

# Near Point of Convergence Deficits and Treatment Following Concussion: A Systematic Review

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**Context:** Convergence dysfunction following concussion is common. Near point of convergence (NPC) is a quick and easy assessment that may detect oculomotor dysfunction such as convergence insufficiency (CI), but NPC measurements are rarely reported. Convergence dysfunction is treatable in otherwise healthy patients; the effectiveness of oculomotor therapy following concussion is unclear. **Objectives:** The purpose of this article was to systematically review the literature and answer the following clinical questions: (1) Is performance on NPC negatively affected in patients diagnosed with a concussion compared with pre-injury levels or healthy controls? (2) In patients diagnosed with concussion, what is the effect of oculomotor/vision therapy on NPC break measurements? **Evidence Acquisition:** The search was conducted in CINAHL, SPORTDiscus, MEDLINE, and PubMed using terms related to concussion, mild traumatic brain injury, convergence, vision, and rehabilitation. Literature considered for review included original research publications that collected measures of NPC break in concussion patients, with a pretest–posttest comparison or comparison with a healthy control group. A literature review was completed; 242 relevant articles were reviewed, with 18 articles meeting criteria for inclusion in the review. **Evidence Synthesis:** Articles were categorized according to the clinical question they addressed. The patient or participant sample (number, sex, age, and health status), study design, instrumentation, or intervention used, and main results were extracted from each article. **Conclusions:** The authors' main findings suggest that there is a moderate level of evidence that patients have impaired NPC up to several months postconcussion, and a low level of evidence that impairments can be successfully treated with oculomotor therapy. These findings should be cautiously evaluated; the studies are limited by weak/moderate quality, small sample sizes, varied methodology, and nonrandomized treatment groups. Future research should explore factors affecting convergence postconcussion and include randomized, controlled studies to determine if performing vision therapy improves visual measures and promotes recovery.

**Keywords:** neuroscience, recovery, rehabilitation, brain-concussion, evaluation

Traumatic brain injury (TBI) is a public health concern. TBI is common in sports and can be difficult to diagnose. Concussion, a form of mild traumatic brain injury (mTBI), can be defined as “a complex pathophysiological process”<sup>1</sup> in which damage occurs to the brain, causing a wide variety of signs and symptoms, including cognitive and physical impairments. Generally, these impairments resolve over several weeks, as the brain recovers. Some individuals experience lasting impairments, potentially for several years following concussion.<sup>2</sup> Unfortunately, there is no gold standard for the assessment of concussion. Currently, the recommendation is to use a multitude of assessments, including a clinical examination, symptoms, neurocognitive, and balance assessments.<sup>3</sup> Several researchers and clinicians have suggested that instead of categorizing concussion as a single diagnosis, health care professionals may be able to identify specific clinical trajectories or subtypes of concussion.<sup>4–6</sup> Proposed subtypes of concussion include cervical, cardiovascular, cognitive/fatigue, mood/affective, headache/migraine, vestibular, and visual/oculomotor.<sup>4–6</sup> In order to identify these various trajectories, a comprehensive evaluation including assessments in several clinical domains must be used. Therefore, it has been suggested that clinicians should use vision or oculomotor assessments to aid in the diagnosis and treatment of concussion.<sup>7</sup>

It is likely that the visual system is affected following a brain injury, because over half of the brain's circuits are involved in vision.<sup>8</sup> Subjective visual complaints, such as blurred vision, light sensitivity, and difficulty reading,<sup>9–11</sup> and objective oculomotor impairments are common following concussion.<sup>12</sup> Several vision assessments have been proposed for inclusion in the evaluation of concussion, ranging from simple inexpensive clinical measures to assessments that are expensive and use sophisticated equipment.<sup>13</sup> These assessments measure various aspects of vision, such as saccades, smooth pursuits, accommodation, and convergence.<sup>13</sup> One vision assessment that is showing promise is convergence, which is commonly evaluated by measuring near point of convergence (NPC).

In recent years, convergence insufficiency (CI) has been identified in patients following concussion. CI is a binocular vision disorder, often characterized by exophoria and reduced positive fusional vergence at near, and receded NPC.<sup>14</sup> NPC is clinically useful, because it is used as one of primary diagnostic tests in the assessment of CI.<sup>15</sup> While NPC is typically used as part of the criteria for diagnosis of CI, receded NPC and CI are not synonymous. There is some variability in the criteria used for CI, such as measurement parameters of abnormal NPC (eg, >5 cm<sup>7,14,16,17</sup> vs 17.5 cm<sup>18</sup>). Rates of CI in the healthy population are about 5%.<sup>14</sup> CI following concussion has been recognized throughout various forms of sports medicine and ocular scientific literature. Values for the rate of CI following concussion range from 42%<sup>16</sup> to 55%.<sup>19</sup> While many patients with receded NPC have CI, not all patients with receded NPC meet the criteria to be diagnosed with CI.<sup>20</sup> In a

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recent study, 89% of symptomatic postconcussion patients had receded NPC, while only 36% met the criteria for CI.<sup>20</sup> However, among patients with receded NPC, 95% had an oculomotor disorder.<sup>20</sup> The majority of studies that examine convergence dysfunction following concussion focus on a diagnosis of CI, and fail to report whether or not patients had receded NPC. Diagnosis of CI requires the use of more sophisticated measures, whereas NPC is a simple clinical measure that can be used by a variety of clinicians. While several methods of measuring NPC exist, typically a target (vertical line, pencil tip, fingertip, etc) is moved slowly toward the patient's nose, until it appears double or the examiner notices an eye deviating outward (exophoria). The distance measured from the target to the patient's nose when it appears double or exophoria is noticed and recorded as the NPC break. NPC recovery is the point measured from the tip of the nose to the target when the target appears single again, as the target is moved away from his/her nose. Receded NPC break is likely to be associated with various underlying oculomotor dysfunctions, so it may be a quick and easy way to identify patients in need of referral for oculomotor dysfunction following concussion.

Identifying domains of impairment following concussion can lead to establishment of targeted active interventions. Interventions such as oculomotor therapy with a focus on vergence could promote recovery in concussed individuals. Patients with visual deficits that go unidentified or unaddressed could have a prolonged recovery. In fact, after controlling for confounding variables, concussion patients with CI had an increased risk of prolonged recovery ( $\geq 28$  d from injury) by 12.3-fold.<sup>21</sup> Patients with visual dysfunction following concussion also have higher symptoms scores, reduced reading abilities<sup>22</sup> and impairments on verbal memory, visual motor speed, and reaction time.<sup>16</sup> Additionally, binocular vision is one of the most important visual cues for spatial orientation, making it of utmost importance in many sports. Athletes perform significantly better than nonathletes on measures of vergence facility, saccades, visual reaction time, peripheral awareness, and NPC.<sup>23</sup> Therefore, visual dysfunction in athletes may not only affect quality of life, but ability to return to sport as well. It is important to identify if impairments in NPC exist following concussion so that patients with receded NPC can be referred to an eye care specialist for further evaluation and possibly treatment. Several studies have demonstrated that CI is treatable in an otherwise healthy population through vision therapy.<sup>24–26</sup> These findings cannot be directly applied to a concussed population, because CI following concussion appears

to be due to a different mechanism.<sup>27</sup> Therefore, it is important to determine if oculomotor or vision therapy is effective in improving convergence in patients with receded NPC following concussion. We conducted a systematic review of the literature to synthesize the current evidence around this topic and provide clinical recommendations when appropriate.

## Objectives

This literature review discusses the effects of concussion on NPC and the efficacy of oculomotor and vision therapy in the treatment of CI following concussion. The purpose of this article was to systematically review the literature and answer the following clinical questions:

1. Is performance on NPC break negatively affected in patients diagnosed with a concussion compared to pre-injury levels or healthy control participants?
2. In patients diagnosed with concussion, what is the effect of oculomotor or vision therapy on NPC break measurements?

## Evidence Acquisition

An electronic search was conducted in 4 databases (CINAHL, SPORTDiscus, MEDLINE, and PubMed). A summary of the search terms used, and number of articles resulting from the search are included in Table 1. We also performed hand searches for relevant citations on all included articles. All searches were conducted between February 15, 2019 and April 1, 2019. Therefore, only articles published from database inception to April 1, 2019 were included in this review.

At the conclusion of the search, duplicates were removed. Two reviewers (A.L.S. and M.L.R.) screened titles and abstracts of all primary articles to determine studies eligible for inclusion. If there was not sufficient information in the title and abstract to determine whether or not inclusion criteria were met, a full-text evaluation was performed. The same 2 reviewers then independently evaluated the full text of potentially relevant articles. If there were conflicts or disagreements about whether or not an article should be included, a meeting was held to obtain a consensus. The following inclusion criteria were used:

1. Published prior to April 1, 2019
2. Published in English

**Table 1 Search Terms and Number of Articles Identified by Database**

Search terms	CINAHL	SPORTDiscus	MEDLINE	PubMed	Total
Concussion AND convergence	45	22	65	65	197
Concussion AND convergence AND rehabilitation or therapy or treatment	13	9	28	29	79
Concussion AND vision AND rehabilitation or therapy or treatment	42	24	88	97	251
Concuss* AND convergence	46	22	66	67	201
Concuss* AND convergence AND rehabilitation or therapy or treatment	15	9	28	29	81
Concuss* AND vision AND rehabilitation or therapy or treatment	45	24	92	99	260
Mild traumatic brain injury AND convergence	46	6	70	40	162
Mild traumatic brain injury AND convergence AND rehabilitation or therapy or treatment	13	6	27	17	63
Mild traumatic brain injury AND vision AND rehabilitation or therapy or treatment	52	18	85	73	228
Total	317	140	549	516	1522

3. Participants must have been human (ie, no animal studies)
4. Original research
5. Must have included participants diagnosed with a concussion or mTBI
6. Must have included a measure of NPC break, with either a pretest–posttest comparison, or a comparison to a healthy control group.

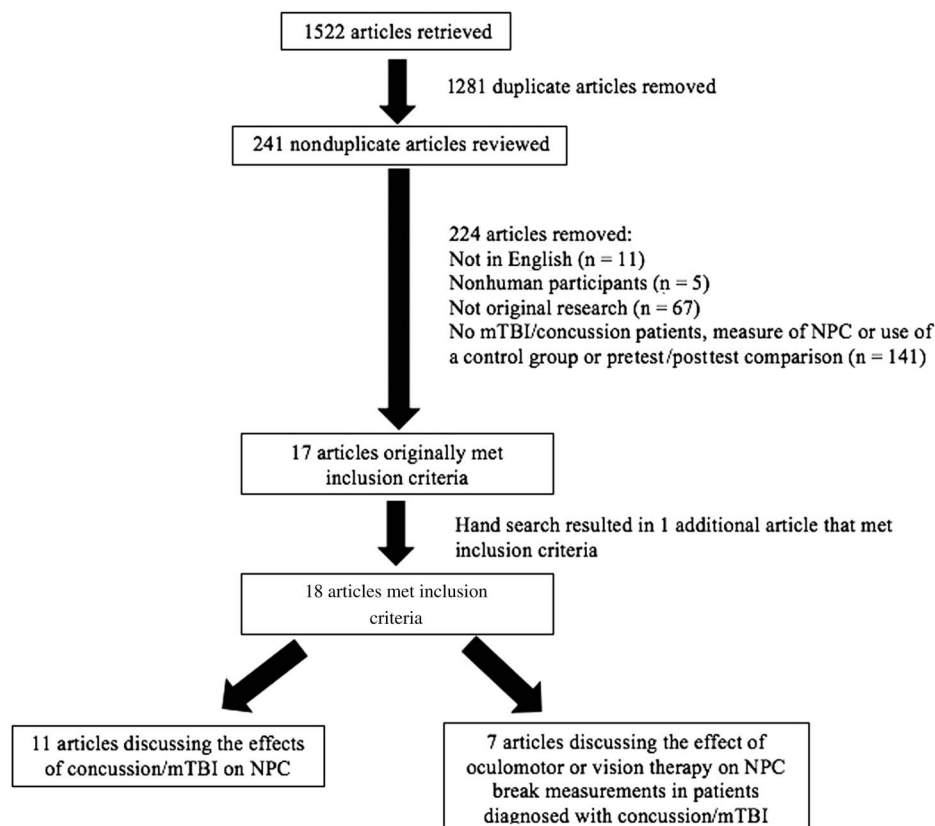
Data were independently extracted by 2 reviewers to carry out descriptive analyses. Articles were categorized according to the clinical question they addressed. The patient or participant sample (number, sex, age, and health status), study design, instrumentation, or intervention used, and main results were extracted from each article. Means and SDs for NPC break measurements were obtained if available. Meta-analyses were not performed, because studies were heterogeneous in sample (participant age and general characteristics) and methodology. In accordance with previous literature,<sup>7,14,16,17</sup> NPC measurements >5 cm were considered abnormal for the purpose of this review. Many of the studies had primary and secondary outcomes. We limited extraction and presentation of the outcomes to those that fit the clinical questions of interest for this review. The quality of the articles was assessed, and studies were assigned a level of quality as described by the quality assessment tool for quantitative studies (QATQS).<sup>28</sup> The QATQS has been demonstrated to have fair to excellent interrater reliability<sup>28</sup> and acceptable construct validity.<sup>29</sup> The tool evaluates 8 components, including selection bias, study design, confounders, blinding, data collection methods, withdrawals and dropouts, intervention integrity, and analyses. Each component is rated as weak, moderate, or strong. An overall or global rating is assigned to

the paper as follows: weak (2 or more weak ratings on first 6 components), moderate (one weak rating on first 6 components), or strong (no weak ratings on first 6 components). Scores were agreed upon by 2 reviewers consistent with the instructions for the QATQS.<sup>28</sup> Finally, we graded our recommendations using Grading of Recommendations, Assessment, Development and Evaluations (GRADE).<sup>30</sup> The GRADE is a framework for summarizing evidence and providing clinical recommendations.<sup>30</sup> An overall GRADE rating was applied to the outcome for each of our clinical questions. GRADE has 4 levels of evidence, including very low, low, moderate, and high.<sup>30</sup> Levels of evidence were agreed upon by 2 reviewers.

## Evidence Synthesis

A total of 1522 studies were initially identified through the electronic database searches (Table 1). After exclusion of duplicate articles (n = 1281), 241 articles were screened. Of the remaining articles, 191 articles were removed due to title/abstracts alone and 33 studies were removed after full-text evaluation. Articles were removed if they did not meet the inclusion criteria for the study (Figure 1). A total of 18 studies met the inclusion criteria for this review; 11 articles assessed the effects of concussion/mTBI on NPC break and 7 articles addressed the effect of oculomotor or vision therapy on NPC break measurements in concussion/mTBI patients.

Eleven studies evaluated the effects of concussion on NPC break measurements (Table 2). All of the studies were prospective and included the following designs: case-control,<sup>9,32</sup> cohort,<sup>34,37</sup> controlled observational,<sup>35</sup> cross sectional,<sup>7,36,38</sup> and repeated measures.<sup>17,31,33</sup> While Capó-Aponte et al<sup>31</sup> used a repeated-measures



**Figure 1** — Study selection process. mTBI indicates mild traumatic brain injury; NPC, near point of convergence.

Table 2 Summary of Studies Examining the Effect of Concussion on NPC

Article	Participants	Methods	Method of administering NPC	Key results
Capó-Aponte et al <sup>31</sup>	n = 40 Type: US military personnel mTBI group n = 20 (18 males and 2 females) Age: 29.70 (7.68) y Age-matched control group n = 20 (14 males and 6 females) Age: 32.65 (8.94) y No history of TBI, head concussion, or blast exposure	Design: prospective, within-subject, repeated-measures correlational All participants received a comprehensive ophthalmic and oculomotor exam, which included the following: - NPC - Stereo acuity - Ocular alignment at distance and near - Distance phoria - Gradient accommodative convergence/accommodation ratio - Amplitude of accommodation Time since injury not specified	Not specified	There was a statistically significant difference between the mTBI group and control group on NPC ( $P = .01$ ) NPC values, mean (SD) mTBI group: 9.95 (7.43) cm Control group: 2.9 (2.43) cm
Capó-Aponte et al <sup>9</sup>	n = 40 Type: US military personnel Age: 31.2 (7.36) y (range: 20–43 y) mTBI group n = 20 Age-matched control group n = 20 No history of TBI, head concussion, or blast exposure	Design: prospective, case-control All participants received a comprehensive ophthalmic and oculomotor exam, which included the following: - NPC - Stereopsis - Ocular alignment at distance and near - Near and distance phoria - Gradient accommodative convergence/accommodation - Maximum near negative and positive vergence - Motor fusion - Fixation disparity - Amplitude of accommodation - Monocular accommodative facility - Smooth pursuits mTBI participants were seen a median of 30.5-d postinjury (range: 16–45 d)	Not specified	There was a statistically significant difference between the mTBI group and control group on NPC ( $P = .0003$ ) NPC values, mean (SD) mTBI group: 9.95 (7.43) cm Control group: 2.90 (2.43) cm 55% of participants in the mTBI group presented with dysfunction on the NPC
Capó-Aponte et al <sup>32</sup>	n = 200 Type: active duty service members Age: 26 (6) y (range: 19–44 y) Acute mTBI (<72 h postinjury) n = 100 (87 males and 13 females) Matched controls n = 100 (79 males and 21 females)	Design: case-control correlational design Participants were assessed on the following measures: - Pupillary light reflex - NPC break - King-Devick test time - CISS Acute mTBI group must have been in the acute phase of injury (<72 h postinjury): - 31% seen within 24 h - 40% seen within 48 h - 29% seen within 72 h	Measured using Royal Air Force near point rule Participants were instructed to focus on a single high-contrast 20/30 size letter target Examiner moved slider toward participants' eyes and stopped when one eye deviated outward Distance in centimeters was recorded (minimum value of 5 cm) NPC break was measured twice with a 5-min interval between test administration	The acute mTBI group had exceeded NPC compared with controls ( $P < .001$ ) NPC values, mean (SD) mTBI group: 13.25 (8.07) cm Control group: 8.18 (2.15) cm

(continued)

**Table 2 (continued)**

Article	Participants	Methods	Method of administering NPC	Key results
Cheever et al <sup>33</sup>	n = 89 (48 males and 41 females) Type: Division I NCAA sport or club sport participants Healthy control group n = 58 Age: 21.7 (3.5) y Height: 173.2 (9.4) cm Mass: 71.4 (12.2) kg Acute concussed group n = 21 Age: 20.5 (2.3) y Height: 174.4 (10.7) cm Mass: 72.8 (8.4) kg Prolonged recovery group n = 10 Age: 20.5 (2.7) y Height: 178.3 (9.9) cm Mass: 75.1 (8) kg	Design: prospective repeated-measures design with a known-groups approach Initial visit: - Acute group: ≤10-d postinjury - Prolonged recovery: >16-d postinjury - Healthy group: no concussions in past 6 mo Follow-up visits: - 2 wk after initial visit - 6 wk after initial visit Participants were given several symptom-oriented clinical tests, including gaze stabilization test, rapid eye horizontal, optokinetic stimulation, smooth-pursuit slow, and smooth-pursuit fast Oculomotor function was assessed: - NPC - King-Devick test	Not specified	There were differences between groups on NPC at the initial visit ( $F_{2,70} = 8.53$ , $P < .001$ ): - Acute concussed group performed worse than healthy control group ( $P = .02$ ) - Prolonged recovery group performed worse than healthy control group ( $P = .04$ ) - No significant differences between the acute concussed group and prolonged recovery group ( $P = .11$ ) There were no significant changes in NPC across time ( $F_{4,150} = 1.05$ , $P = .38$ ) NPC values at initial visit, mean (SD) Acute concussed: 5.37 (2.8) cm Prolonged recovery: 8.19 (5.3) cm Healthy controls: 3.41 (1.9) cm
Elbin et al <sup>17</sup>	n = 63 (44 males and 19 females) Type: concussed athletes Age: 15.53 (1.06) y	Design: prospective, repeated-measures Participants' performance on NPC was analyzed over time at the 3 time points: - Baseline/preinjury - 1- to 7-d postinjury 5.02 ± 1.73 d - 8- to 14-d postinjury 11.70 ± 1.95 d	Administered as part of VOMS Participant and examiner were seated, and the participant was instructed to focus on a small target (~14 point font) at arm's length and slowly bring it toward the tip of nose Participant was instructed to stop moving the target when they see 2 distinct images or examiner notices outward deviation of one eye Distance in centimeters between target and tip of the nose is recorded 3 trials are performed, and average is used Not specified	Scores at both time points postinjury were significantly worse compared with baseline ( $P \leq .05$ ) NPC values, mean (SD) Baseline: 1.63 (2.74) cm 1- to 7-d postinjury: 5.51 (6.78) cm 8- to 14-d postinjury: 3.23 ± 3.98 cm
Hellerstein et al <sup>34</sup>	n = 32 mTBI group n = 16 patients with mTBI Mean age: 38.88 y Control group n = 16 patients with non-TBI Mean age: 38.93 y Matched by age	Design: prospective, cohort study Testing protocol included a history, determination of refractive status and measurement of ocular motility, binocularity, and accommodation Only 10/16 patients with mTBI were able to respond to near vergence testing Time since injury not specified	Not specified	Significant differences were found between the 2 groups in NPC break ( $t = -4.019$ , $P = .001$ )

(continued)

**Table 2 (continued)**

Article	Participants	Methods	Method of administering NPC	Key results
Matuseviciene et al <sup>35</sup>	n = 45 mTBI group n = 15 (7 males and 8 females) Median age: 25 y (range: 18–39 y) n = 15 (11 males and 4 females) Median age: 27 y (range: 18–40 y) Noninjured control group n = 15 (9 males and 6 females) Median age: 26 y (range: 19–36 y)	Design: prospective, controlled, observational study Assessments were performed 4–13 and 81–322 d after injury, and included: - NPC - CISS - Visual acuity - Refractive error - Stereoacuity - Near point of accommodation - Facility of accommodation - Nonstrabismic eye-tum - Eye motility - Fusional vergence	Measured using the push-up method (Royal Air Force ruler)	NPC was receded in the mTBI group at baseline and statistically significantly improved at follow-up ( $P = .015$ )
McDevitt et al <sup>36</sup>	n = 72 (42 males and 30 females) Type: active college student athletes Age: 21.5 (3.4) y Healthy group 60 healthy participants Age: 21.7 (3.6) y Height: 68.3 (3.7) in Mass: 71.4 (12.2) kg Concussed group 12 concussed participants Age: 20.5 (1.8) y Height: 69.4 (4.2) in Mass: 72.8 (8.4) kg	Design: cross sectional with known groups approach Groups (healthy vs concussed) were compared for performance on NPC Single testing session Concussed group—seen 2–96 d postinjury (28 [31.87] d) Assessments included: - NPC - Sensory organization test - BESS - Horizontal eye saccades - Smooth-pursuit slow and smooth-pursuit fast - Optokinetic stimulation - Horizontal gaze stabilization test - Head thrust test - Dynamic visual acuity test - King–Devick test	Measured using convergence ruler (Bernell Corporation, Mishawaka, IN) Patient seated; ruler placed underneath his/her nose Participant fixated on the letter “F” in 14-point font as the experimenter moved the card toward the participant’s face; started 25 cm away and moved toward face at 1.5–2 cm/s Test was stopped once participant reported that the letter appeared double, and the measurement was recorded from the ruler in centimeters	The mean NPC distance was larger in the concussed group compared with the control group, but was not statistically significant ( $P = .069$ ) NPC values, mean (SD) Concussed group: 6.0 (4.1) cm Control group: 3.6 (2.2) cm
Mucha et al <sup>7</sup>	n = 142 Type: athletes Concussed group 64 concussed patients (36 males and 28 females) Age: 13.9 (2.5) y Control group 78 control participants (57 males and 21 females) Age: 12.9 (1.6) y	Design: cross sectional Groups (concussed vs control) were compared on performance on the VOMS, which includes a measure of NPC Concussed group was seen approximately 5.5 (4) d after injury	Participant and examiner were seated, and the participant was focused on small ~14-point font target at arm’s length and slowly bring it toward the tip of nose Participant was instructed to stop moving target when he/she saw 2 distinct images or when the examiner noticed outward deviation of one eye Distance in centimeters between target and the tip of nose was recorded 3 trials were performed; average of 3 trials was used Normal NPC values were considered within 5 cm	The mean NPC distance was significantly greater in the concussed group compared with the control group ( $P < .001$ ) NPC values, mean (SD) Concussed group: 5.9 (7.7) cm Control group: 1.9 (3.2) cm An NPC distance of $\geq 5$ cm increased the probability of correctly identifying concussed patients by 38%

(continued)

**Table 2 (continued)**

Article	Participants	Methods	Method of administering NPC	Key results
Szymano-wicz et al <sup>37</sup>	Concussed group 21 concussed patients (6 males and 15 females) Age: 45.7 (3.1) y Concussion participants were visually symptomatic Control group 10 control participants (3 males and 7 females) Age: 36.7 (5.4) y	Design: prospective and cohort study Groups (concussed vs control) were compared on performance on NPC Time since injury not specified	Not specified	The concussed group with visual symptoms had significantly worse NPC compared with the control group ( $P = .03$ ) NPC values, mean (SD) Concussed group: 13.98 (2.06) cm Control group: 7.03 (0.33) cm
Wright et al <sup>38</sup>	n = 72 Concussed group 14 (8 males and 6 females) concussed patients Age: 21.7 (3.5) y Control group 58 control patients (33 males and 25 females) Age: 21.7 (3.5) y	Design: cross-sectional All participants in concussion group were seen within 6 mo of injury; mean = 36 d (range: 10–120 d) Participants performed balance, vestibular, and oculomotor assessments, including - NPC - Virtual reality-based balance device - BESS - Optokinetic stimulation - Horizontal gaze stabilization test - Head thrust test	Standard push-up method	The mean NPC distance was significantly greater in the concussed group compared with the control group ( $P < .010$ ) NPC values, mean (SD) Concussed group: 7.51 (1.34) cm Control group: 3.42 (0.26) cm

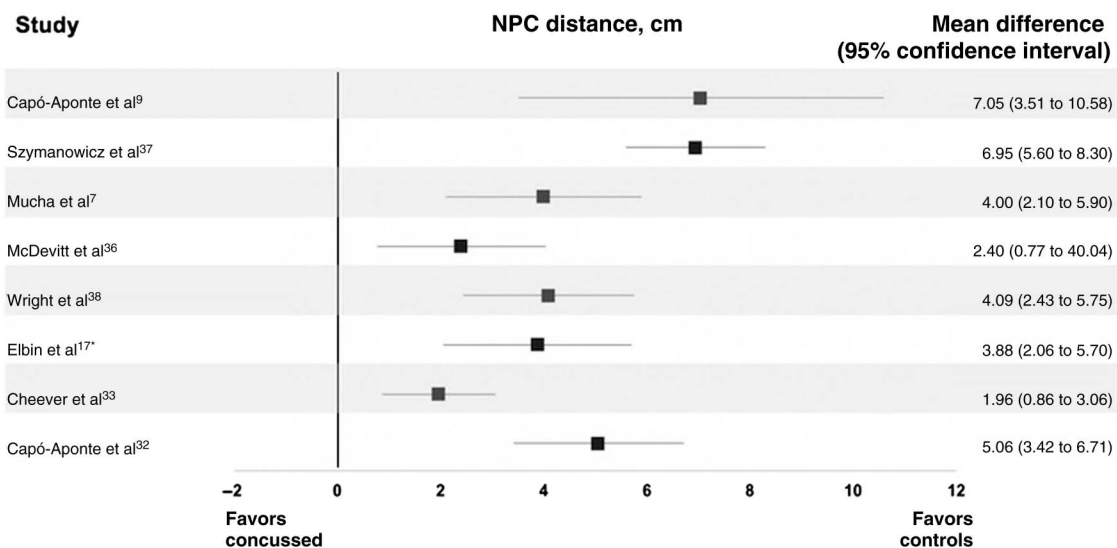
Abbreviations: BESS, Balance Error Scoring System; CISS, Convergence Insufficiency Symptom Survey; mTBI, mild traumatic brain injury; NCAA, National Collegiate Athletic Association; NPC, near point of convergence; mTBI, mild traumatic brain injury; VOMS, Vestibular/Ocular-Motor Screening.

design, only a single time-point measurement of NPC was discussed. Ten studies compared individuals' performance on NPC break following concussion to healthy controls, and one study used a pretest–posttest design, where participants acted as his/her own control. The studies had various patient populations, including military personnel (n = 3),<sup>9,31,32</sup> athletes (n = 4),<sup>7,17,33,36</sup> and the general population (n = 4).<sup>34,35,37,38</sup> The majority of the studies assessed young adults or adults (n = 10), and one study assessed the youth population. Initial assessments were performed anywhere from 1-day postinjury to 6-month postinjury. Follow-up assessments occurred from 1-week postinjury to 10-month postinjury. Four studies did not specify how long following injury the assessments were conducted. In all 11 studies, NPC was greater (worse) in patients following concussion compared with controls or pre-injury levels. Mean differences in NPC distance between concussed and healthy participants for the 9 studies that reported means and SDs are presented in Figure 2; 2 of the 11 studies did not report means or SDs.<sup>34,35</sup> Nine of the 11 studies demonstrated a statistically significant difference in scores, with worse NPC break measurements in the concussed participants compared with controls or the participant's own baseline measures.<sup>7,9,17,31–34,37,38</sup> Two studies<sup>35,36</sup> did not demonstrate a statistically significant impairment in NPC following concussion. McDevitt et al<sup>36</sup> demonstrated that the mean NPC distance was larger in the concussed group compared with the control group, but it was not statistically significant. Matuseviciene et al<sup>35</sup> demonstrated a significant improvement in the mTBI group between baseline and follow-up, but no statistically significant difference between or within the control groups. Two studies<sup>34,35</sup> did not report means for NPC but presented statistical results for the comparison of measures. All of the means presented for NPC during initial assessments following injury were abnormal (>5 cm). All of the means of the control groups were considered normal (<5 cm), except for in 2 of the studies, in which they were 8.18 cm<sup>32</sup> and 7.03 cm.<sup>37</sup>

Seven studies evaluated the effect of oculomotor or vision therapy on NPC break measurements in concussion/mTBI patients

(Table 3). The study designs were prospective observational trial (n = 4),<sup>24,41–43</sup> retrospective cohort (n = 1),<sup>40</sup> pilot study (n = 1),<sup>44</sup> and case report (n = 1).<sup>39</sup> All of the studies except for Kontos et al,<sup>41</sup> solely used vision or oculomotor therapy. Kontos et al<sup>41</sup> prescribed targeted therapies based upon the patient's deficits, and included behavioral, vestibular, vision, and exertion therapies. The majority of the studies examined the use of oculomotor therapy in adults (n = 6), and one study analyzed adolescents and young adults.<sup>24</sup> Half of the studies employed therapy with a combination of in-office vision therapy and at-home reinforcement,<sup>24,39,40</sup> whereas the remaining half used in-office therapy only.<sup>42–44</sup> One study did not specify the type of intervention.<sup>41</sup> Several studies did not specify the time frame that patients initiated rehabilitation, but those that did initiated therapy anywhere from 3-week postinjury<sup>39</sup> to 24-month postinjury.<sup>24</sup> All of the studies demonstrated NPC break values were lower (better) after therapy. All of the studies, except for the case study,<sup>39</sup> statistically compared participants' NPC break measurements pretherapy to posttherapy, and all 6 of them demonstrated that there was a statistically significant improvement in NPC break. Mean differences in NPC values pre-to-post vision therapy for the 3 studies that reported means and SDs are presented in Figure 3; four of the 7 studies did not report means or SDs. Even though NPC improved, the posttreatment NPC measures in studies that reported NPC measurements were still considered abnormal (>5 cm) in 3 of the studies<sup>41–43</sup> and normal (≤5 cm) in 3 of the studies.<sup>24,39,40</sup> The lengths of the interventions were not specified in many of the studies; those that reported information had total interventions lasting from 9 hours over 6 weeks of therapy<sup>42</sup> to 12 to 20 hours over 12 weeks of therapy.<sup>24</sup>

The QATQS resulted in 0—strong, 9—moderate, and 9—weak articles (Table 4). The majority of the articles satisfied the requirements for selection bias, study design, confounders, and data collection. None of the studies were double blinded, and very few studies (n = 3) were single blinded. In the majority of studies, it was difficult to identify if the participants were appropriately



**Figure 2** — Differences in near point of convergence (NPC) distance between concussed and healthy participants. Only the studies that reported means and SDs were included, as mean difference could otherwise not be calculated. The following studies did not report means or SDs: Hellerstein et al<sup>34</sup> and Matuseviciene et al.<sup>35</sup> There are 2 articles from Capó-Aponte et al,<sup>9,31</sup> but both articles reported the same exact same means and SDs, so the mean difference is only listed once. For all included studies, NPC was significantly better (smaller) in the control group. \*Elbin et al used preseason baselines from the same patients as the control values.



**Table 3 Summary of Studies Examining the Effect of Oculomotor of Vision Therapy on NPC Break Measurements in Concussion Patients**

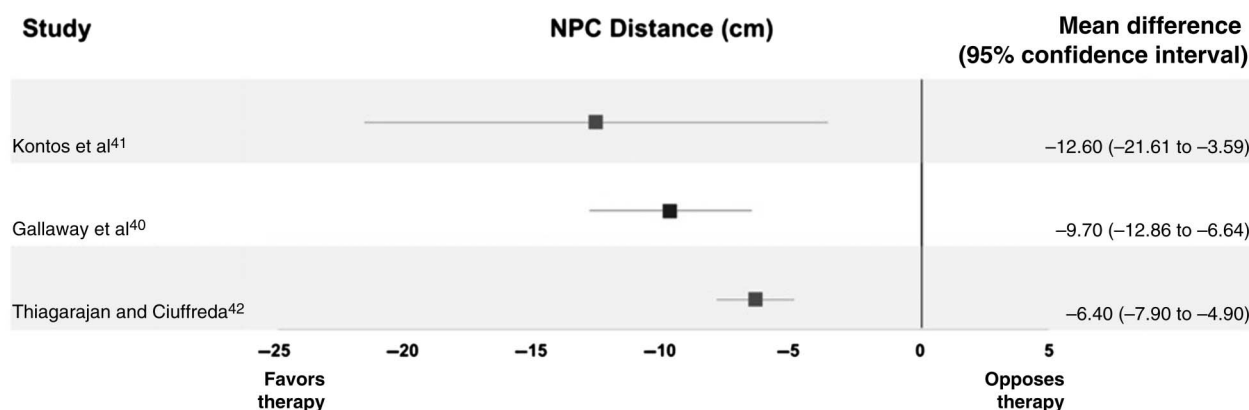
Article	Participants	Design/methods	Interventions	Outcome measures	Key results
Connolly and Lyon al <sup>39</sup>	n = 1 20-y-old female diagnosed with mTBI	Case report Patient was seen 3 wk following mTBI diagnosis	Vision therapy Weekly to bimonthly in-office vision therapy with at-home reinforcement Convergence Insufficiency Treatment Trial was used as guideline	NPC Cover test Von Graefe phorias Worth 4 Dot Stereopsis Accommodative facility Monocular estimate method Negative and positive relative accommodation Smooth vergence ranges	Patient's NPC improved following therapy. NPC values, mean (SD) Pretherapy: 45 cm Posttherapy: 0 cm (or bridge of nose)
Galloway et al <sup>40</sup>	n = 218 Concussion patients (58% female) Age: 20.5 y (range: 6–72 y) Patients with CI n = 43	Retrospective case series Records from an 18-mo period of patients who were referred for postconcussion vision problems were reviewed Seen at an average of 31-wk postconcussion	Vision therapy 45-min in-office sessions 1–2 d/wk and ~15 min/d home therapy for 3–5 d/wk	NPC Base-out and Sheard's criteria CISS	Patients with CI showed improvement in NPC from treatment ( $P < .0001$ ) NPC values, mean (SD) Pretherapy: 13.0 cm Posttherapy: 3.3 cm Vision therapy was successful in 85% of patients with CI (criteria: NPC < 6 cm, base-out > 20 or passed Sheard's criteria, and CISS < 16)
Kontos et al <sup>41</sup>	n = 26 (20 males and 6 females) Patients with chronic mTBI	Initial and 6-mo postintervention comprehensive mTBI assessment Patients were seen 1- to 3-y postinjury	Prescribed targeted interventions and therapies (eg, behavioral, vestibular, vision and exertion) based on their deficits "Coaches" worked individually with patients to facilitate interventions	Symptoms Cognitive measure VOMS, including NPC	NPC significantly improved from preintervention to postintervention ( $P = .003$ ) NPC values, mean (SD) Pretherapy: 21.0 (21.1) cm Posttherapy: 8.4 (8.8) cm
Scheinman et al <sup>24</sup>	n = 5 (2 adolescents and 3 young adults) Patients with concussion-related, symptomatic CI Age: 22.2 y (range: 12–20 y)	Prospective, observational trial Average of 11.6 mo (range of 2 to 24 mo) between concussion and first vision exam	Weekly office-based visual therapy with home reinforcement	Near exophoria CISS score NPC break Positive fusional vergence blur or break Vergence facility at near Near point of accommodation Accommodative facility	There were statistically and clinically meaningful changes in NPC break from before until after visual therapy ( $P = .008$ ) NPC values, mean (SD) Pretherapy: 17.2 cm Posttherapy: 4.7 cm
Thiagarajan and Ciuffreda <sup>42</sup>	n = 12 (4 males and 8 females) Patients with near vision symptoms following mTBI Age: 29 (3) y (range: 23–33 y)	Crossover; each participant acted as his/her own control Single blinded All participants were 1- to 10-y postinjury Pre/posttest Baseline measures Week 2–7: Intervention I (oculomotor or placebo) Week 8: repeat baseline measures Week 9–14: Intervention II (whichever one the patient has not already done; oculomotor or placebo) Week 14: Repeat baseline measures	Each Intervention: 2 sessions/wk, 60 min each, total of 9 h OMT included step vergence amplitude training, step vergence facility training, and ramp vergence training Placebo did not involve any disparity stimulation, because it's the primary drive for vergence system	Clinical measures (including NPC) Laboratory-based measures (mean response amplitude, peak velocity, time constant and steady-state response variability for both convergence and divergence) Subjective visual attention test CISS	There was a significant improvement in NPC break from baseline to posttraining ( $P = .01$ ), but they did not normalize NPC values, mean (SD) Pretherapy: 15.6 (2.3) cm Posttherapy: 9.2 (1.0) cm

(continued)

Table 3 (continued)

Article	Participants	Design/methods	Interventions	Outcome measures	Key results
Thiagarajan and Ciuffreda <sup>43</sup>	n = 12 All had medically documented mTBI Age: 29 (3) y	All participants were at least 1-y post-injury The study had the following phases: Baseline measures Oculomotor training Repeat baseline measures	6 wk of OMT Each session included 30 minutes of actual training and about 10 minutes of rest throughout Total training time of 6 h	Static accommodation and vergence measures, including NPC break and recovery Dynamic accommodation and vergence measures, including convergence peak velocity and divergence peak velocity	NPC break significantly improved from preintervention to postintervention ( $P < .05$ ) NPC values, mean (SD) Pretherapy: 15.6 cm Posttherapy: 9.2 cm
Thiagarajan and Ciuffreda <sup>44</sup>	n = 15 (4 males and 11 females) All had medically documented mTBI with brain injury Age: 31 (4) y	Pilot study Repeated measures All participants were 1- to 10-y postinjury Baseline clinical measures were administered and repeated at 3 mo and 6 mo following OMT	Each intervention: 2 sessions/wk for 6 wk	NPC break and recovery Monocular and binocular accommodative amplitudes Reading rate	NPC break improved with OMT ( $P < .01$ ) compared with baseline at both the 3- and 6-mo reassessments

Abbreviations: CI, convergence insufficiency; CISS, Convergence Insufficiency Symptom Survey; mTBI, mild traumatic brain injury; NPC, near point of convergence; OMT, oculomotor training; VOMS, Vestibular/Ocular-Motor Screening.



**Figure 3** — Differences in near point of convergence (NPC) distance pre-to-post vision therapy. Mean differences and 95% confidence intervals for NPC distance following vision therapy. Only the studies that reported means and SDs pretreatment and posttreatment were included, as mean difference could otherwise not be calculated. The following studies did not report means or SDs: Connolly and Lyon,<sup>39</sup> Scheiman et al,<sup>24</sup> and Thiagarajan and Ciuffreda.<sup>43,44</sup> For all included studies, NPC was significantly better (smaller) following vision therapy.

**Table 4** Quality Appraisal of Included Studies According to the Quality Assessment Tool for Quantitative Studies

Study	Selection bias	Study design	Confounders	Blinding	Data collection	Withdrawals	Overall rating
Capó-Aponte et al <sup>31</sup>	Moderate	Moderate	Weak	Moderate	Strong	Not applicable	Moderate
Capó-Aponte et al <sup>9</sup>	Moderate	Moderate	Weak	Moderate	Moderate	Not applicable	Moderate
Capó-Aponte et al <sup>32</sup>	Moderate	Moderate	Strong	Weak	Strong	Not applicable	Moderate
Cheever et al <sup>33</sup>	Moderate	Moderate	Weak	Weak	Strong	Not Applicable	Weak
Connolly and Lyon <sup>39</sup>	Weak	Weak	Strong	Weak	Strong	Strong	Weak
Elbin et al <sup>17</sup>	Moderate	Moderate	Strong	Weak	Strong	Strong	Moderate
Gallaway et al <sup>40</sup>	Moderate	Moderate	Strong	Weak	Moderate	Not applicable	Moderate
Hellerstein et al <sup>34</sup>	Moderate	Weak	Weak	Weak	Weak	Not applicable	Weak
Kontos et al <sup>41</sup>	Moderate	Moderate	Strong	Weak	Moderate	Weak	Weak
Matuseviciene et al <sup>35</sup>	Moderate	Moderate	Weak	Weak	Strong	Strong	Weak
McDevitt et al <sup>36</sup>	Moderate	Moderate	Moderate	Weak	Strong	Not applicable	Moderate
Mucha et al <sup>7</sup>	Moderate	Moderate	Moderate	Weak	Moderate	Not applicable	Moderate
Scheiman et al <sup>24</sup>	Weak	Moderate	Strong	Weak	Moderate	Weak	Weak
Szymanowicz et al <sup>37</sup>	Moderate	Moderate	Strong	Weak	Moderate	Not applicable	Moderate
Thiagarajan and Ciuffreda <sup>42</sup>	Weak	Moderate	Strong	Moderate	Strong	Weak	Weak
Thiagarajan and Ciuffreda <sup>43</sup>	Moderate	Moderate	Strong	Weak	Moderate	Weak	Weak
Thiagarajan and Ciuffreda <sup>44</sup>	Moderate	Moderate	Strong	Weak	Weak	Weak	Weak
Wright et al <sup>38</sup>	Moderate	Moderate	Strong	Weak	Moderate	Not applicable	Moderate

blinded. Overall, we rated the quality of evidence regarding performance on NPC break in patients diagnosed with a concussion as moderate and the evidence regarding the effect of oculomotor or vision therapy on NPC break measurements as low using GRADE.

### Discussion

It is important to understand the various impairments that occur following concussion in order to create effective, evidence-based treatment paradigms. While vision assessments, such as NPC, are starting to be implemented in clinical concussion evaluations, there is little information about how these measures should be used in the evaluation and treatment of concussion. In this article, we aimed to evaluate the current literature to determine the effect of concussion

on NPC and the effect of oculomotor or vision therapy on NPC break measurements in concussion patients. The key findings of this systematic review are that concussion patients have impaired NPC acutely following concussion, and oculomotor rehabilitation can improve NPC break measurements in concussion patients. The NPC values of concussed participants mentioned in this review ranged from 5.37<sup>33</sup> to 13.98 cm,<sup>37</sup> indicating that the scores were considered abnormal in all of the studies. However, Szymanowicz et al’s population<sup>37</sup> may not be representative of all concussion patients, because only patients who were experiencing visual symptoms were included in the study. In comparison, the preinjury values or control group values for NPC ranged from 1.63<sup>17</sup> to 8.18 cm<sup>32</sup> and were considered normal in most of the studies. These findings suggest that receded NPC is common following concussion. Therefore, including NPC as part of a multifaceted approach

to the evaluation of concussion may lead to an increased sensitivity and specificity of the test battery. While the sensitivity and specificity of NPC as a single measure in evaluating concussion is unclear, an NPC break of  $\geq 5$  cm has a high rate (84%) of identifying concussions and an area under the curve of 0.73.<sup>7</sup> McDevitt et al<sup>36</sup> recently reported that a battery including signs and symptoms scores for 2 vision tests (optokinetic stimulation and gaze stabilization tests) and NPC was a sensitive model for discriminating concussed athletes from healthy controls (accuracy = 94.4%). Similarly, a test battery of NPC, and number of symptoms following the rapid eye horizontal, optokinetic stimulation, and gaze stabilization tests differentiated between healthy and concussed athletes with an accuracy of 90%.<sup>33</sup> Additionally, the Vestibular/Ocular-Motor Screening, which includes NPC, demonstrated internal consistency and sensitivity in identifying concussion patients.<sup>7</sup> This suggests that while NPC is a very valuable concussion assessment, clinicians should continue to use a multifaceted approach that incorporates multiple systems of the body. There is moderate evidence that clinicians should implement NPC as part of a visual screening following concussion. Clinicians should consider tools that assess not only NPC, but multiple components of vision that are sensitive to concussion, including vestibular ocular reflex and visual motion sensitivity. Several screening tools and surveys are available to clinicians, such as the Vestibular/Ocular-Motor Screening, the King-Devick test (assesses saccadic eye movements), the Convergence Insufficiency Symptom Survey, and the Dizziness Handicap Inventory.

Deficits in NPC can lead to vision- and oculomotor-related symptoms, such as blurred vision, headaches, difficulty in reading, eyestrain, sleepiness, and difficulty concentrating.<sup>45,46</sup> Visual dysfunction following concussion is also associated with decreased reading speed and comprehension.<sup>22</sup> Athletes with CI following a sport-related concussion have worse neurocognitive impairment and higher symptoms scores than concussion patients with normal NPC.<sup>16</sup> Specifically, athletes with CI had lower scores on measures of verbal memory, visual motor speed, and reaction time.<sup>16</sup> The symptoms and combination of visual and cognitive deficits caused by receded NPC can result in difficulty returning to school or working, especially when completing tasks that require reading and writing.<sup>47</sup> Clinicians should monitor NPC throughout the recovery process. Patients with impaired NPC may particularly benefit from academic or cognitive accommodations. Appropriate accommodations would include reducing the use of electronic devices, reducing brightness on screens, and considering the use of audio recordings to replace reading or note taking.<sup>48</sup> Oculomotor dysfunction can also cause motor deficits. Adolescents with receded NPC following concussion have more gait-related deficits compared with healthy controls, suggesting that abnormal NPC may be related to motor system dysfunction.<sup>19</sup> Therefore, it is imperative that NPC has returned to normal before athletes return to play. NPC break is a quick and easy measurement that can be used by clinicians to identify receded NPC. Concussion patients with receded NPC should be referred to a vision specialist for a more thorough examination to determine associated oculomotor impairments.<sup>20</sup> While the timeline of referral is unclear, clinicians should monitor performance on NPC throughout the recovery process, and if patients are getting worse, or still have significant impairments 2 to 3 weeks following concussion, then a referral to a vision specialist should be considered. The patient population should be considered when determining the timing of referral. For example, college athletes typically recover from sport-related concussion in about 7 days,

while high school athletes typically recover in 15 days.<sup>49</sup> Therefore, referral should be considered sooner for college athletes.

Receded NPC in an otherwise healthy population is treatable through vision therapy. Randomized clinical trials have demonstrated the effectiveness of office-based vergence/accommodative therapy in the treatment of children with symptomatic CI.<sup>24-26</sup> Currently, there are no randomized clinical trials examining the effectiveness of vision therapy in the treatment of receded NPC following concussion. It is possible that individuals diagnosed with concussion, presenting with visual or oculomotor deficits could benefit from vision or oculomotor therapy. Tailoring rehabilitation to deficits will allow clinicians to better focus interventions and treatment. Based on the 7 studies we reviewed, we assigned a GRADE rating of low level of evidence supporting the use of oculomotor or vision therapy to improve NPC break measures in patients diagnosed with concussion. All of the studies demonstrated improvements in NPC break measures following treatment. Therapy also improved symptoms, verbal memory, balance, and other visual measures.<sup>50</sup> Most studies used a combination of office-based therapy and home reinforcement. Therapy typically included vergence-based exercises, and spectacle lenses to reduce symptoms. NPC mean improvements reported ranged from 5.4<sup>24</sup> to 12.6 cm,<sup>50</sup> while the case report demonstrated improvement of 45 cm.<sup>39</sup>

Although all of the studies demonstrated an improvement in NPC values following therapy, the mean NPC values were still considered abnormal in several studies.<sup>24,40,51</sup> Thiagarajan and Ciuffreda<sup>44</sup> suggests that the oculomotor therapy needs to be longer in order for scores to normalize. The lengths of the interventions were not specified in many of the studies. The length of reported interventions ranged from 9 to 20 hours over 6 to 12 weeks.<sup>24,27</sup> In individuals diagnosed with CI who are otherwise healthy, oculomotor therapy administered over 12 weeks resulted in a normalization of scores.<sup>52</sup> This may suggest that receded NPC in concussed patients may be due to a different mechanism than in an otherwise healthy population.<sup>27</sup> However, the improvements in NPC following oculomotor therapy were still present 6 months following therapy in concussion patients.<sup>44</sup> The persisting effect of oculomotor therapy suggests that mechanisms of neuroplasticity and motor relearning remain intact in concussion patients.<sup>44</sup> There are a variety of treatments available for addressing impaired NPC, including both office- and home-based programs. Office-based treatments are typically administered by a vision therapist (O.D., M.D., orthoptists, or vision therapy-trained technicians) and often includes the use of Brock Strings, Barrel Cards, Vectograms, and Life-Saver cards.<sup>26</sup> Home-based therapy is often prescribed by optometrists and ophthalmologists, and it provides a cost-effective option.<sup>53</sup> Home-based therapies typically include simple exercises, such as pencil push-ups and computer-based software. Several software programs and web-based applications have been developed for vision therapy, such as CVS, Computerized Home Vision Therapy Systems, Vision Therapy Solutions, and Oculomotor Therapy Program. The treatment of CI is beneficial, with 85% of patients having a successful outcome.<sup>40</sup> Treatment of accommodative insufficiency was only successful in 33% of patients, and treatment of saccadic dysfunction was successful in 83% of patients.<sup>40</sup> Therefore, concurrent or underlying oculomotor dysfunctions associated with receded NPC may play a role in how a patient responds to therapy. It is important to determine if specific oculomotor deficits (eg, CI or an accommodative disorder) or individual characteristics (eg, age, sex, and medical history) influence whether or not those with receded NPC recover spontaneously or require therapy, and whether or not they respond to therapy.

While the results of this systematic review are promising, showing that impaired NPC following concussion can be improved through oculomotor therapy, more research in this area is needed. NPC values reported in the literature and in this systematic review vary greatly. Differences in mean NPC values could be due to differences in ages of the patient populations or the type of target or assessment used to measure NPC, which was not specified in several studies. In order to aid in interpretation and clinical implications of findings, future studies should specify the target type and methods used for the assessment of NPC. Additionally, there is little information about normative values on NPC for athletes. Given that concussions are common in sports, future studies should determine if current cutoff scores for abnormal NPC in the general population are applicable to athletes. Additionally, the effect of age on NPC measures should be further established. It is possible that a baseline postinjury comparison would be more accurate than clinical cutoffs at diagnosing deficits in athletes. Several of the studies included in this systematic review examined non-sport-related mechanisms of injury (eg, jumping from an airplane, blast exposure, motor vehicle accidents or assault) and severities of injury that may not be generalizable to sport-related concussion.<sup>32</sup> Additionally, data were collected at fairly large time intervals following concussion, so more information about recovery trajectories for NPC following concussion is necessary. Furthermore, several of the studies included in this review seem to report redundant data with the same or very similar findings in both studies by the same first author.<sup>9,31,43,51</sup> Finally, studies often failed to control for factors that may affect NPC, such as age; sex; and history of visual, oculomotor, or vestibular abnormalities. Future studies should determine factors that affect whether or not individuals experience abnormal NPC following concussion. It is suggested that a history of ocular motor dysfunction, such as nystagmus or strabismus may be risk factors for poor outcomes following concussion.<sup>5</sup> Therefore, future studies should take these potential confounding variables into account when evaluating NPC postconcussion.

Randomized, controlled studies determining whether or not performing vision therapy improves NPC and other visual measures (such as accommodation, saccades, etc) in order to aid in recovery following concussion are needed. Additionally, future studies should focus on the best timeline for implementing visual rehabilitation. In the current studies, 3-week postinjury<sup>39</sup> is the earliest oculomotor rehabilitation was initiated, while several studies waited at least 1 year following injury to initiate rehabilitation.<sup>41–44</sup> With timelines for implementing therapy being so widespread, it is unclear what timeframe is most beneficial for treatment of CI following concussion. It is possible that initiating oculomotor therapy earlier in the rehabilitation process may result in improved recovery. Future studies should focus on identifying the best timeline for implementing oculomotor rehabilitation in post-concussion patients with visual dysfunction.

This systematic review is not without its limitations. Due to the mix of observational and interventional studies and the lack of clinical trials, an in-depth analysis of methodological quality and risk of bias was not included. In addition, because of the small number of studies that included a repeated-measures evaluation of NPC in concussion patients, and the heterogeneity of the patient populations and study designs, a meta-analysis was not performed. While we were able to include 18 articles in this review, the majority of articles did not meet requirements for blinding. The relevance of blinding varies according to the circumstances and is less important for studies using objective outcomes.<sup>54</sup> If the

blinding component of the QATQS was not considered when determining the overall rating, then 7 of the studies would have been categorized as strong, 6 as moderate, and 5 as weak. However, using the overall rating according to the QATQS, the articles were considered moderate (n=9) and weak (n=9). Additionally, one of the articles is a case report, and is therefore a low level of evidence and is not sufficient to generate clinical recommendations. The overall rating of evidence for the clinical recommendations presented in this paper based on GRADE is low to moderate. Therefore, the findings from studies with lower levels of evidence need to be cautiously evaluated, before they are implemented into clinical practice. This highlights the need for higher level studies, such as randomized control trials, evaluating the effects of concussion on NPC and the efficacy of oculomotor and vision therapy in the treatment of CI following concussion.

## Conclusions

This review evaluated the available literature on the effect of concussion on NPC break measures and the effect of oculomotor or vision therapy on NPC break measurements. The results suggest that individuals have impaired NPC following concussion, and that vision therapy improves NPC in concussion patients. While the results of the review are promising, there is a lot of heterogeneity in the patient populations and methodology in the studies included in this review. Given the available evidence, we conclude that NPC should be included as an assessment following concussion in order to determine the patients who need referral for further evaluation and may benefit from vision or oculomotor therapy to promote recovery. Future research should continue to explore factors affecting convergence following concussion and include randomized, controlled studies to determine whether or not performing vision therapy improves visual measures to promote recovery following concussion.

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