnerability to one or more pathways and networks

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contributing to the visual system after rapid head acceleration/deceleration.

Therefore, the purpose of the study was to examine the incidence of remote NPC (6 cm or greater when repeated 3 times) after SRC in a cohort of Canadian interuniversity athletes. We hypothesized that the incidence of remote NPC would be higher in athletes after SRC compared to athletes after MSK injuries.

METHODS

Participants

Participant enrollment occurred between August 2013 and April 2019 as part of a multiyear study conducted at an academic institution. One hundred and thirty-two athletes across 10 sports participated in the study. Sixty-eight athletes with a SRC and 64 athletes with a MSK injury were tested before the beginning of their competitive season and again after their injury (median = 4 days, interquartile range = 3-6 days). Sport-related concussion diagnosis was made by a sports medicine physician in accordance with the Concussion in Sport Guidelines (CISG).[8] The decision to medically clear an athlete from SRC was also made by a physician in alignment with the CISG guidelines.[8] Musculoskeletal injury was defined as an injury to the structure and/or function of the MSK system requiring an athlete to abstain from all sport participation for a minimum of seven days, as assessed by a sports medicine physician. The same physician making the diagnosis made the medical clearance decision based on restoration of function to the injured area, psychological readiness, and risk of reinjury.[22]

Near-Point of Convergence

To measure NPC, the participant was instructed to focus both eyes on a near-point target (ie, a pen tip) as the research member moved the target toward the participant's nose. The recorded endpoint consisted of any of the following criteria: the distance in centimeters at which point the participant reported seeing double, the point at which the research member observed an outward turn of one eye, or the point at which the participant could no longer tolerate the testing. Three serially repeated measures of NPC were performed, and the average of all trials was calculated; this approach has been recommended in previous literature.[23] The calculated average was used as the NPC value for the participant when performing data analysis.

Symptoms

Participant symptom burden was evaluated by the 22-item Postconcussion Symptom Scale as part of the Sport Concussion Assessment Tool–Fifth Edition.[24] Participants were asked to rate each symptom on a 7-point Likert scale from which a summative symptom severity score was calculated by aggregating the rated score for each symptom. In addition, four categories of symptom clusters were created through summation.[25–27] The clusters were termed "somatic" (headache, pressure in head, neck pain, nausea/vomiting, dizziness, blurred vision, balance problems, sensitivity to light, and sensitivity to noise), "cognitive" (feeling slowed down, feeling "in a fog", "do not feel right", difficulty concentrating, difficulty remembering, and confusion), "fatigue" (fatigue/low energy, drowsiness, and trouble falling asleep), and "emotion" (more emotional, irritability, sadness, and nervous/anxious).

Data Analysis

To understand whether an SRC can lead to acute decrements in vergence function, NPC test results were compared at preinjury and postinjury time points (within-group comparisons). In addition, to appreciate whether remote NPC is a unique feature of concussion as opposed to a common consequence of sports injury, a non-SRC comparison group was evaluated; NPC test results were compared in athletes pre-MSK and post-MSK injury. Then, to infer stability and generalizability of these results to the clinical community who may not have access to an athlete's historical test results, two between-group comparisons were conducted. First, NPC test results from athletes after SRC were compared with healthy preseason tests from athletes in the MSK group. Then, NPC test results were compared in athletes after MSK injury to the healthy preseason NPC test results from athletes in the SRC group. Finally, a set of exploratory analyses were conducted in athletes after SRC to understand whether the prediction of NPC test performance was influenced by the addition of demographic indices (sex and history of concussion) or symptom burden. Logistic models were used for both group comparisons and exploratory analysis. For details, including model form, prior choice (including prior predictive distributions), contrast creation, and model performance measures, please see the **Supplemental Digital Content 1** (see **Supplementary Methods**, http://links.lww.com/JSM/A357) and Supplementary Figures 1 and 2, **Supplemental Digital Content 3**, http://links.lww.com/JSM/A356).

All models were fit using the Hamiltonian Monte Carlo engine Stan[28] through R[29] and the RStudio Integrated Development Environment.[30] The R package "rethinking"[31] was used to interface between RStudio and RStan.[32] Plots were created using "ggplot2"[33] and "bayesplot"[34,35] packages, and tables were created using the "gt"[36] and "gtsummary"[37] packages.

RESULTS

Athlete Characteristics

Preinjury athlete characteristics in both the SRC and MSK groups can be seen in Table 1. Both groups of athletes were a median age of 20 years, with similar sex distributions (47% female SRC and 42% female MSK). More athletes in the SRC group reported having a history of multiple concussions compared with the MSK group (34% vs 19%).

Injury characteristics in both groups can be seen in Table 2. Unsurprisingly, symptom scores were higher in athletes after SRC compared with those after MSK injury. Athletes in the MSK group took approximately 10 more days to recovery and had a higher median time from their preinjury baseline test to their postinjury assessment compared with athletes in the SRC group (median 379 vs 126 days, respectively). Both groups

TABLE 1. Participant Characteristics

Characteristic	SRC, N = 68*	MSK, N = 64*
Age	20 (19-21)	20 (18-21)
Female sex	32 (47)	27 (42)
Concussion history		
None	30 (45)	35 (55)
One	14 (21)	17 (27)
Multiple	23 (34)	12 (19)
Sport		
Baseball	0 (0)	1 (1.6)
Basketball	4 (5.9)	3 (4.7)
Field hockey	1 (1.5)	3 (4.7)
Football	11 (16)	14 (22)
Ice hockey	12 (18)	17 (27)
Lacrosse	7 (10)	3 (4.7)
Rugby	17 (25)	12 (19)
Soccer	7 (10)	8 (12)
Volleyball	6 (8.8)	3 (4.7)
Water polo	3 (4.4)	0 (0)

** Median (IQR); n (%).*
IQR, interquartile range.

completed the test assessment at a median of 4 days from injury.

Modeled Incidence of NPC

Within-Group

In athletes with SRC who passed their preinjury NPC test, a mean of 22% failed their postinjury test (95% CI, 14%-33%). Comparatively, in the MSK group, a mean of 3% of athletes who passed their preinjury NPC test failed their test postinjury (95% CI, 1%-7%). A direct comparison of both injury groups yielded a mean 19% higher incidence of failed NPC tests after SRC versus MSK injury (95% CI, 10%-30%).

Between-Group

Regardless of preinjury test performance, 22% of all athletes failed their NPC test after SRC (95% CI, 14%-33%), which was 18% higher (95% CI, 8%-29%) than the percentage of healthy athletes who failed their preseason test (modelled mean = 5%, 95% CI, 1%-10%). Conversely, there was no meaningful difference in the percentage of athletes who failed their NPC test performance after

TABLE 2. Participant Injury Characteristics

Characteristic	SRC, N = 68*	MSK, N = 64*
NPC postinjury		
Fail	18 (26)	2 (3.1)
Pass	50 (74)	62 (97)
NPC pre–post		
Pass then pass	47 (69)	58 (91)
Fail then fail	1 (1.5)	0 (0)
Pass then fail	17 (25)	2 (3.1)
Fail then pass	3 (4.4)	4 (6.2)
Total symptoms	10 (4-15)	2 (1-5)
Symptom severity	15 (5-36)	3 (1-8)
Days to recovery	27 (16-64)	37 (16-57)
Days from baseline to injury	126 (30-409)	379 (113-720)
Days from injury to assessment	4 (3-5)	4 (3-6)

An NPC score of >6 cm was considered a failed test.
** n (%); median (IQR).*
IQR, interquartile range; NPC, near-point of convergence.

MSK injury (mean = 3%, 95% CI, 1%-7%) compared with the percentage of healthy athletes who failed their preseason test (mean 5%, 95% CI, 1%-10%).

Model Comparison

Results of a series of single-predictor logistic models tested for their out-of-sample performance in predicting a concussed athletes' probability of failing an NPC test can be found in Table 3. The intercept-only model was not improved by the addition of any individual predictor. The addition of history of concussion to the model (indexed as 1 = none, 2 = single concussion, and 3 = multiple concussions) yielded worse performance than the intercept-only model due to the incurred penalty for additional parameters (widely available information criterion difference = 9.1, 95% CI, 1.26-16.94). Hence, after SRC, knowing the sex of an athlete or their concussion history offered no additional predictive benefit of their NPC test performance. Furthermore, knowing the athlete's symptom burden, including distinct clusters (somatic, cognitive, emotion, and fatigue) or Likert scores of vision-related symptoms ("sensitivity to light" and "blurred vision"), offered no predictive benefit.

DISCUSSION

The primary aim of this study was to identify the incidence of athletes with remote NPC after SRC. Approximately 20% of athletes with SRC failed their postinjury NPC test, whereas NPC test performance was similar regardless of whether an athletes' preinjury NPC test performance was known or not; ~20% of athletes who passed their preinjury baseline NPC test failed their postinjury test. Furthermore, no additional predictive information for NPC performance was gained by knowing the participants' sex, concussion history, or symptom presentation.

The extent of remote NPC after SRC has varied greatly in the literature, ranging from 24% to 55%.[2,13–15,17] The variability of estimates likely reflects heterogeneity in both time from injury and in study samples, and the application of different cut points and/or NPC determination (ie, one trial vs three trial average). Importantly, our analytic approach included regularizing priors that likely produced a more conservative estimate of the incidence of remote NPC after SRC. Our results also suggest that knowledge of an athletes' preinjury NPC test results may not be necessary, as it is only expected that 1 of every 20 healthy athletes (~5%) will fail their test, in alignment with what has been previously reported for a general healthy population.[38] Indeed, after injury, within-group and between-group comparisons both show a ~20% increase in failed NPC tests. Thus, careful consideration of resources available for coordinating and conducting baseline NPC assessments, as well as clinical procedures for abnormal NPC at baseline (eg, referral for additional vision assessment) are required if preseason NPC assessments are to be conducted.

To the best of our knowledge, this is the first study to leverage a MSK injury comparison group to evaluate remote NPC in athletes after SRC. Although it is well documented that visual processes involve many structures in the brain including the cerebral cortex, cerebellum, and brain stem, a comparison group of athletes with MSK injuries allowed us to explore potential sources of poor NPC performance among athletic injuries in general (eg, pain, removal from play, and motivation). In both approaches (ie, pre–post or postinjury), we identified few athletes with MSK injury who failed their NPC test; the present findings are aligned with our hypothesis that remote NPC is specific to concussion.

Given numerous reports of differences between male and female athletes on preseason tests of oculomotor function, cognition, and balance,[39–41] as well as postinjury symptomology, cognitive performance, and dual task abilities,[42–44] for exploratory purposes, we sought to evaluate the relationship between remote NPC and sex after SRC. We found no differences between males and females on NPC performance postinjury; this is similar to our previous study of healthy athletes where no differences were found in NPC performance between sexes or in those with versus without a history of concussion.[39] We also explored the relationship between symptoms and NPC performance, and found that NPC offers an objective evaluation of oculomotor dysfunction, irrespective of the symptom status. There are mixed findings in the literature regarding the relationship between remote NPC and symptoms scores after concussion. Howell et al[13] did not identify significant differences in symptom scores between normal NPC and remote NPC groups; however, others have noted a relationship between symptoms and NPC performance after SRC.[14,45] Future research should continue to explore the relationships between symptoms and NPC performance, given the variability of symptoms postconcussion. For example, although it is promising that NPC evaluation seems to be unaffected by symptoms at the low-

TABLE 3. Out of Sample Model Comparisons

Predictor	WAIC	SE	Difference	Difference SE	Model Penalty
Intercept	78.1	9.5	NA	NA	1.1
Blurred vision	79.8	9.8	1.7	1.0	1.3
Sensitivity to light	79.8	9.8	1.7	0.9	1.3
Somatic	80.0	9.8	1.9	0.5	2.1
Symptom severity	80.5	9.9	2.4	0.9	2.0
Cognitive	80.5	9.9	2.4	0.9	2.0
Fatigue	80.9	10.0	2.8	1.8	1.9
Emotion	81.0	10.0	2.9	1.6	2.0
Sex	81.7	11.5	3.6	2.3	2.3
Concussion history	87.3	13.4	9.1	4.0	3.7

Single predictor models are ordered from best-to-worst performance.
SE, standard error; WAIC, widely available information criterion.

to-moderate levels, other symptom scales specific to visual function (eg Brain Injury Vision Symptom Survey[46]) may be better suited to explore potential relationships[47] among concussion, symptomology, and NPC performance.

The sensitivity and specificity of a single cut point in determining remote NPC is unclear, as both >5 and >6 cm values have been used in prior concussion studies.[48] Given this outstanding empirical question of identifying an optimal cut point, we adopted a more conservative >6 cm threshold aligned with a prior randomized clinical trial.[48] It is important to highlight that an abnormal NPC result is not diagnostic of convergence insufficiency specifically per se, and remote NPC results should thus be interpreted simply as "an eye teaming issue of some degree that requires further work-up by an appropriately qualified eye care professional". To this point, in a study on referred concussion patients who failed NPC screening, Raghuram et al[49] showed that of 83 referrals for "remote NPC", although 74 had a reduced NPC result, only 8% in fact met the definition of true convergence insufficiency; over 95% had saccadic or pursuit deficits, and 41% had significant accommodative disorders diagnosed after formal examination. This lends credence to our overall conclusion that NPC be treated as a screening test and not a diagnosis of convergence insufficiency. If an NPC test is failed, consideration of a more detailed evaluation of the athlete by an appropriately trained and regulated eye care professional (ie, optometry or ophthalmology) appears justified.

The results of our study must be considered within the context of its limitations. Multiple research members completed the NPC measurements with our participants. Although all research members were properly trained using the same technique, we are unable to account for possible issues with inter-rater reliability. In addition, the participants in this study were interuniversity athletes with a median age of 20 years old in both the MSK and SRC groups. As such, our results may not generalize to younger, older, or nonathlete populations.

CONCLUSIONS

Remote NPC occurs in approximately 1 of 5 athletes after SRC and is rarely observed after MSK injury. NPC offers a rapid and low resource means to screen for an important visual function, and performance does not appear to be greatly influenced by sex, prior concussions, or symptom status. This potentially useful clinical information can be implemented to prompt a more thorough investigation of the visual and vergence system by a qualified eye care professional, leading to appropriate, personalized rehabilitation strategies.

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