Postconcussion: Receded Near Point of Convergence is not Diagnostic of Convergence Insufficiency

APARNA RAGHURAM, SUSAN A. COTTER, SOWJANYA GOWRISANKARAN, JAMEEL KANJI, DAVID R. HOWELL, WILLIAM P. MEEHAN III, AND ANKOOR S. SHAH

• PURPOSE: To determine the frequency of occurrence of receded near point of convergence (NPC) in patients with chronic concussion-related symptoms and in those with receded NPC to enumerate the frequency of convergence insufficiency and other oculomotor disorders.

• DESIGN: Retrospective cross-sectional study.

• METHODS: Clinic charts were retrospectively reviewed for the prior 3.5 years to identify all patients < 21 years old who were > 28 days postconcussion, had chronic concussion-related symptoms, had normal visual acuity, and had received a comprehensive sensorimotor examination. The frequency of receded NPC and oculomotor diagnoses were determined.

• RESULTS: Of the 83 eligible patients, 74 (89%) had receded NPC. Of these, 70 (95%) had oculomotor disorders; 30 (41%) had disorders of accommodation only; 21 (28%) had convergence insufficiency and accommodation deficits; and 6 (8%) had convergence insufficiency only. Six (8%) had a convergence deficit other than convergence insufficiency (all with concurrent accommodative disorders); 4 (5%) had both a nonspecific vergence dysfunction and accommodation deficits; 2 (3%) had convergence excess only; and 1 (1%) had both convergence excess and accommodative deficits.

• CONCLUSION: A receded NPC was present in the majority of young patients with chronic postconcussion symptoms. Associated with numerous underlying oculomotor dysfunctions, the clinical finding of a receded NPC is not synonymous with the diagnosis of convergence insufficiency. Because treatment options for the various oculomotor dysfunctions differ, it is prudent that these patients undergo a thorough examination of their vergence and accommodative systems so that an accurate diagnosis can be made and appropriate treatment prescribed. (Am J Ophthalmol 2019;206:235–244.

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From the Department of Ophthalmology, Boston Children's Hospital, Boston, MA (A.R., S.G., A.S.S.); Department of Ophthalmology, Harvard Medical School, Boston, MA (A.R., A.S.S.); Southern California College of Optometry, Marshall B. Ketchum University, Fullerton, CA (S.A.C.); New England College of Optometry, Boston, MA (J.K.); The Micheli Center for Sports Injury Prevention, Waltham, MA (D.R.H., W.P.M.); Division of Sports Medicine, Department of Orthopedics, Boston Children's Hospital, Boston, MA (D.R.H., W.P.M.); Brain Injury Center, Boston Children's Hospital, Boston, MA (D.R.H., W.P.M.); Department of Orthopedic Surgery, Harvard Medical School, Boston, MA (W.P.M.); Department of Pediatrics, Harvard Medical School, Boston, MA (W.P.M.); Department of Ophthalmology, Massachusetts Eye and Ear, Boston, MA (A.S.S.), USA.

Inquiries to Aparna Raghuram, Department of Ophthalmology, Boston Children's Hospital, 300 Longwood Ave, Boston, MA 02115, USA; e-mail: aparna.raghuram@childrens.harvard.edu

CONCUSSION, THE MOST COMMON TYPE OF TRAUMATIC brain injury (TBI), is a form of mild TBI (mTBI) that is caused by a closed head injury. A conservative estimate of sports-related TBIs alone is 3.8 million annually in the USA,[1] with many more that are probably unrecognized or unreported.[1–3] Although most patients who suffer concussions recover over the course of a few weeks, some have significant long-term cognitive, physical and/or emotional sequelae that persist for months or years.[3]

There has been increased interest in identifying simple and rapid tests to diagnose deficits related to concussion, including those affecting visual function.[4,5] A clinical measure of visual function that has received considerable attention in the evaluation of sports-related concussion is the near point of convergence (NPC).[4,6–9] A measure of how close one can bring a small object to the nose while maintaining fusion (total convergence ability), NPC testing is easy to administer and to interpret. Generally, if the NPC measure is more than 5 to 7 cm distant from the center of the forehead or from the lateral canthus, it is considered receded (ie, abnormal).[10–12]

Of the 5 components of the Vestibular/Ocular Motor Screening[4,6,13,14] tool that is commonly used in sports-related concussion evaluations, a receded NPC has been identified postconcussion in some athletes.[9,15] There are reports of a 24% frequency in 5- to 18-year-olds after acute concussion in a selected population referred to a specialty clinic[9] and of at least a 49% (total not reported) of adolescents cared for in a comprehensive concussion program at a tertiary care hospital.[15] A receded NPC may also be associated with repetitive subconcussive head impacts in collegiate football players[16] and with worse neurocognitive impairment postconcussion.[8]

Although NPC testing has utility as a rapid screening tool for acute and subacute postconcussion symptoms,[4,8,9,16] the clinical finding of a receded NPC is not

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synonymous with the diagnosis of convergence insufficiency. Convergence insufficiency is a medical diagnosis for a specific oculomotor dysfunction. A diagnosis of convergence insufficiency is made based on a combination of clinical findings, most commonly described as an exophoria (a tendency for the eyes to drift apart) of larger magnitude at near-viewing distances than at far-viewing distances and accompanied by a receded NPC and/or decreased near convergence amplitudes (positive fusional vergence ranges).[17–19]

The objective of this study was to determine the frequency of occurrence of receded NPC in young patients with chronic concussion-related symptoms treated at a tertiary care hospital and to determine the frequency of convergence insufficiency and other oculomotor dysfunctions in those with receded NPC.

METHODS

• **STUDY DESIGN:** Retrospective cross-sectional study.

• **PATIENT SELECTION:** We conducted a retrospective chart review of patients with diagnoses of concussion who underwent comprehensive sensorimotor evaluations conducted by the first author (AR) in the Multidisciplinary Concussion Clinic between July 2014 and January 2016 or in the Pediatric Ophthalmology Clinic between August 2012 and December 2015. The diagnosis of concussion was made by the treating neurologist or sports-medicine physician in accordance with the Berlin Consensus Statement on Concussion in Sport.[20] Patients < 21 years of age who had complete sensorimotor examination findings (see test procedures below) and best-corrected distance visual acuity of 20/25 or better in each eye and were examined > 28 days postconcussion were included. Patients with amblyopia, constant strabismus, history of vision therapy or orthoptics, malingering or conversion syndrome diagnosis by a board-certified psychologist, or ocular pathology were excluded. The Boston Children's Hospital Institutional Board Review approved the study under an exempt medical records review protocol.

• **TEST PROCEDURES:** The sensorimotor evaluation included measures of eye alignment and near stereoacuity and a comprehensive assessment of the vergence and accommodative systems (Figure 1).[21] The vergence measures were the NPC, near convergence and divergence amplitudes (positive and negative fusional vergence ranges) and near vergence facility. Accommodative testing was composed of accommodative amplitude and accommodative facility measures. All tests were done with best distance refractive correction in place (if needed for distance visual acuity of 20/25 or better).

• **VERGENCE TEST PROCEDURES:** *Near point of convergence*. Using a 20/50 letter target (Figure 1, A) placed 40-50 cm from the patient's eyes, the examiner slowly moved the target at a velocity of 1-2 cm/second[16,22] toward the patient's eyes. The patient was asked to report when the letter doubled or split into two, at which time the examiner stopped moving the target and measured the distance from the target to the patient's lateral canthus (representative of the center of rotation of the eyes) in centimeters.[12,23] The examiner then moved the target away from the patient until single vision was reported and similarly measured that distance. Patient report of fusion loss and recovery were confirmed by the examiner's observation of misalignment and realignment of the patient's eyes. When the examiner's objective assessment and the patient's subjective report differed, the test was repeated; if the measures still differed, the examiner's results were recorded.

Vergence Amplitudes (Fusional Vergence Ranges) at Near. Near convergence and divergence amplitudes (positive and negative fusional vergence ranges) were measured by a horizontal prism bar (1–40Δ) (Figure 1, B). For convergence amplitudes, the patient viewed a 20/50-sized single-letter target at 40 cm while the examiner slowly introduced increasing magnitudes of base-out prism after asking the patient to report when the target doubled or split into two; this was considered the endpoint and recorded as the "break." The prism was then reduced in magnitude, and the patient reported when the two images fused back into a single image; this was the "recovery" finding. Divergence amplitudes were measured similarly using base-in prism.

Vergence Facility. For vergence facility at near, the examiner used a hand-held vergence facility prism set (Figure 1, C), composed of a 3Δ base-in prism mounted on top of a 12Δ base-out prism (Gulden Ophthalmics, Elkins Park, Pennsylvania, USA). While the patient viewed a pen tip at approximately 40 cm, the examiner placed the base-in prism over the patient's right eye. The patient was instructed to try to fuse the two images into one as quickly as possible if two pen tips were noted and to report as soon as a single image was seen. When the pen tip was reported to be single, the examiner then quickly slid the vergence facility set upward so that the 12Δ base-out prism replaced the 3Δ base-in prism. The examiner counted the number of cycles (one cycle being the ability to fuse the image with base-in prism followed by the base-out prism) attained in one minute. The examiner recorded whether it was more difficult to fuse with one base orientation vs the other.

• **ACCOMMODATION TEST PROCEDURES:** *Amplitude of accommodation*. Monocular amplitude of accommodation was measured in each eye using the push-up method.[24]

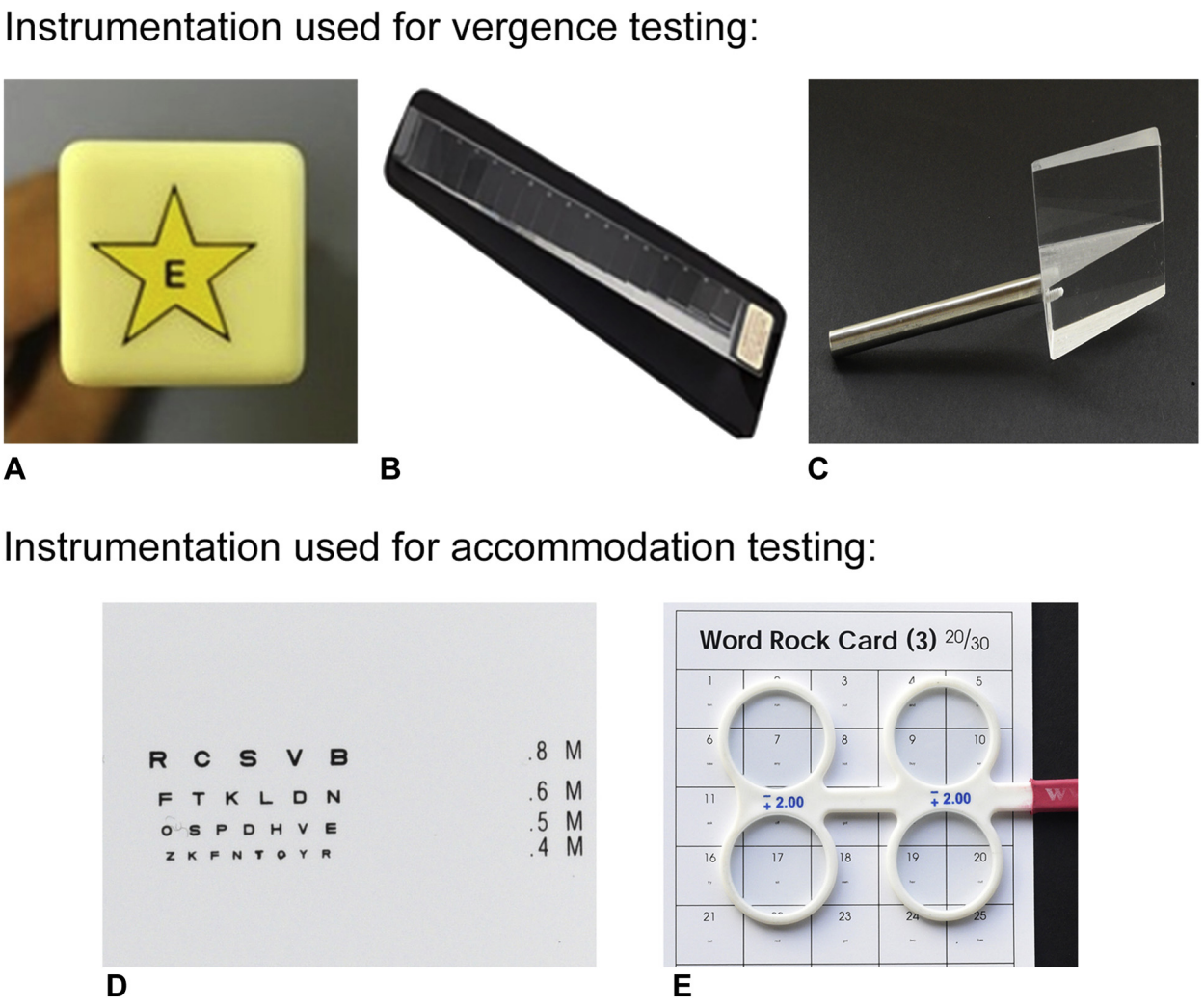

FIGURE 1. Assessment of vergence and accommodation. Top photos show instrumentation used for vergence testing. (A) Accommodative target to test near point of convergence; (B) Horizontal prism bar used for convergence and divergence amplitudes (fusional vergence ranges); (C) Vergence facility wedge (12Δ base out and 3Δ base in). Bottom photos show instrumentation used for accommodation testing. (D) The first line of letters on the card corresponds to 0.8 M (~20/40; 6-point type) used for assessment of accommodative amplitude; (E) word card used and ± 2.00 diopter flipper lens used for accommodative facility testing.

With the fellow eye occluded, a target consisting of 0.8 M-sized letters (~20/40 or 6-point type) (Figure 1, D) was slowly moved from a starting point of ~60 cm toward the patient's open eye. The distance in centimeters from the lateral canthus to the point when the patient reported sustained blurring of the letters was recorded as the *distance to blur*. The target was then slowly moved away from the patient until it became clear, and this distance was recorded as the *distance to recovery*. The mean of the distance to blur and the distance to recovery, measured in centimeters, was converted to meters, and its inverse was recorded as the accommodative amplitude in diopters (D).[25,26]

Accommodative Facility. Monocular accommodative facility was measured in each eye separately. With the fellow eye occluded, the speed at which the patient reported 20/30-sized words to be clear at 40 cm through alternating +2.00 D and –2.00 D lenses (Figure 1, E) was measured in cycles per minute. One cycle was the ability to clear the plus lens followed by the minus lens. The examiner documented when the patient exhibited increased difficulty in attaining clarity with one lens vs the other.

• **CLINICAL DIAGNOSES:** Each patient was classified as having normal binocular vision, a vergence disorder (ie, convergence insufficiency, convergence deficit, convergence excess, nonspecific vergence dysfunction) and/or accommodative disorder (ie, accommodative insufficiency or infacility) using the criteria in Table 1.[15,21,27]

TABLE 1. Diagnostic Criteria for Vergence and Accommodation Disorders

Clinical Diagnosis and Findings	Diagnostic Criteria
Convergence Insufficiency First criterion and one other must be met	
Exophoria at near	4^{Δ} or greater than magnitude at distance
Near point of convergence (NPC)	> 7 cm
Convergence amplitude at near	$\leq 15^{\Delta}$ break or the Sheard criterion[a] not met
Vergence facility (3ΔBI/12ΔBO)	≤ 9 cpm; difficulty fusing BO prism
Convergence Deficit[b] First criterion and one other must be met	
Near point of convergence (NPC)	> 7 cm
Convergence amplitude at near	≤ 15Δ break or the Sheard criterion[a] not met
Vergence facility (3ΔBI/12ΔBO)	≤ 9 cpm; difficulty fusing BO prism
Convergence Excess First criterion and one other must be met	
Esophoria at near	≥ 3Δ
Divergence amplitude at near	< 8Δ break or if the Sheard criterion[a] not met
Vergence facility (3ΔBI/12ΔBO)	≤ 9 cpm; difficulty fusing BI prism
Nonspecific Vergence Dysfunction Either criterion is met	
Vergence amplitudes	Divergence < 8Δ break and convergence ≤ 15Δ break
Vergence facility (3ΔBI/12ΔBO)	≤ 9 cpm; difficulty fusing with both BI & BO prism
Accommodative Disorders Monocular criteria: met for one or both eyes	
Accommodation insufficiency	> 2 D less than 15-0.25 (age in years)
Accommodative infacility (±2.00D)	≤ 6 cpm

BI = base-in; BO = base-out; cpm = cycles per minute; Δ = prism diopter; D = diopters; NPC = near point of convergence.
[a]Compensating vergence amplitudes (positive or negative fusional vergence) of at least twice the magnitude of the near phoria.
[b]Patients did not have an exophoria greater at near than at far.

TABLE 2. Patient Demographics and Clinical Characteristics

	Mean (SD)	Median	Range
Age (years)	15.3 (2.6)	15.5	8.5 to 20.9
Time from injury to examination (days)	210 (283)	118	32 to 1528
Refractive error (spherical equivalent, D)	0.16 (1.22)	0.50	–5.38 to 1.50
Near stereoacuity (seconds of arc)	44.7	40	20 to 100
Cover test distance (Δ, +exo, –eso)	+0.04 (0.2)	0	0 to +2
Cover test near (Δ, +exo, –eso)	+1.8 (4.7)	+1.0	–14 to +14
Vergence measures			
Near point of convergence break (cm)	11.0 (4.4)	10.5	3 to 33
Convergence amplitude at near (Δ)	23.6 (8.7)	25	4 to 40
Divergence amplitude at near (Δ)	11.0 (3.6)	12	4 to 20
Vergence facility (cpm)	12.8 (6.2)	13.0	0 to 25
Accommodation measures[a]			
Amplitude of accommodation (D)	8.0 (1.8)	8.2	3.1 to 11.8
Accommodative facility ± 2.00 D (cpm)	6.0 (3.8)	5.5	0 to 14

cpm = cycles per minute; Δ = prism diopter; D = diopters; eso = esodeviation; exo = exodeviation; SD = standard deviation.
[a]Monocular testing; worse eye

• **STATISTICAL ANALYSIS:** The frequency of vergence and accommodative dysfunctions, as defined in Table 1, were calculated to determine the prevalence of differing types of oculomotor dysfunction in this clinical sample of patients with postconcussion syndrome. Descriptive statistics are reported using means (± standard deviation), medians and ranges for patient demographics and clinical characteristics.

RESULTS

THIS RETROSPECTIVE REVIEW YIELDED 148 PATIENTS OF whom 83 (56%) met the inclusion criteria. For these 83 patients, the average age at the time of evaluation was 15.3 (± 2.6) years; 53 (64%) were female. The median time postinjury was 118 days (range: 32-1528), with concussion

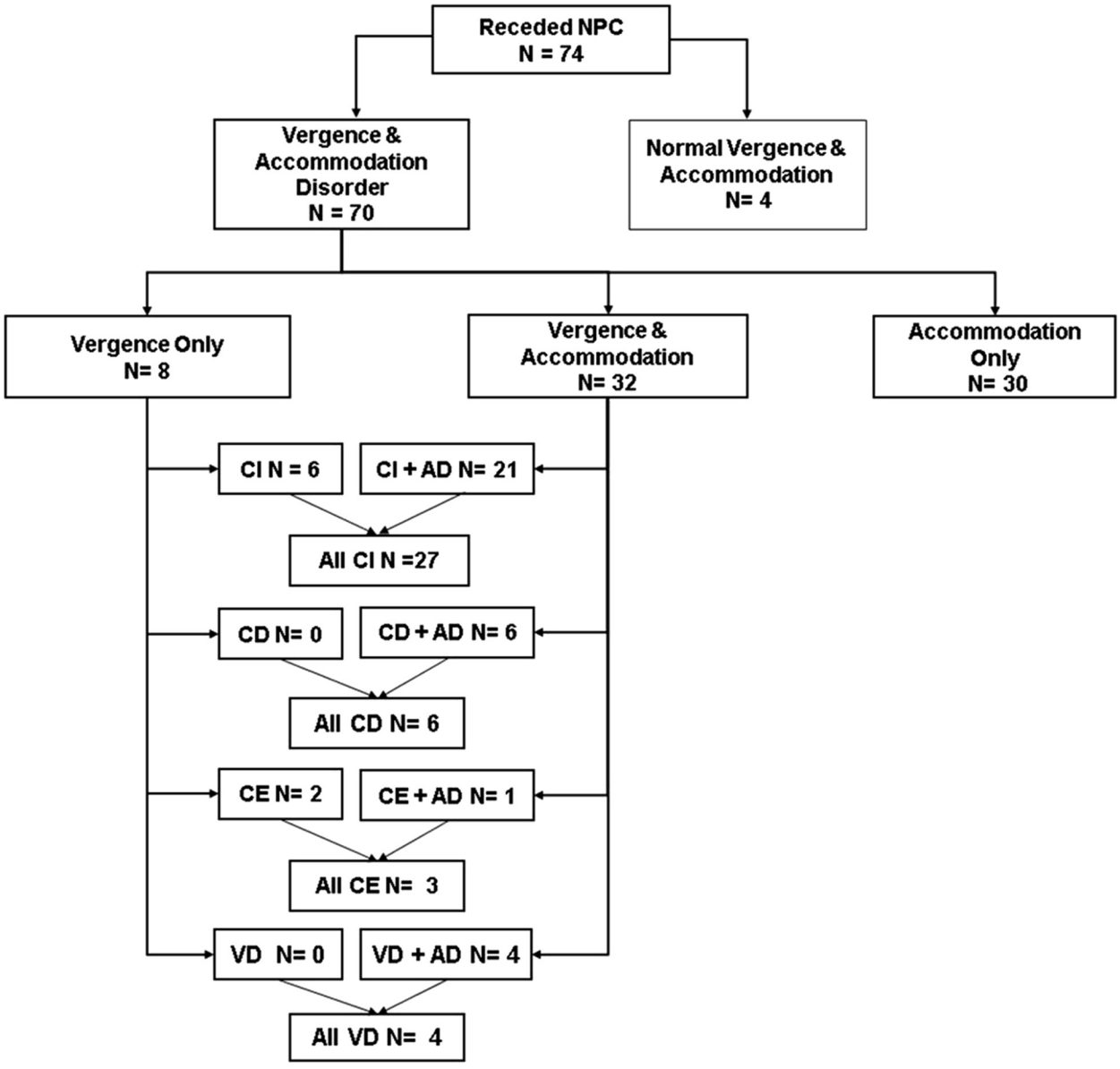

FIGURE 2. Oculomotor disorders in patients with receded near point of convergence (NPC). CI = convergence insufficiency; CD = convergence deficit; CE = convergence excess; VD = non-specific vergence dysfunction; AD = accommodation disorder (insufficiency and/or infacility).

reported to result from sports-related injuries for 50 (60%), motor vehicle accidents for 12 (14%) and other injuries or falls for 21 (25%) of the patients. For most patients (n = 48; 58%), this was their first concussion; for 18 (22%) it was their second, and for 17 (20%) it was at least their third concussion. Emmetropic to low hyperopic (spherical equivalent ≤ 1.50 D) refractive error was found in 67 (81%) of the patients. The demographic and clinical characteristics of these patients are shown in Table 2.

The sensorimotor evaluation revealed that 74 of the 83 (89%) patients with postconcussion symptoms had receded NPC. Of these patients with receded NPC, 70 (95%) had an oculomotor disorder. Deficits in accommodation were present in 84% (62 of 74), either solely (41%; 30 of 74) or combined with disorders of vergence (43%; 32 of 74). Vergence disorders were found in 54% (40 of 74), and these were usually (78%, 32 of 41) accompanied by an accommodative disorder (Figure 2).

As illustrated in Table 3, the patients with receded NPC exhibited various types of oculomotor disorders. Although 45% (33 of 74) of the patients with receded NPC had deficient near convergence ability, only 27 of 74 (36%) met

TABLE 3. Patients with Receded NPC: Oculomotor Dysfunction Diagnosis

Oculomotor Diagnosis	N (80)	%
Accommodative Disorder Only		
• Insufficiency	12	15%
• Infacility	7	9%
• Both insufficiency and infacility	12	15%
Total Accommodative Disorder Only	31	39%
Convergence Insufficiency		
Only	6	8%
Concurrent Accommodative Disorder		
• Accommodative insufficiency	9	11%
• Accommodative infacility	2	3%
• Both insufficiency & infacility	10	12%
Total Convergence Insufficiency	27	34%
Convergence Deficit		
Only	1	1%
Concurrent Accommodative Disorder		
• Accommodative insufficiency	3	4%
• Accommodative infacility	0	0%
• Both accommodative insufficiency and infacility	5	6%
Total Convergence Deficit	9	11%
Convergence Excess		
Only	2	3%
Concurrent accommodative insufficiency & infacility	1	1%
Total Convergence Excess	3	4%
Non-specific Vergence Dysfunction		
Concurrent Accommodative Disorder		
• Insufficiency	1	1%
• Both insufficiency and infacility	4	5%
Total Non-specific Vergence Dysfunction	5	6%
Normal Binocular Vision	5	6%

NPC = near point of convergence.

the criteria for the diagnosis of convergence insufficiency; among these patients with convergence insufficiency, 21 of 27 (78%) had a concurrent accommodative disorder. Convergence insufficiency, as the sole oculomotor diagnosis, was present in only 6 cases (8%). Convergence excess and nonspecific vergence dysfunctions were diagnosed in 2 of 74 (3%) and 4 of 74 (5%), respectively.

DISCUSSION

IN THIS CLINICAL COHORT OF YOUNG PATIENTS WITH chronic concussion-related symptoms, a receded NPC was the most common vision-related clinical finding, occurring with a frequency of 89%. Because there are no population-based data in regard to the prevalence of or natural history of receded NPC in the general or postconcussion populations, we cannot compare our data. A report on a clinically based cohort of adolescents with concussion,[15] however, provided a prevalence of at least 49% for receded NPC; because they did not report data for NPC apart from its being a requirement for the diagnosis of convergence insufficiency, the exactprevalence of receded NPC in their cohort is unknown.

Among those with receded NPC, nearly all (95%) had an oculomotor disorder affecting vergence, accommodation or both. Overall, an accommodative deficit, whether independent or coexisting with a vergence disorder, was the most common oculomotor disorder found in these young patients who were symptomatic postconcussion. Convergence insufficiency, in isolation or concurrent with an accommodative disorder, was the most common vergence disorder, but it occurred in only one-third of the patients.

Our findings support prior observations that receded NPC is a common sequela in young patients after concussion[9,15] and demonstrate that a receded NPC can persist for many months or even years after injury. However, our data illustrate that a receded NPC postconcussion is not synonymous with the diagnosis of convergence insufficiency. Among those with receded NPC, there were many patients who had only accommodative disorders, and there were even some who had convergence excess (a tendency of the eyes to turn inward, rather than outward). Thus, alhough the clinical finding of receded NPC in patients with postconcussion syndrome can be a harbinger of various oculomotor disorders, it is not synonymous with the diagnosis of convergence insufficiency.

Accommodative disorder, characterized by a reduced ability to focus or sustain focus at near, based on age-expected norms (accommodative insufficiency),[21,28,29] or reduced latency and speed of the accommodative response (accommodative infacility)[30,31] was the most common anomaly (84%) found in our patients after concussion who had receded NPC. Accommodative system dysfunction is commonly found in association with convergence insufficiency in young individuals without concussion[31–33]; thus, it is not remarkable to find compromised accommodation among patients after concussion who have receded NPC. Accommodation and convergence are coupled physiologically,[34] and a receded NPC may result from understimulation of convergence because of inadequate accommodative input through the accommodative-convergence link.[35,36] Some theorize that when convergence insufficiency and accommodative insufficiency coexist, the accommodative deficit is often primary,[32,36–39] and treatment of the accommodative disorder results in resolution of the vergence disorder.[21,35] This obviously has implications for treatment. For instance, base-in prisms would not be an appropriate treatment if the source of the presumed convergence insufficiency is hypo-accommodation, whereas accommodative therapy or added plus lenses at near would be appropriate.

TABLE 4. Procedure for Near Point of Convergence Testing

1. Ensure that patient is wearing his or her refractive correction and that there is good illumination using ambient and overhead lighting.
2. Place a target consisting of a single vertical line of 20/30 letters (or single letter) in the movable target holder on the Near Point Rule at approximately the 40 to 50 cm mark.
3. Gently rest the end of Near Point Rule between the patient's eyes at the level of the eyebrows.
4. Instruct the patient to "look at the line of letters and try to keep them single (one) as long as possible, but tell me when they break into two and you see double."
5. Slowly move the target toward the patient's eyes at a rate of 1 to 2 cm/second until the target is reported to be double.
6. When the patient reports the target has split into two, ask the patient if she/he "can get the target back into one, or does it stay double (two)?"
7. If the target is reported to come back into one, continue to move the target closer until the target doubles again. When the patient can no longer keep the target single, record the value noted on the near point rod to the nearest half centimeter using the center of the brow as the zero-measure point.

Of note:

- One can repeat the NPC 2 or 3 times and use the mean of the measures.
- Some patients do not see diplopia because they suppress it; thus, the examiner should watch the eyes carefully for a loss of fusion (one of the eyes moves outward instead of continuing to converge with the other eye). Loss of fusion in the absence of diplopia is also an endpoint, and the distance at which this happens is the near point of convergence.

Adapted from the Convergence Insufficiency Treatment Study Procedures Manual[53] and the Convergence Insufficiency Treatment Trial Manual of Procedures.[54]

Accommodative disorders have been reported to be common postconcussion sequelae in other studies,[15,40–43] but they are not necessarily associated with a receded NPC.

It is difficult to make direct comparisons of the frequencies of oculomotor disorders found in this study with those found in other studies because of differences in patient age, time since concussion, measurement protocols, definitions of oculomotor disorders, and inherent differences between the general population of patients with concussion and those referred to a specialty clinic at a tertiary care hospital. In regard to measurement protocols, the convergence amplitudes for this study were determined based on the break point rather than the blur point, as is used in some other studies of convergence insufficiency.[18] This could have underestimated the number of those diagnosed with convergence deficits in our study. Conversely, by using the 2-clinical sign definition of convergence insufficiency in the present study, rather than the 3-clinical sign definition[17] that is often used in treatment-intervention studies,[19,44] we may have overestimated the diagnosis of convergence insufficiency (38% vs 14%). Furthermore, those diagnosed with convergence deficit might be considered by some to have convergence insufficiency, despite not having a greater exodeviation at near than at far.[45–47] Nevertheless, our goal was not to estimate prevalence rates but to determine the types of oculomotor disorders associated with receded NPC.

As is true for any medical condition, an accurate diagnosis is imperative so that the most appropriate treatment can be prescribed. For example, if receded NPC is assumed to be diagnostic of convergence insufficiency in patients with postconcussion vision symptoms, convergence exercises will probably be prescribed. However, this treatment modality would not be appropriate for the many patients who do not have simple convergence insufficiency. Differing treatment options or, in the case of a therapy program, differing procedures and sequencing of procedures would be prescribed for the those with other oculomotor dysfunctions, including the convergence insufficiency patients with comorbid accommodation deficits.[21]

In instances of accommodative system dysfunction, the correction of small to moderate (< 1.50 D), uncorrected hyperopic refractive errors may be warranted because the resultant decrease in accommodative demand may alleviate visual symptoms. Furthermore, a hyperopic correction may help to stabilize accommodation and facilitate normal binocular vision.[28] This also applies to other types of refractive error, particularly astigmatism, where consistently clear and maintained retinal images from refractive error correction have been shown to result in the recovery of normal vergence and accommodation.[48,49] Aside from refractive correction, the types of eye exercises and vision therapy to be prescribed and whether prism glasses or bifocal lenses would be beneficial differ based on the type of the oculomotor disorder. For example, bifocal lenses are often helpful for symptomatic relief for those with accommodative insufficiency or with convergence excess.[21] Specific to mTBI, a recent pilot study of spectacle treatment that optimized near visual function was reported to reduce symptoms and enhance reading performance in a number of patients.[50]

NPC measurements are noninvasive, do not require expensive equipment, can be obtained quickly, and are reliable.[51] Moreover, testing is easily accessible by a variety of health care providers (eg, primary care physicians, neurologists, sports medicine providers, and allied health

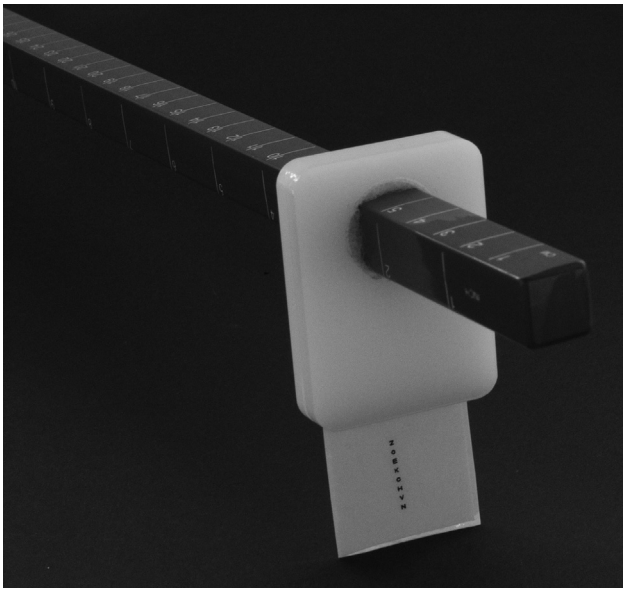

FIGURE 3. Near point rule with the single vertical line target used for near point of convergence (NPC) testing.

professionals). With NPC testing becoming more widespread among those caring for patients with concussions,[8,13,52] we recommend employing a standardized NPC testing protocol (see Table 4 and Figure 3)[53,54] using the near point rule (accommodation rule) (Gulden Ophthalmics, Elkin Park, Pennsylvania, USA), a plastic rod marked with centimeter and dioptric increments and including a sliding card holder, where a fixation target composed of small letters is inserted. The zero-measure point should be the center of the forehead at the level of the brow (ie, glabella), not the tip of the nose, as has been done in some studies,[4,7,8] because the latter underestimates the NPC measure. A measure of 6 cm or greater, based on patient report of diplopia or examiner observation of loss of fusion, is considered abnormal.[11,17,18,55] We recommend that this standardized method with the accommodative rule (Table 4) (Figure 3) be used clinically and for research purposes. It has been used in a number of recent randomized treatment trials[19,44,55] and is widely utilized by pediatric eye care professionals.

As with all studies, there are limitations that should be considered. Our findings should be viewed in the context of our clinical setting and the clinical profile of the patient cohort. The upper age limit was 20 years, and all patients had been referred to a multidisciplinary concussion clinic or specialty eye clinic specifically to rule out vision disorders associated with persistent postconcussion symptoms. Thus, our patient sample was likely to have been enriched with individuals with vision problems, which would contribute to the high frequency of receded NPC found. However, because there are no population-based or clinic-based data in regard to the prevalence of or natural history of receded NPC in the general or postconcussion populations, we cannot compare our data. In addition, although all patients had chronic symptoms, symptom data were not collected in a systematic manner, making it impossible to correlate symptom severity with oculomotor diagnosis. The slight procedural differences in the present study (ie, 20/50 single-letter target and the lateral canthus as the reference point) compared with the NPC procedure we now recommend (Table 4) are unlikely to have impacted our NPC measures in a significant manner. There is no reason to expect a different accommodative response to have occurred, given the small difference in letter size and that patients were told to keep the letter clear. Furthermore, using the lateral canthus as the reference point, with a 7 cm cut-off, vs using the middle of the forehead and a 6 cm cut-off, results in the same NPC measure.

Particular strengths of the study were that all patients underwent comprehensive sensorimotor evaluations that were conducted in a standardized manner by the same eye care specialist.

CONCLUSION

RECEDED NPC IS A SINGLE CLINICAL MEASURE OF CONVERgence ability; it is not diagnostic of convergence insufficiency. Instead, receded NPC is associated with various underlying oculomotor dysfunctions that commonly require different forms of treatment, including lenses, prisms and active therapy regimens. Thus, patients who have persistent symptomatic postconcussion symptoms and receded NPC should be referred to an eye care specialist for a comprehensive sensorimotor evaluation so that any underlying vergence or accommodative dysfunctions can be identified and the most appropriate treatment prescribed.

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REFERENCES

1. Langlois JA, Rutland-Brown W, Wald MM. The epidemiology and impact of traumatic brain injury: a brief overview. *J Head Trauma Rehabil* 2006;21(5):375–378.
2. Arbogast KB, Curry AE, Pfeiffer MR, et al. Point of health care entry for youth with concussion within a large pediatric care network. *JAMA Pediatr* 2016;170(7):e160294.
3. Harmon KG, Drezner JA, Gammons M, et al. American Medical Society for Sports Medicine position statement: concussion in sport. *Br J Sports Med* 2013;47(1):15–26.
4. Mucha A, Collins MW, Elbin RJ, et al. A brief Vestibular/Ocular Motor Screening (VOMS) assessment to evaluate concussions: preliminary findings. *Am J Sports Med* 2014;42(10):2479–2486.
5. Ventura RE, Jancuska JM, Balcer LJ, Galetta SL. Diagnostic tests for concussion: is vision part of the puzzle? *J Neuroophthalmol* 2015;35(1):73–81.
6. Ellis MJ, Cordingley DM, Vis S, Reimr KM, Leiter J, Russell K. Clinical predictors of vestibulo-ocular dysfunction in pediatric sports-related concussion. *J Neurosurg Pediatr* 2017;19(1):38–45.
7. Howell DR, O'Brien MJ, Raghuram A, Shah AS, Meehan WP 3rd. Near point of convergence and gait deficits in adolescents after sport-related concussion. *Clin J Sport Med* 2018;28(3):262–267.
8. Pearce KL, Sufrinko A, Lau BC, Henry L, Collins MW, Kontos AP. Near point of convergence after a sport-related concussion: measurement reliability and relationship to neurocognitive impairment and symptoms. *Am J Sports Med* 2015;43(12):3055–3061.
9. Storey EP, Master SR, Lockyer JE, Podokak OE, Grady MF, Master CL. Near point of convergence after concussion in children. *Optom Vis Sci* 2017;94(1):96–100.
10. Hayes GJ, Cohen BE, Rouse MW, De Land PN. Normative values for the nearpoint of convergence of elementary schoolchildren. *Optom Vis Sci* 1998;75(7):506–512.
11. Scheiman M, Gallaway M, Frantz KA, et al. Nearpoint of convergence: test procedure, target selection, and normative data. *Optom Vis Sci* 2003;80(3):214–225.
12. Khurana AK. Theory and practice of optics and refraction. 4th ed. Rohtak, India: Elsevier; 2017.
13. McDevitt J, Appiah-Kubi KO, Tierney R, Wright WG. Vestibular and oculomotor assessments may increase accuracy of subacute concussion assessment. *Int J Sports Med* 2016;37(9):738–747.
14. Anzalone AJ, Blueitt D, Case T, et al. A positive Vestibular/Ocular Motor Screening (VOMS) is associated with increased recovery time after sports-related concussion in youth and adolescent athletes. *Am J Sports Med* 2017;45(2):474–479.
15. Master CL, Scheiman M, Gallaway M, et al. Vision diagnoses are common after concussion in adolescents. *Clin Pediatr (Phila)* 2016;55(3):260–267.
16. Kawata K, Rubin LH, Lee JH, et al. Association of football subconcussive head impacts with ocular near point of convergence. *JAMA Ophthalmol* 2016;134(7):763–769.
17. Rouse MW, Borsting E, Hyman L, et al. Frequency of convergence insufficiency among fifth and sixth graders. *Optom Vis Sci* 1999;76(9):643–649.
18. Scheiman M, Mitchell GL, Cotter S, et al. A randomized clinical trial of treatments for convergence insufficiency in children. *Arch Ophthalmol* 2005;123(1):14–24.
19. Pediatric Eye Disease Investigator Group. Home-based therapy for symptomatic convergence insufficiency in children: a randomized clinical trial. *Optom Vis Sci* 2016;93(12):1457–1465.
20. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport: the 5th International Conference on Concussion in Sport, Berlin, Germany, October 2016. *Br J Sports Med* 2017;51(11):838–847.
21. Scheiman M, Wick B. Clinical management of binocular vision: heterophoric, accommodative, and eye movement disorders. Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins; 2014.
22. Siderov J, Chiu SC, Waugh SJ. Differences in the nearpoint of convergence with target type. *Ophthal Physiol Opt* 2001;21(5):356–360.
23. Rabbetts RB. Bennett & Rabbetts' Clinical Visual Optics. Edinburgh, UK: Elsevier Butterworth-Heinemann; 2007.
24. Daum KM. Accommodative dysfunction. *Doc Ophthalmol* 1983;55(3):177–198.
25. Barrett TB. Assessment of binocular vision and accommodation, 4th ed. In: Elliott D, ed. Clinical Procedures in Primary Eye Care. Elsevier; 2013:147–208.
26. Rosenfield M. Clinical Assessment of Accommodation, 2nd ed. In: Rosenfield M, Logan N, eds. Optometry: Science, Techniques and Clinical Management. Edinburgh: Elsevier; 2009:230–232.
27. Jimenez R, Perez MA, Garcia JA, Gonzalez MD. Statistical normal values of visual parameters that characterize binocular function in children. *Ophthal Physiol Opt* 2004;24(6):528–542.
28. Eskridge JB, Amos JF, Bartlett JD. Clinical procedures in optometry. Philadelphia: Lippincott; 1991:xv.
29. Cacho Martinez P, Garcia Munoz A, Ruiz-Cantero MT. Treatment of accommodative and nonstrabismic binocular dysfunctions: a systematic review. *Optometry* 2009;80(12):702–716.
30. Garzia RP, Richman JE. Accommodative facility: a study of young adults. *J Am Optom Assoc* 1982;53(10):821–825.
31. Scheiman M, Cotter S, Kulp MT, et al. Treatment of accommodative dysfunction in children: results from a randomized clinical trial. *Optom Vis Sci* 2011;88(11):1343–1352.
32. Marran LF, De Land PN, Nguyen AL. Accommodative insufficiency is the primary source of symptoms in children diagnosed with convergence insufficiency. *Optom Vis Sci* 2006;83(5):281–289.
33. Davis AL, Harvey EM, Twelker JD, Miller JM, Leonard-Green T, Campus I. Convergence insufficiency, accommodative insufficiency, visual symptoms, and astigmatism in Tohono O'odham students. *J Ophthalmol* 2016;2016:6963–6976.
34. Fincham EF, Walton J. The reciprocal actions of accommodation and convergence. *J Physiol* 1957;137(3):488–508.
35. Schor C. Influence of accommodative and vergence adaptation on binocular motor disorders. *Am J Optom Physiol Opt* 1988;65(6):464–475.
36. Jampolsky A. Ocular divergence mechanisms. *Trans Am Ophthalmol Soc* 1970;68:730–822.

37. Duane A. Studies in monocular and binocular accommodation, with their clinical application. *Trans Am Ophthalmol Soc* 1922;20:132–157.
38. Bugola J. Hypoaccommodation and convergence insufficiency. *Am Orthopt J* 1977;27:85–90.
39. Rutstein RP, Daum KM. Exotropia associated with defective accommodation. *J Am Optom Assoc* 1987;58(7):548–554.
40. Ciuffreda KJ, Kapoor N, Rutner D, Suchoff IB, Han ME, Craig S. Occurrence of oculomotor dysfunctions in acquired brain injury: a retrospective analysis. *Optometry* 2007;78(4):155–161.
41. Green W, Ciuffreda KJ, Thiagarajan P, Szymanowicz D, Ludlam DP, Kapoor N. Accommodation in mild traumatic brain injury. *J Rehabil Res Dev* 2010;47(3):183–199.
42. Master CL, Master SR, Wiebe DJ, et al. Vision and vestibular system dysfunction predicts prolonged concussion recovery in children. *Clin J Sport Med* 2018;28(2):139–145.
43. Matuseviciene G, Johansson J, Moller M, Godbolt AK, Pansell T, Deboussard CN. Longitudinal changes in oculomotor function in young adults with mild traumatic brain injury in Sweden: an exploratory prospective observational study. *BMJ Open* 2018;8(2):e018734.
44. Convergence Insufficiency Treatment Trial Study Group. Randomized clinical trial of treatments for symptomatic convergence insufficiency in children. *Arch Ophthalmol* 2008;126(10):1336–1349.
45. Cooper J, Jamal N. Convergence insufficiency-a major review. *Optometry* 2012;83(4):137–158.
46. Passmore JW, Maclean F. Convergence insufficiency and its managements; an evaluation of 100 patients receiving a course of orthoptics. *Am J Ophthalmol* 1957;43(3):448–456.
47. Von Noorden GK, Campos EC. Binocular vision and ocular motility: theory and management of strabismus. 6th ed. Saint Louis, Missouri: Mosby; 2002:xvi.
48. Dwyer P, Wick B. The influence of refractive correction upon disorders of vergence and accommodation. *Optom Vis Sci* 1995;72(4):224–232.
49. Sreenivasan V, Irving EL, Bobier WR. Binocular adaptation to near addition lenses in emmetropic adults. *Vision Res* 2008;48(10):1262–1269.
50. Johansson J, Nygren de Boussard C, Oqvist Seimyr G, Pansell T. The effect of spectacle treatment in patients with mild traumatic brain injury: a pilot study. *Clin Exp Optom* 2017;100(3):234–242.
51. Rouse MW, Borsting E, Deland PN. Convergence Insufficiency Reading Study (CIRS) Group. Reliability of binocular vision measurements used in the classification of convergence insufficiency. *Optom Vis Sci* 2002;79(4):254–264.
52. DuPrey KM, Webner D, Lyons A, Kucuk CH, Ellis JT, Cronholm PF. Convergence insufficiency identifies athletes at risk of prolonged recovery from sport-related concussion. *Am J Sports Med* 2017;45(10):2388–2393.
53. Convergence Insufficiency Treatment Study Group. Procedures Manual. Available at: http://publicfiles.jaeb.org/pedig/manuals/CITS_Procedures_Manual_v_5_0_03_04_14.pdf. Accessed January 4, 2019.
54. Convergence Insufficiency Treatment Trial Group. Manual of procedures. Available at: https://optometry.osu.edu/CITT-manual-procedures. Accessed January 4, 2019.
55. CITT-ART Investigator Group, Scheiman M, Mitchell GL, et al. Convergence Insufficiency Treatment Trial: Attention and Reading Trial (CITT-ART): Design and Methods. *Vis Dev Rehabil* 2015;1(3):214–228.