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ORIGINAL ARTICLE

Vergence and accommodation deficits in paediatric and adolescent patients during sub-acute and chronic phases of concussion recovery

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Abstract

Introduction: Visual function deficits have been reported in adolescents following concussion. We compared vergence and accommodation deficits in paediatric and adolescent patients at a tertiary medical centre in the sub-acute (15 days to 12 weeks) and chronic (12 weeks to 1 year) phases of concussion recovery.

Methods: The study included patients aged 7 to <18 years seen between 2014 and 2021, who had a binocular vision (BV) examination conducted within 15 days and 1 year of their concussion injury. Included patients had to have 0.10 logMAR monocular best-corrected vision or better in both eyes and be wearing a habitual refractive correction. BV examinations at near included measurements of near point of convergence, convergence and divergence amplitudes, vergence facility, monocular accommodative amplitude and monocular accommodative facility. Vergence and accommodation deficits were diagnosed using established clinical criteria. Group differences were assessed using nonparametric statistics and ANCOVA modelling.

Results: A total of 259 patients were included with 111 in the sub-acute phase and 148 in the chronic phase of concussion recovery. There was no significant difference in the rates of vergence deficits between the two phases of concussion recovery (sub-acute = 48.6%; chronic = 49.3%). There was also no significant difference in the rates of accommodation deficits between the two phases of concussion recovery (sub-acute = 82.0%; chronic = 77.0%).

Conclusion: Patients in both the sub-acute and chronic phases of concussion recovery exhibited a high frequency of vergence and accommodation deficits, with no significant differences between groups. Results indicate that patients exhibiting vision deficits in the sub-acute phase may not resolve without intervention, though a prospective, longitudinal study is required to test the hypothesis.

KEYWORDS
accommodation, adolescent, binocular vision, concussion, paediatrics, vergence

INTRODUCTION

Concussions are a common form of mild traumatic brain injury (mTBI); a recent study estimated that 1.1–1.9 million sports and recreation-related concussions occur in children and adolescents every year.[1] Although concussion symptoms often resolve within 2–4 weeks of injury, some paediatric patients experience ongoing symptoms for >3 months.[2–4]

Oculomotor deficits and vision symptoms are common in the acute phase of concussion injury (≤14 days) and can continue throughout a prolonged recovery.[5–9] Children and adolescents with persistent concussion symptoms often complain of blurred vision, diplopia, light sensitivity, eye fatigue and strain, which can affect their ability to perform in school or sports.[10,11] One prospective study found that 70% of symptomatic adolescents evaluated 4- to 12-weeks post-concussion had one or more oculomotor deficits, suggesting the importance of a comprehensive vision evaluation after injury.[12] It is unknown whether chronically symptomatic patients exhibit the same deficits and symptoms as there has not been a comprehensive assessment of visual function in patients beyond 12-week post-concussion.

At our institution, symptomatic concussion patients receive a comprehensive vision evaluation when referred to providers in the Department of Ophthalmology specifically for vision symptoms, or when they are evaluated at the multidisciplinary concussion clinic (MDCC) for a wide range of post-concussion symptoms.[13] This study aimed to characterise vergence and accommodation deficits among paediatric patients in the sub-acute (15 days to 12 weeks) and chronic phases (>12 weeks to 1 year) of concussion recovery.[2,12,14–16]

Key points

- Children and adolescents can experience visual function deficits after concussion, which can greatly impact their quality of life.
- This study compared binocular vision findings for patients in the sub-acute (15 days to 12 weeks) and chronic (12 weeks to 1 year) phases of concussion recovery.
- Sub-acute and chronic patients exhibited vision deficits at a high frequency and there were no significant differences between the groups.

METHODS

We conducted a retrospective chart review of patients with a diagnosis of concussion seen by the senior author (AR) at our institution through the Department of Ophthalmology outpatient clinic (referred) or the MDCC from July 2014 to December 2021. This study was approved by the institutional review board. Patients aged 7 to <18 years were included if they had complete binocular vision examinations (described below) and a distance visual acuity of 0.10 logMAR or better in each eye using their habitual correction, if worn. Patients with hyperopia > +2.00 D, myopia < −1.00 D, astigmatism > 1.25 D or anisometropia > 1.00 D had to be wearing their habitual refractive error correction or be tested in trial lenses to be included. If requiring correction, hyperopia could not be symmetrically reduced by more than 1.50 D, myopia and astigmatism had to be corrected within 1.00 D and the cylinder axis had to be within ±10° if astigmatism was >1.00 D. Exclusion criteria included amblyopia, constant strabismus for distance and near, malingering or conversion syndrome diagnosis from a board-certified psychologist and ocular pathology that may impact vergence or accommodative measures.

Concussion diagnoses were made by a physician in accordance with the Consensus Statement on Concussion in Sport; patients were diagnosed after experiencing an impulsive force to the head or neck causing neurologic dysfunction or symptoms without signs of diffuse structural injury.[17] Patients with evaluations between 15 days and 1 year after their concussion injury were included. Patients were grouped based on the time from injury. The sub-acute phase included patients with evaluations between 15 days and 12 weeks from their concussion injury while the chronic phase included patients with evaluations >12 weeks and <1 year from their injury.[13–15]

The comprehensive binocular vision evaluation included assessment of eye alignment (cover uncover and prism alternate cover test [PACT] at distance and near), stereoacuity and measures of vergence and accommodation at near. Vergence measures included near point of convergence (NPC) from the lateral canthus or the forehead, convergence and divergence amplitudes and vergence facility at near (VF). Accommodation measures included monocular accommodative amplitude (AA) and monocular accommodative facility (MAF). Detailed descriptions of measures can be found elsewhere.[18] Accommodative measures from the right eye were used for analysis. If more than one measure was obtained for an individual test, the average was reported and used for analysis. Table 1 lists the criteria used to diagnose vergence and accommodation deficits.

The frequency of oculomotor deficits was reported for the sub-acute and chronic phases of concussion recovery. Categorical data are presented as frequency; continuous data are presented as median and interquartile range or mean and standard deviation. Data were analysed using non-parametric methods including chi-square, Fisher's exact test, Kruskal–Wallis and Wilcoxon rank-sum tests to assess group and subgroup differences with a 0.05 alpha level. A one-way analysis of covariance (ANCOVA) was used to analyse the effect of concussion phase on clinical tests while controlling for clinic, sex, age and the number of past concussions. Linear and logistic regression were used to estimate the effects of significant covariates. Statistical analyses were performed using R Statistical Software (version 4.2.2, r-project.org).

RESULTS

Of the 413 records reviewed, 259 met the inclusion criteria. In total, 154 patients were excluded: 69 due to their age at the time of visit (<7 or >18 years), 28 due to

TABLE 1 Diagnostic criteria for vergence and accommodation disorders.

Convergence insufficiency	
First criterion and one other must be met	
Exophoria at near	4Δ or greater than magnitude at distance
Near point of convergence	>7 cm break
Convergence amplitude at near	≤15Δ convergence break or Sheard's criterion[a] not met
Vergence facility (3Δ BI/12Δ BO)	≤9 cpm; difficulty fusing BO prism
Convergence deficit	
First criterion and one other must be met	
NPC	>7 cm break
Convergence amplitude at near	≤15Δ convergence break or Sheard's criterion[a] not met
Vergence facility (3Δ BI/12Δ BO)	≤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 divergence break or Sheard's criterion[a] not met
Vergence facility (3Δ BI/12Δ BO)	≤9 cpm; difficulty fusing the BI prism
Divergence deficit	
Both criteria must be met	
Divergence amplitude at near	<8Δ divergence break or Sheard's criterion[a] not met
Vergence facility (3Δ BI/12Δ BO)	≤9 cpm; difficulty fusing the BI prism
Fusional vergence dysfunction	
Either criterion is met	
Vergence amplitudes	Divergence <8Δ break and convergence ≤15Δ break
Vergence facility (3Δ BI/12Δ BO)	≤9 cpm; difficulty fusing with both BI and BO prism
Accommodative insufficiency	
Either criterion must be met	
Amplitude of accommodation	>2.5 D and <Hofstetter's minimum age-appropriate value[b]
Accommodative facility (±2.00 D)	≤6 cpm and difficulty with −2.00 D lens
Accommodative excess	
Accommodative facility (±2.00 D)	≤6 cpm and difficulty with +2.00 D lens
Accommodative infacility	
Accommodative facility (±2.00 D)	≤6 cpm and difficulty with +2.00 D and −2.00 D lens
Accommodative dysfunction	
Both criteria must be met	
Accommodative amplitude	>2.5 D and <Hofstetter's minimum age-appropriate value[b]
Accommodative facility (±2.00 D)	≤6 cpm; difficulty with +2.00 D lens

Abbreviations: Δ, prism dioptre; BI, base-in; BO, base-out; cpm, cycles per minute; D, dioptres; NPC, near point of convergence; SD, standard deviation.

[a]Compensating vergence amplitudes (positive or negative fusional vergence) of at least twice the magnitude of the near heterophoria.

[b]<(15−0.25 [age in years]) − 2 D.

concussion injury occurring more than a year before their examination, 24 due to visual acuity worse than 0.10 logMAR in at least one eye, 10 related to uncorrected refractive error or incorrect habitual correction, 22 had incomplete oculomotor examinations and 1 had an initial examination outside of the dates of interest. Of the included patients, 92 were male and 167 were female. The median age was 15.3 years (IQR: 13.6, 16.8 years). The median time from concussion injury to evaluation was 101 days (58, 166 days). The median number of lifetime concussions was 1 (1, 2); 43.2% (112/259) had more than one concussion. 56.4% (146/259) of the concussions were sports related, 43.6% (113/259) were not sports-related (motor vehicle accidents = 11.2%, 29/259; other causes = 32.4%, 84/259). Some (54.4%, 141/259) were seen in the Department of Ophthalmology outpatient clinic (referred). A total of 111 of the included patients were in the sub-acute phase of recovery and 148 were in the

TABLE 2 Patient characteristics.

	Sub-acute (15–84 days from concussion injury) ($n = 111$)	Chronic (85–365 days from concussion injury) ($n = 148$)	Statistical comparisons
Age (years)	15.3 (13.6, 16.8)	15.4 (13.6, 16.8)	$W = 7989$, $p = 0.71$
Sex (female)	66 (59.4%)	101 (67.8%)	$\chi^2 = 2.1$, $p = 0.14$
Outpatient clinic (referred)	64 (57.7%)	77 (52%)	$\chi^2 = 0.63$, $p = 0.43$
Outpatient multidisciplinary concussion clinic (MDCC)	47 (42.3%)	70 (48%)	$\chi^2 = 0.63$, $p = 0.43$
Number of concussions	2 (1, 3)	1 (1, 2)	$W = 9631$, $p = 0.008$
>1 lifetime concussion	58 (52.3%)	54 (36.5%)	$\chi^2 = 5.8$, $p = 0.02$
Mechanism of concussion			
Sports related	57 (51.4%)	89 (60.1%)	$\chi^2 = 2.0$, $p = 0.16$
Non-sports related	54 (48.6%)	59 (39.9%)	$\chi^2 = 2.0$, $p = 0.16$
Time from concussion to vision assessment (days)	53 (39.5, 69)	155 (116, 226)	$H = 190$, $p < 0.001$

Note: Data are presented as frequency (percentage) for categorical data and median (interquartile range: 25–75) for continuous data. Group differences were assessed using chi-squared tests (χ^2) for categorical data and Wilcoxon rank-sum (W) and Kruskal–Wallis (H) tests for continuous data.

chronic phase. Table 2 summarises the demographic and clinical characteristics of included patients by concussion temporality (sub-acute, chronic).

Vergence

There was no significant difference in the rates of vergence deficits between the two phases of concussion recovery (sub-acute = 48.6% [54/111]; chronic = 49.3% [73/148], $\chi^2 = 0.01$, $p = 0.91$). Furthermore, there were no significant differences in the values or frequency of abnormal findings between the sub-acute and chronic phases for NPC, exophoria, esophoria, convergence amplitude, divergence amplitude or vergence facility (Figure 1 and Table 3). NPC was the most frequently abnormal test for both groups (Figure 1 and Table 3). There were also no significant differences in the frequency of vergence diagnoses (Figure 1b and Table 3).

In our ANCOVA model, clinic and sex emerged as significant covariates of the effect of concussion phase on the NPC break point, controlling for age and the number of past concussions ($F = 2.9$, $p = 0.02$). Patients referred directly for vision issues had a more receded NPC (10.7 ± 6.3 cm) compared to those seen in MDCC (9.1 ± 5.1 cm; $F = 4.9$, $p = 0.03$). This corresponded with a significant difference in the frequency of abnormal NPC values (referred = 70.4% [100/142] vs. MDCC = 53.8% [63/117]; $\chi^2 = 6.9$, $p = 0.009$). Males had a more receded NPC than females (11.3 ± 7.6 cm vs. 9.2 ± 4.5; $F = 7.1$, $p = 0.01$), although this did not correspond with a significant difference in abnormal values (males = 67.4% [62/92] vs. females = 60.4% [101/167]; $\chi^2 = 0.94$, $p = 0.33$). Age was a significant covariate for vergence facility at near ($F = 3.7$, $p = 0.003$); on average, 1-year increase in age corresponded to 0.6 (95% CI: 0.3–0.9, $p < 0.001$) increase in cycles per minute ($F = 14.0$, $p < 0.001$). This corresponded with a log-odds of an abnormal vergence facility test decrease by 0.13 (95% CI: 0.007–0.24, $p = 0.04$) for every 1-year increase in age. Demographic factors were not otherwise significant covariates in clinical tests of vergence.

Accommodation

Sub-acute patients had a slightly higher rate of accommodation deficits compared to chronic patients, though this was not a significant difference (82.0%, 91/111 vs. 77.0%, 114/148; $\chi^2 = 0.94$, $p = 0.33$). There was not a significant difference in the rates of abnormal accommodation diagnosis without a co-occurring vergence diagnosis (38.7%, 43/111 vs. 37.6%, 56/148; $p = 0.88$, $\chi^2 = 0.02$). There were no significant differences in values or frequency of abnormal values for amplitude of accommodation and accommodative facility tests (Figure 2a and Table 4) between the two phases. There were also no significant differences in accommodation diagnoses (Figure 2b and Table 4).

In our ANCOVA model, clinic setting was a significant covariate of the effect of concussion phase on amplitude of accommodation when controlling for sex, age and number of past concussions ($F = 3.2$, $p = 0.009$). Referred patients had a more reduced amplitude of accommodation (8.7 ± 2.3 D) compared to MDCC patients (9.9 ± 2.6; $F = 15.3$, $p < 0.001$). Correspondingly, referred patients had a significantly higher frequency of abnormal values for amplitude of accommodation than MDCC patients (referred = 54.2% (77/142) vs. MDCC = 38.5% (45/117); $\chi^2 = 1.8$, $p = 0.02$). Demographic factors did not otherwise emerge as significant covariates for measures of accommodation.

DISCUSSION

Binocular vision deficits can contribute to prolonged symptoms post-concussion. In this study, we compared the frequencies of vergence and accommodation deficits

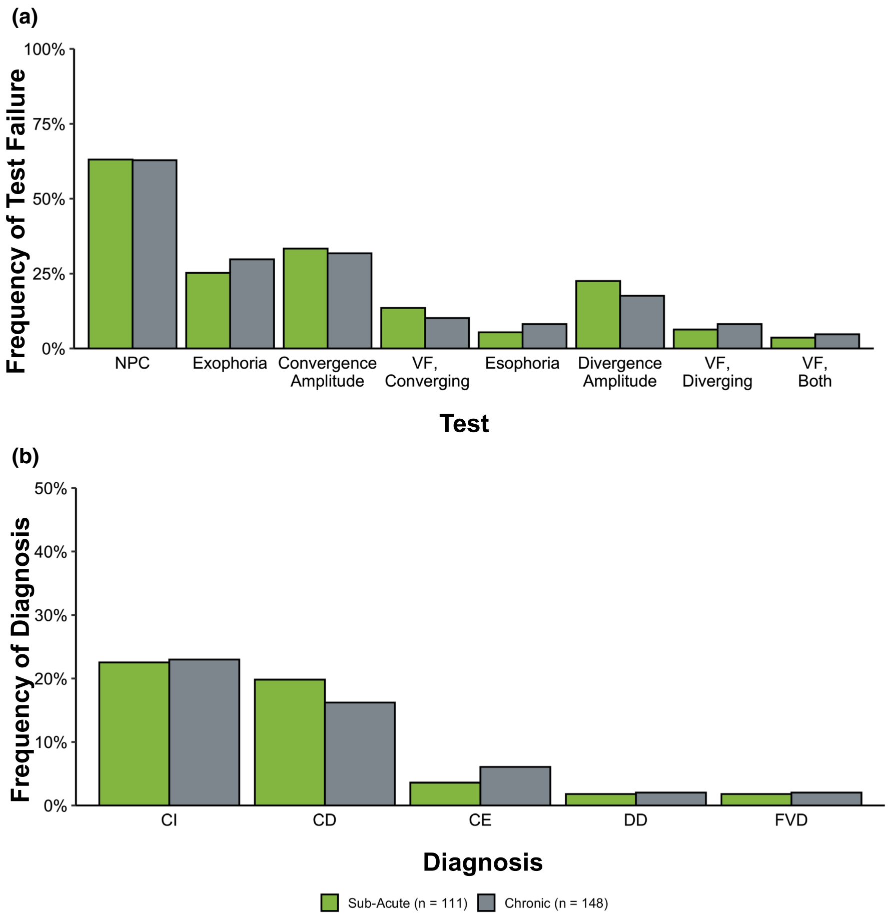

FIGURE 1 Frequency of vergence test failure and diagnosis by phase of concussion recovery. (a) Frequency of abnormal vergence findings for sub-acute ($n = 111$) and chronic ($n = 148$) patients. (b) Frequency of vergence diagnoses among the sub-acute and chronic patients. There were no significant differences between groups for any test in (a) or diagnosis in (B). CD, convergence deficit; CE, convergence excess; CI, convergence insufficiency; DD, divergence deficit; FVD, fusional vergence dysfunction; NPC, near point of convergence; VF, vergence facility.

in different phases of concussion recovery in a paediatric population. Overall, we observed no significant differences in the rates of oculomotor disorders and clinical findings between the two phases of concussion recovery. We found that nearly half of both sub-acute and chronic patients were diagnosed with vergence disorders. This is slightly lower than the 60% of participants reported to have vergence disorders in a prospective study of sub-acute, paediatric patients[12]; differences in diagnostic criteria could explain this disparity. For example, Scheiman et al.[12] included distance vergence facility in their testing battery for diagnosing vergence disorders and a ≥6-cm cut-off for NPC break, while this study used >7 cm to account for measurements taken from the lateral canthus and remain consistent with our study group's prior retrospective studies. Our findings for rates of accommodative disorders (82% for sub-acute patients and 77% for chronic patients) were higher than those reported by Scheiman et al. (57%). This difference could stem from the higher rates of failure for accommodative facility testing in the present study. Slight differences in instruction or testing methodology could explain the lower MAF values of patients in this study compared to established norms; for example, asking patients to report if the letters were clear or asking them to read a word aloud on each flip.

Receded NPC was the most common abnormal vergence measure, but not all of the patients with a receded NPC met the criteria for convergence insufficiency or convergence deficit. Some who failed NPC had no diagnosed deficit or only an accommodative disorder, while several had a diagnosis of convergence excess. This finding expands on previous observations that receded NPC is not indicative of convergence insufficiency or even a vergence disorder in concussed children and adolescents.[12,19] A possible explanation for abnormal NPC without other indicators of reduced convergence ability is the effect of having a target moving towards the participant, also known as optic flow. The observer is asked to fixate on a target that is looming towards their nose, simulating radial expansion, a visual stimulus that requires higher order processing.[20] A study of children with mTBI revealed that concussed children performed significantly worse at a psychophysical task of identifying radial expansion and contraction acutely after injury compared to controls.[21] Patients with

TABLE 3 Comparing clinical tests and vergence diagnoses between sub-acute and chronic concussion phases.

	Values			Frequency of abnormal values		
Tests	**Sub-acute**	**Chronic**	**Statistical comparisons**	**Sub-acute**	**Chronic**	**Statistical comparisons**
Near point of convergence break (cm)	9 (6.5–12)	8.5 (6–12)	$W=8646$, $p=0.47$	63.1% (70/111)	62.8% (93/148)	$\chi^2=0.0014$, $p=0.97$
Exophoria (Δ)	4 (2.5–6)	4.5 (2–7.5)	$W=1754$, $p=0.58$	25.2% (28/111)	29.7% (44/148)	$\chi^2=0.64$, $p=0.42$
Esophoria (Δ)	2 (1–2.5)	2 (1.4–3.6)	$W=535$, $p=0.68$	5.4% (6/111)	8.1% (12/148)	$\chi^2=0.72$, $p=0.40$
Convergence amplitude (Δ)	20 (13–30)	18 (14–30)	$W=8339$, $p=0.83$	33.3% (37/111)	31.8% (47/148)	$\chi^2=0.07$, $p=0.78$
Divergence amplitude (Δ)	10 (8–12)	10 (8–12)	$W=7578$, $p=0.28$	22.5% (25/111)	17.6% (26/148)	$\chi^2=0.98$, $p=0.32$
Vergence facility (cpm)						
Difficulty						
Base-out	10 (6.5–12.5)	9.5 (7.5–13.5)	$W=250$, $p=0.88$	13.5% (15/111)	10.1% (15/148)	$\chi^2=0.71$, $p=0.40$
Base-in	9.5 (7–13.5)	11 (7–13.5)	$W=565$, $p=0.56$	6.3% (7/111)	8.1% (12/148)	$\chi^2=0.3$, $p=0.58$
Both demands equal	18 (15–20)	17.5 (13.5–20)	$W=2523$, $p=0.86$	3.6% (4/111)	4.7% (7/148)	OR = 1.3, $p=0.76$
Diagnoses						
Convergence insufficiency	25/111	34/148		22.5%	23.0%	$\chi^2=0.007$, $p=0.93$
Convergence deficit	22/111	24/148		19.8%	16.2%	$\chi^2=0.56$, $p=0.45$
Convergence excess	4/111	9/148		3.6%	6.1%	OR = 1.72, $p=0.40$
Divergence deficit	2/111	3/148		1.8%	2.0%	OR = 1.1, $p>0.99$
Fusional vergence dysfunction	2/111	3/148		1.8%	2.0%	OR = 1.1, $p>0.99$

Note: Data are presented as frequency (percentage) for categorical data and median (interquartile range: 25–75‰) for continuous data. Group differences were assessed using chi-squared tests (χ^2) or Fisher's exact tests (odds ratio, OR) for categorical data and Wilcoxon rank-sum (*W*) for continuous data. For comparing exophoria values, patients with a near cover test finding >0Δ were included (sub-acute = 51; chronic = 73). For comparing esophoria values, patients with a near cover test <0Δ were included (sub-acute = 28; chronic = 36).

visual symptoms that persist into sub-acute and chronic phases of concussion recovery may be exhibiting continued deficits in higher level visual processing, thus affecting their performance on NPC testing.

Accommodative disorders were most common among all patients, with monocular accommodative facility (difficulty clearing plus lenses) and amplitude of accommodation being the most frequently failed tests. 23% of patients had abnormal values for both tests, meeting the criteria for accommodative dysfunction and suggesting difficulty with both focusing and relaxing accommodation. Our observation of decreased accommodative amplitude among sub-acute and chronic patients is consistent with the finding by Master et al.[11] of abnormal accommodative amplitude as a predictor of prolonged concussion recovery. A possible explanation for the significantly higher rate of accommodative dysfunction among chronic patients specifically seen for vision symptoms could be due to autonomic nervous system (ANS) dysfunction causing persistent post-concussion symptoms.[22–24] Pupil dynamics are controlled through the sympathetic and parasympathetic innervation of the ANS. Studies have shown that pupils are relatively dilated and exhibit a slower rate of constriction following a concussion injury, indicating deficits in the parasympathetic pathway.[23,24] Pupil function is involved in the accommodation pathway.[25] Pupil constriction increases the depth of focus, which decreases the accommodative demand.[25] Thus, deficits in pupil control could result in lower subjective amplitude of accommodation and less efficient use of the accommodative system.

Deficits for males and females within the sub-acute and chronic cohorts were similar. In general, female patients in this study had normal values on clinical tests more frequently than male patients, but most of these differences were not significant. This data set included nearly twice as many female as male patients. This is consistent with prior studies which have shown that females have a higher incidence of concussion and are more likely to report symptoms than males.[26,27]

Patient data included in this study were obtained from two different clinical settings. As expected, those who were referred specifically for vision symptoms post-concussion had significantly more deficits in NPC and amplitude of accommodation, thus leading to higher rates of oculomotor diagnosis. However, these deficits were not significantly higher in all clinical tests. Furthermore, both referred and MDCC patients had higher rates of abnormal accommodation and vergence than the reported prevalence in the general paediatric and adolescent population.[28] This suggests that vision deficits in MDCC patients may have been a contributing factor to their post-concussive symptom burden.

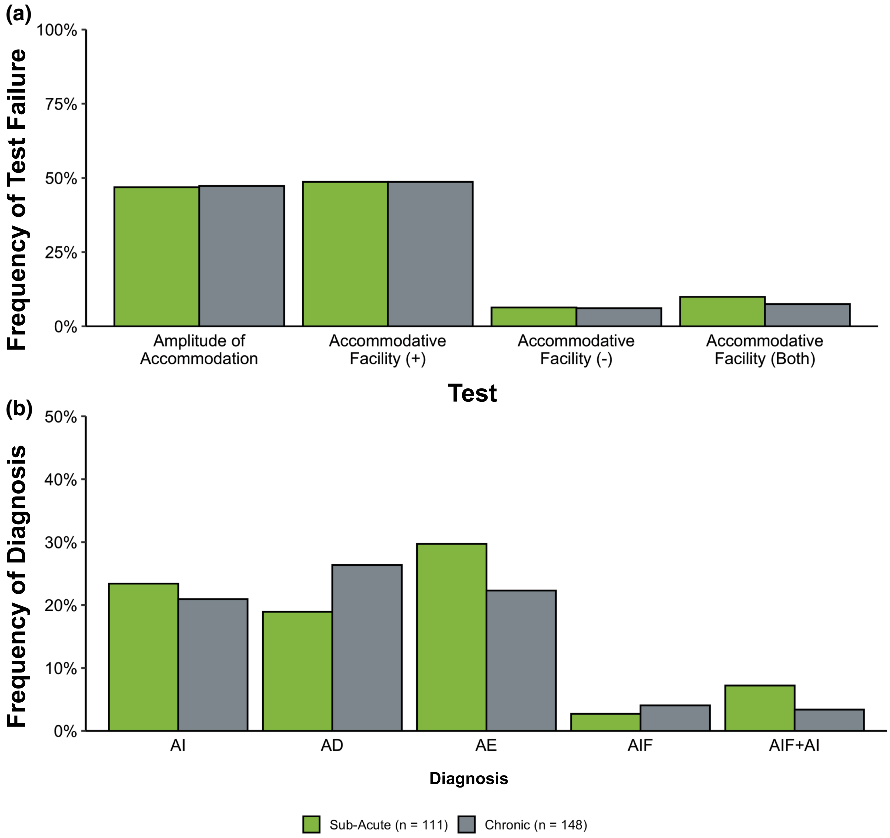

FIGURE 2 Frequency of accommodation test failure and diagnosis for sub-acute and chronic phases of concussion recovery. (a) Frequency of abnormal accommodation findings for sub-acute ($n = 111$) and chronic ($n = 148$) patients. (b) Frequency of accommodation diagnoses among the sub-acute and chronic patients. There were no significant differences in the rates of accommodation deficits between the two phases of concussion recovery. AD, accommodative dysfunction; AE, accommodative excess; AI, accommodative insufficiency; AIF, accommodative infacility.

TABLE 4 Comparing clinical tests and accommodation diagnoses between sub-acute and chronic concussion phases.

	Values			**Frequency of abnormal values**		
Tests	**Sub-acute**	**Chronic**	**Statistical comparisons**	**Sub-acute**	**Chronic**	**Statistical comparisons**
Amplitude of accommodation (D)	9 (7.5–10.5)	9 (8–10.5)	$W = 8187$, $p = 0.96$	46.8% (52/111)	47.2% (70/148)	$\chi^2 = 0.005$, $p = 0.94$
Accommodative facility (cpm)						
Difficulty						
Plus	4.5 (3–6)	5 (2.5–6.5)	$W = 2972$, $p = 0.35$	48.6% (54/111)	48.6% (72/148)	$\chi^2 = 0$, $p > 0.99$
Minus	5.5 (3–7)	5 (1.5–8)	$W = 80$, $p = 0.89$	6.3% (7/111)	6.1% (9/148)	$\chi^2 = 0$, $p > 0.99$
Both demands equal	9 (3.5–10)	9.5 (5–12)	$W = 487$, $p = 0.15$	9.9% (11/111)	7.4% (11/148)	$\chi^2 = 0.23$, $p = 0.63$
Diagnoses						
Accommodative insufficiency	26/111	31/148		23.4%	20.9%	$\chi^2 = 0.23$, $p = 0.63$
Accommodative dysfunction	21/111	39/148		18.9%	26.4%	$\chi^2 = 2.0$, $p = 0.16$
Accommodative excess	33/111	33/148		29.7%	22.3%	$\chi^2 = 1.8$, $p = 0.17$
Accommodative infacility	3/111	6/148		2.7%	4.1%	OR = 1.5, $p = 0.74$
Accommodative infacility + accommodative insufficiency	8/111	5/148		7.2%	3.4%	OR = 0.45, $p = 0.25$

Note: Data are presented as frequency (percentage) for categorical data and median (interquartile range: 25–75‰) for continuous data. Group differences were assessed using chi-squared (χ^2) or Fisher's exact tests (OR) for categorical data and Wilcoxon rank-sum (W) for continuous data. cpm, cycles per minute.

This study is not without limitations. The retrospective nature of data collection is one of the main limitations of this study. The imbalance of the groups and demographic factors reduces the statistical power of the analysis. Patients were evaluated after being specifically referred for vision symptoms (outpatient clinic) or complex post-concussion symptoms (MDCC); these findings on the frequencies of binocular vision deficits are likely greater than the general population of concussed children and adolescents and may not apply to all clinical settings. By only analysing an initial visit to the clinic, we were unable to report on differences in time to symptom resolution for sub-acute and chronic patients, and therefore cannot determine if the sub-acute and chronic patients would have the same course of recovery.

These findings show high frequencies of vergence and accommodative deficits for adolescents in both the sub-acute and chronic phases of concussion recovery. The similar frequencies of oculomotor disorders for sub-acute and chronic patients suggest that many concussed children and adolescents who do not necessarily experience acute symptom resolution and are experiencing vision symptoms at the sub-acute stage may continue to have chronic symptoms and measurable binocular vision deficits. This affirms the importance of paediatric and adolescent patients receiving a comprehensive vision evaluation if they remain symptomatic more than 2-week post-concussion. Prospective, longitudinal studies with an age-matched control group that evaluate the same individual at different time points from injury are necessary to determine the true prevalence of convergence and accommodation disorders in children and adolescents post-concussion.

AUTHOR CONTRIBUTIONS

Sophia Marusic: Conceptualization (supporting); data curation (equal); formal analysis (lead); project administration (supporting); visualization (lead); writing – original draft (lead); writing – review and editing (equal). **Neerali Vyas:** Data curation (equal); methodology (equal); project administration (equal); writing – review and editing (supporting). **Ryan N. Chinn:** Conceptualization (supporting); data curation (equal); methodology (equal); project administration (equal). **Michael J. O'Brien:** Investigation (supporting); writing – review and editing (equal). **Tawna L. Roberts:** Conceptualization (supporting); methodology (supporting); writing – review and editing (equal). **Aparna Raghuram:** Conceptualization (lead); data curation (equal); funding acquisition (lead); investigation (lead); methodology (lead); resources (lead); supervision (lead); writing – original draft (supporting); writing – review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

There are no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

The data sets generated and analysed in this study are not publicly available due to patient privacy considerations.

PATIENT CONSENT STATEMENT

Prior to participating in the study, participants gave their written assent and their parent or guardian gave written informed consent.

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