ORIGINAL INVESTIGATION

Vergence and Accommodation Deficits in Children and Adolescents with Vestibular Disorders

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SIGNIFICANCE: The high frequency of vergence and accommodation deficits coexisting in patients with a vestibular diagnosis merits a detailed visual function examination.

PURPOSE: Deficits in vergence and saccades have been reported in patients with vestibular symptomatology. We retrospectively evaluated visual function deficits in adolescents with vestibular diagnoses and concussion.

METHODS: The following inclusion criteria were used: vestibular and optometric evaluations between 2014 and 2020, 6 to 22 years old, and 20/25 best-corrected vision or better. Clinical criteria assigned vestibular diagnoses and concussion diagnoses. Vestibular diagnoses included vestibular migraine, benign paroxysmal positional vertigo, and persistent postural perceptual dizziness. Visual function deficits were compared with a pediatric control group (30). Nonparametric statistics assessed differences in group distribution.

RESULTS: A total of 153 patients were included: 18 had vestibular diagnoses only, 62 had vestibular diagnoses related to concussion, and 73 had concussion only. Vergence deficits were more frequent in patients with vestibular diagnoses and concussion (42%) and concussion only (34%) compared with controls (3%; all $P = .02$). Accommodation deficits were more frequent in patients with vestibular diagnoses only (67%), vestibular diagnoses and concussion (71%), and concussion (58%) compared with controls (13%; all $P = .002$). Patients with vestibular migraine and concussion (21) had more vergence deficits (62%) and accommodation insufficiency (52%) than concussion-only patients (47%, $P = .02$; 29%, $P = .04$). Patients with benign paroxysmal positional vertigo and concussion (20) had lower positive fusional vergence and failed near vergence facility (35%) more than concussion-only patients (16%; $P = .03$).

CONCLUSIONS: Visual function deficits were observed at a high frequency in patients with a vestibular diagnosis with or without a concussion and particularly in vestibular migraine or benign paroxysmal positional vertigo. Visual function assessments may be important for patients with vestibular diagnoses.

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The vestibular system consists of organs within the inner ear, which sense the motion and position of the head, and these organs connect to regions of the brain, eyes, neck, and body, which aid in maintaining a sense of orientation in space, stable posture, and stable vision during head movements.[1] Extensive central pathways integrate sensory inputs from the eyes and vestibular organs; the two systems share roles in maintaining balance, and the vestibular system stabilizes images on the retina (vestibulo-ocular reflex).[2,3] Deficits in these systems may lead to symptoms such as dizziness/vertigo, motion sensitivity, blurry vision, double vision, and/or imbalance.[4]

A growing body of evidence supports the multidimensional effects of concussion on both vestibular and ocular motor function.[5,6] However, little is known about the interrelations of dysfunction in the visual and vestibular pathways in the setting of concussion and in patients with vestibular disorders in the absence of concussion. At our institution, an optometrist specializing in visual function and binocular vision disorders (co-senior author, AR) and a pediatric otologist specializing in pediatric vestibular disorders (co–senior author, JRB) routinely work in tandem to evaluate many patients complaining of dizziness, imbalance, and vision issues. They also evaluate concussed patients who may or may not complain of these symptoms through our multidisciplinary concussion clinic.[7] As a result, we have observed many pediatric patients with vestibular disorders such as vestibular migraine, persistent postural perceptual dizziness, and benign paroxysmal positional vertigo to have coexisting deficits in vergence and accommodation. This association is intriguing, as the vestibular system functionally does not require direct input from the vergence or the accommodation system; however, animal studies have shown that vestibular-visual training improves vergence tracking indicating possible interaction.[8]

The purpose of this study was twofold: (1) to assess the frequency of vergence and accommodation deficits in patients with vestibular migraine, benign paroxysmal positional vertigo, and persistent postural perceptual dizziness compared with a control group of typically developing children with no history of concussion, vestibular symptoms, or other conditions associated with oculomotor dysfunction and (2) to assess if the frequency of binocular vision deficits was more commonly associated with a preceding concussion and/or particular vestibular diagnoses.

METHODS

Institutional Review Board Approval

The present study is in accordance with the tenets of the Declaration of Helsinki and was approved by the institutional review board of Boston Children's Hospital.

Study Design and Participants

In this retrospective cohort study, we reviewed medical records of patients who underwent vestibular and optometric evaluations by the two senior authors at Boston Children's Hospital between 2014 and 2020. Patient evaluations were conducted on the same day through a multidisciplinary outpatient concussion clinic or over two appointments; the first was by one of the senior authors in their outpatient clinic, and patients were subsequently seen for referred follow-up. Inclusion criteria were 6 to 22 years of age, vestibular evaluation, and best-corrected visual acuity better than or equal to 20/25 in each eye. Refractive correction had to be worn for ≥2.00 D hyperopia, ≥−1.00 D myopia, ≥1.00 D anisometropia, or ≥1.25 D astigmatism. If meeting these criteria, refractive correction had to correct for full hyperopic refractive error or be symmetrically reduced by 2.00 D or less and correct for spherical equivalent for myopia and spherical equivalent for anisometropia within 0.75 D of full correction. Exclusion criteria included diagnosis of structural abnormalities of the eye, strabismus, amblyopia, or other ocular pathological conditions. Patients were divided into three study groups: (1) vestibular diagnosis exclusively, (2) vestibular diagnosis in the setting of a concussion, and (3) concussion diagnosis in the absence of a vestibular diagnosis. Clinical findings were compared against a cohort of typically developing children 7 to 12 years old previously collected by Raghuram and colleagues[9] between April and October of 2016. Henceforth, this cohort will be referred to as the (historical) control group. The control group's inclusion criteria of best-corrected visual acuity and exclusion criteria were like those of the other groups, with the exception of vestibular evaluation. Because of an age difference between the control group and study groups, an age-matched cohort was created by selecting subsets of the control and study groups to maintain a statistically nonsignificant group difference for age.

Measures

Vision Testing

Vision testing included a routine standard-of-care comprehensive eye examination including dilated fundoscopic examinations and cycloplegic refraction. Visual assessment included evaluation of vergence and accommodation. For vergence, the following were assessed: eye alignment at distance and near (unilateral and prism alternating cover test); near point of convergence using a 20/50 letter target placed 40 to 50 cm from participant's eyes; vergence amplitudes using a horizontal prism bar (1 to 40Δ), including convergence (positive fusional vergence) and divergence (negative fusional vergence) at near (40 cm); and near vergence facility using a prism wedge of 3Δ base in and 12Δ base out (Gulden Ophthalmics, Elkins Park, PA). For accommodation, the following were assessed: amplitude of accommodation using the push-up method and monocular accommodative facility using ±2.00 D flippers with the fellow eye occluded. The senior author followed testing procedures detailed by Raghuram et al.[10] in a previous work. All tests were done with best distance refractive correction in place (if needed for distance visual acuity of 20/25 or better). Results of the visual function testing were used to provide vergence and accommodation deficit diagnoses to each participant, based on the criteria described in Appendix Table A1, available at http://links.lww.com/OPX/A582.

Determining Visual Function Deficit Diagnoses

Clinical measures that fell outside of the 95th percentile of the control group's measures were considered abnormal and used as cutoff criteria for failure for each of the clinical measures of vergence and accommodation. For measures of accommodation performed monocularly, the measurement from the right eye was used for analysis, although no difference was noted between eyes.

Concussion Diagnoses

Patients with concussion were diagnosed by the treating neurologist or sports medicine provider based on the criteria established by the 2012 International Consensus on Concussion in Sport.[11,12] The criteria have been universally applied to sport- and non–sport-related pediatric and adolescent concussion.[10,13]

Vestibular Diagnoses

Vestibular evaluations consisted of a comprehensive otological and neurological examination by an otolaryngologist and/or nurse practitioner specializing in the evaluation and management of pediatric vestibular disorders. Many patients also underwent a vestibular test battery, with the specific tests varying by patient age and clinical presentation.

Patients diagnosed with benign paroxysmal positional vertigo demonstrated characteristic nystagmus and vertigo in at least one diagnostic positional maneuver, such as the Dix-Hallpike, supine head roll, and/or midline head hang maneuvers, with the assistance of videonystagmography goggles (Micromedical Technologies, Chatham, IL). Patients diagnosed with vestibular migraine met the criteria established by the International Classification of Headache Disorders, Third Edition.[14] Patients diagnosed with persistent postural-perceptual dizziness met the diagnostic criteria established by the Bárány Society consensus statement on the diagnosis of persistent postural-perceptual dizziness.[15] Some patients had other vestibular diagnoses in addition to one of the three described previously, which included anatomic abnormalities of the inner ear such as enlarged vestibular aqueduct or superior semicircular canal dehiscence, as well as traumatic injuries to the inner ear such as perilymphatic fistula, which were confirmed by imaging studies, vestibular testing results, and/or surgical exploration.

Statistical Analysis

Demographics and patient characteristics are presented as frequency and percentage for categorical data, and median and interquartile range for continuous data. Comparisons between the control group, records from the review, and stratified group analyses were performed using the χ^2 test, Fisher exact test, the Wilcoxon rank sum test, or Kruskal-Wallis test as appropriate. Continuous data were assessed for normality using the Shapiro-Wilk test, which revealed significant skewness and departure from a Gaussian distribution for all continuous variables within each group. Therefore, results are presented as median and interquartile range and analyzed using nonparametric methods. Stratified group analyses were performed within the records from the review based on concussion diagnosis. Statistical analyses were performed using R (version 4.02; R Foundation for Statistical

Computing, Vienna, Austria) and RStudio (version 1.3.1073; RStudio PBC, Boston, MA). A two-tailed α level of 0.05 was used to determine statistical significance, and a two-tailed Bonferroni-adjustment was applied to account for multiple comparisons.

RESULTS

Of the 197 patient records reviewed, 153 records met the study criteria. Twenty-eight were excluded due to the best-corrected visual acuity criteria; eight had incomplete evaluations of visual function; two were evaluated by another vision provider; one did not carry a vestibular or concussion diagnosis; four had a vestibular diagnosis other than vestibular migraine, persistent postural-perceptual dizziness, or benign paroxysmal positional vertigo; and one lacked appropriate refractive-error correction during binocular vision evaluation. Of the 153 included in the analysis, the median age at presentation was 15.4 years (13.7 to 17.3 years), and 62% (95) were female. Most patients (104 [68%]) were seen by both providers through the multidisciplinary concussion clinic. Of the 153 records,

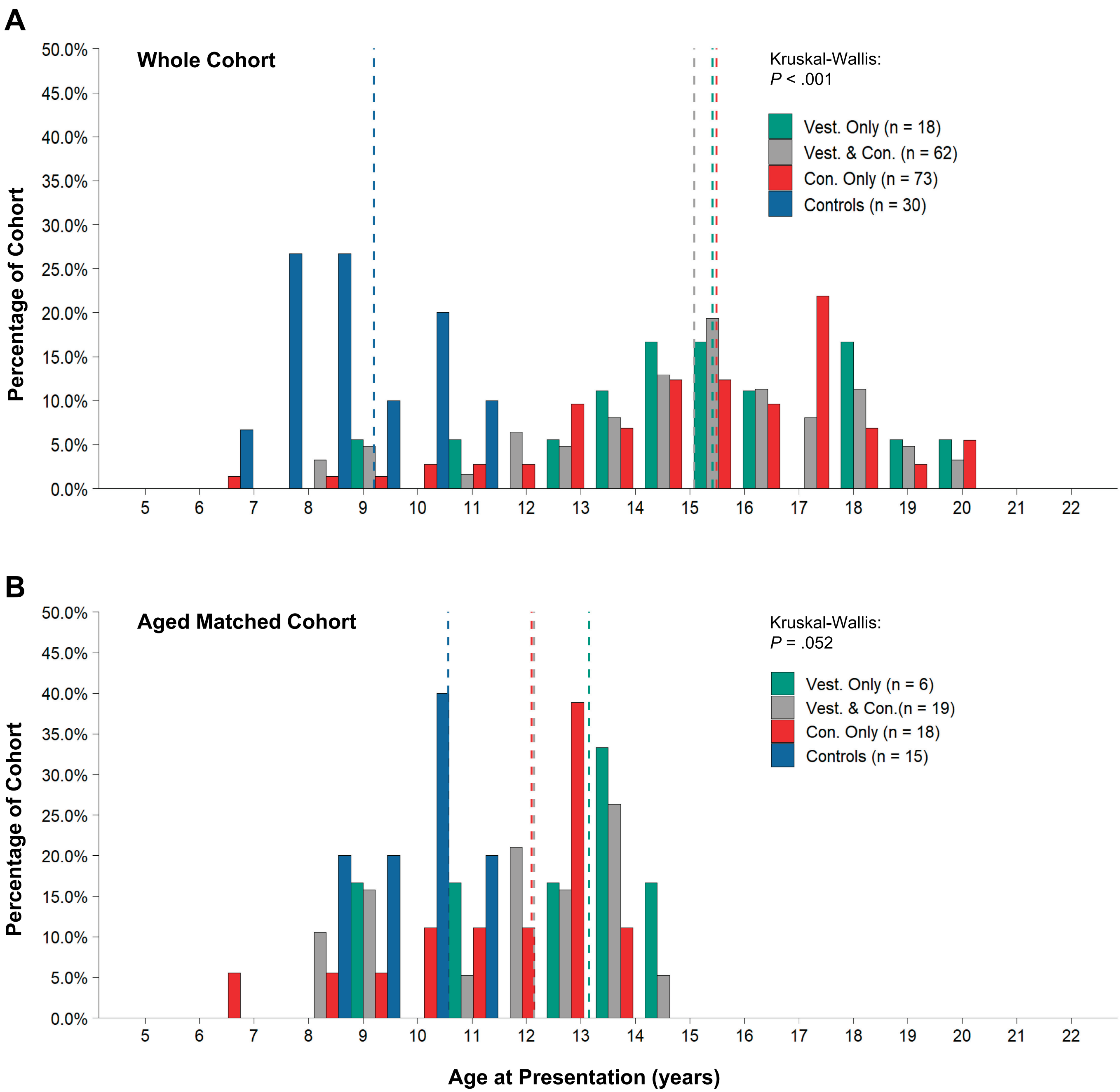

FIGURE 1. Age distribution at time of examination of the (A) whole cohort (n = 153) and controls (n = 30), and (B) age-matched cohort (n = 43) and age-matched controls (n = 15). Vertical dashed lines represent each respective subgroup's median age at examination. Kruskal-Wallis test compared measures across all four subgroups with significance values reported in boxes. Con. = concussion; Vest. = vestibular.

18 carried a vestibular diagnosis exclusively, 62 carried a vestibular and concussion diagnosis, and 73 carried a concussion diagnosis in the absence of a vestibular diagnosis. The control group included 30 children who had normal eye examinations administered by the last author. They were significantly younger (9.2 years [8.1 to 10.5 years]; $P < .001$, Fig. 1A) from the study group cohort and consisted of a similar proportion of female participants (63%). Table 1 summarizes the demographics and clinical characteristics of the study cohort by diagnosis group (vestibular only, vestibular and concussion, concussion only, and control). Table 2 summarizes the frequency of benign paroxysmal positional vertigo, persistent postural-perceptual dizziness, and vestibular migraine, among the patients with vestibular diagnoses and the overlap of the conditions.

The age-matched cohort included 43 of 153 original records (28%), 6 with only vestibular diagnosis (median age, 13.2 years [11.4 to 13.7 years]), 19 with only vestibular and concussion diagnosis (12.1 years [10.1 to 12.7 years]), and 18 with only concussion diagnosis (12.1 years [9.91 to 13.3 years]). The age-matched control group comprised 15 of 30 original control records (50%; 10.6 years [9.7 to 11.2 years]). Age was not significantly different between the four age-matched groups ($P = .052$, Fig. 1B).

The clinical cutoff criteria calculated from the control group varied marginally from the established clinical criteria for the following measures: near point of convergence (≥8.5 vs. >6 cm), convergence ranges (≤20 vs. ≤15 prism diopters [Δ]), vergence facility (≤8 vs. ≤9 cycles per minute [cpm]), amplitude of accommodation (<1.75 vs. <2 D to Hofstetter's minimum), and accommodative facility (≤3.5 vs. ≤6 cpm). Divergence ranges (<8 Δ) were similar between the clinical cutoff criteria and established clinical criteria. Control group's calculated diagnostic criteria were similar in the whole cohort and age-matched cohort for near point of convergence, divergence ranges, and accommodative facility. For convergence ranges, vergence facility, and amplitude of accommodation, the diagnostic criteria were different between the whole cohort and the age-matched cohort. A complete comparison of the vergence and accommodation diagnostic criteria for the whole cohort and age-matched cohort is included in Appendix Table A1, available at http://links.lww.com/OPX/A582. Diagnostic criteria based on the whole cohort and age-matched cohort did not produce significant differences in the frequency of vergence and accommodation deficits for each subgroup. Table 3 contains specific vergence and accommodation deficit by each whole cohort study group. Appendix Table A2 (available at http://links.lww.com/OPX/A582) contains specific vergence and accommodation deficits for each of the age-matched cohort.

The frequency of vergence and accommodation deficits was higher in the three study subgroups compared with the controls in the whole cohort and the age-matched cohort (Fig. 2). In the whole cohort, we observed significantly higher vergence deficits in patients with a vestibular and concussion diagnosis (26 [42%]) and those with a concussion diagnosis alone (25 [34%]) compared with controls (1 [3%]; all $P < .02$) (Fig. 2A). In addition, accommodation deficits were frequent in patients with a vestibular diagnosis only (12 [67%]), vestibular and concussion diagnosis (44 [71%]), and concussion diagnosis (42 [58%]) compared with controls (4 [13%]; all $P < .002$) (Fig. 2B). Similar findings were observed in the age-matched cohort. The frequency of vergence deficits was significantly different between the patients with vestibular and concussion diagnosis (8 [42%]) and the controls (0 [0%]; $P = .03$) (Fig. 2C). The frequency of accommodation deficits was higher in patients with a vestibular and concussion diagnosis (16 [84%]) and with only a concussion diagnosis (13 [72%]) compared with controls (3 [20%]; all $P < .03$) (Fig. 2D).

To understand the contributing factors of the observed diagnostic patterns, we compared individual subgroup vergence and accommodative clinical measures within the whole cohort (Fig. 3). Near point of convergence was significantly receded in patients with a vestibular and concussion diagnosis (8.5 cm [6.6 to 12 cm]) and in patients with only a concussion diagnosis (8 cm [5.5 to 10 cm]) compared with controls (7 cm [5.5 to 8.0 cm]; $P = .01$; .04) (Fig. 3A).

TABLE 1. Demographics and patient characteristics

	Vestibular diagnosis only (n = 18)	Vestibular and concussion diagnosis (n = 62)	Concussion diagnosis only (n = 73)	Controls (n = 30)
Age, median (IQR) (y)	15.4 (13.9–17.4)	15.1 (13.6–17.3)	15.5 (13.7–17.3)	9.2 (8.1–10.5)
Sex (female)	12 (66.7%)	43 (69.4%)	40 (54.8%)	19 (63.3%)
Days between vision and vestibular exams, median (IQR)	31 (21–73)	0 (0–13)	0 (0–0)	—
Concussion				
Average no. concussions, median (IQR)	—	1 (1–3)	1 (1–3)	—
Mechanism of concussion				
Sports related	—	28 (45.2%)	40 (54.8%)	—
Motor vehicle accident	—	6 (9.67%)	10 (13.7%)	—
Other (slips, trips, falls)	—	28 (45.2%)	23 (31.5%)	—
Months from concussion to vision assessment, median (IQR)	—	3.9 (2.1, 6.4)	3.9 (2.2, 6.6)	—
Medical diagnoses				
VM	15 (83.3%)	38 (61.2%)	—	—
PPPD	7 (38.9%)	9 (14.5%)	—	—
BPPV	9 (50.0%)	33 (53.2%)	—	—
Multiple vestibular system diagnoses	12 (66.7%)	18 (29.0%)	—	—

Data are presented as frequency (percentage) for categorical data and median (interquartile range [IQR], 25%ile to 75%ile) for continuous data. BPPV = benign paroxysmal positional vertigo; PPPD = persistent postural perceptual dizziness; VM = vestibular migraine.

TABLE 2. Types of vestibular diagnosis and overlap in with and without concussion

Vestibular diagnosis	Vestibular diagnosis without a concussion (n = 18)	Vestibular diagnosis with a concussion (n = 62)
BPPV only	1	20
PPPD only	0	3
VM only	5	21
BPPV and PPPD	2	1
BPPV and VM	1	10
PPPD and VM	2	4
BPPV and PPPD and VM	3	1
VM and Other vestibular diagnosis*	2	1
BPPV and VM and Other vestibular diagnosis*	2	1

*Other vestibular diagnosis: congenital cochleovestibulopathy, enlarged vestibular aqueduct, chronic rhinosinusitis, internal auditory canal stenosis, perilymphatic fistula, and balance impairment. BPPV = benign paroxysmal positional vertigo; PPPD = persistent postural perceptual dizziness; VM = vestibular migraine.

Convergence ranges were lower in patients with a vestibular diagnosis only (20 Δ [18 to 30 Δ]), vestibular and concussion diagnosis (19 Δ [14 to 25 Δ]), and concussion diagnosis (25 Δ [16 to 30 Δ]) when compared with controls (32.5 Δ [25 to 35 Δ]; all $P < .002$) (Fig. 3B). We found significantly lower amplitude of accommodation in patients with a vestibular diagnosis only (9.3 D [8.3 to 11.1 D]), vestibular and concussion diagnosis (9.1 D [8.1 to 10.5 D]), and concussion diagnosis (10.0 D [8.3 to 11.8 D]) when compared with controls (12.9 D [11.9 to 14.3 D]; all $P < .001$). Because amplitude of accommodation is affected by age, we also calculated the difference between age-expected amplitude of accommodation and participant measures, finding a larger difference (lower amplitude) in patients with vestibular diagnosis (1.65 D [0.77 to 2.76 D]), vestibular and concussion diagnosis (1.95 D [0.55 to 2.90 D]), and concussion diagnosis (1.2 D [–0.51 to 2.76 D]) when compared with controls (–0.29 D [–1.67 to 0.83]; all $P < .007$) (Fig. 3C). Accommodative facility was lower in patients with a vestibular only diagnosis (5.00 cpm [2.25 to 6.00 cpm]) and in the concussion-only group (5.00 cpm [2.5 to 8.5 cpm]) when compared with patients in the control group (7.50 cpm [5.63 to 8.50 cpm]; $P = .02$; .04) (Fig. 3D). Divergence ranges and vergence facility measures were similar between the whole cohort subgroups. Table 4 illustrates the corresponding number of individuals in each subgroup who failed each individual clinical measurement.

Upon analyzing individual vestibular diagnoses, patients with a vestibular migraine diagnosis with or without concussion (53) had significantly lower positive fusional vergence ranges (20 Δ [14 to 25 Δ]) than the concussion-only group (25 Δ [16 to 30 Δ], $P = .02$), which resulted in patients with vestibular migraine having a higher rate of failing positive fusional vergence (37 [70%]) compared with patients diagnosed with only a concussion (38 [52%]; $P = .02$). Significantly more patients with vestibular migraine failed amplitude of accommodation (32 [60%]) compared with concussion-only diagnosis (29 [40%]; $P = .03$). Patients with vestibular migraine also met the criteria for accommodative insufficiency at a higher rate than the concussion-only group (25 [47%] vs. 21 [29%]; $P = .03$) and had more accommodative deficits overall (40 [75%] vs. 42 [58%]; $P = .04$).

Patients with a benign paroxysmal positional vertigo diagnosis with or without concussion (36) had significantly lower positive fusional vergence ranges (19 Δ [14 to 25 Δ]; $P = .049$) compared with the concussion-only group but did not show significant differences in failing the test. Patients with a diagnosis of persistent postural-perceptual dizziness with or without concussion (16) did not show any significant differences in binocular vision deficits compared with the concussion-only group.

Many patients had more than one vestibular diagnosis, as described in Table 2; thus, the vestibular migraine (53), benign paroxysmal positional vertigo (36), and persistent postural-perceptual dizziness (16)

TABLE 3. Comparison of vergence and accommodation deficits by patient group based on control group–based criteria

	Vestibular diagnosis without a concussion (n = 18)	Vestibular diagnosis with a concussion (n = 62)	Concussion diagnosis without a vestibular diagnosis (n = 73)	Controls (n = 30)
Vergence diagnosis				
Convergence insufficiency	1 (5.6%)	10 (16.1%)	7 (9.6%)	0 (0%)
Convergence deficit	1 (5.6%)	12 (19.4%)	8 (11.0%)	0 (0%)
Convergence excess	0 (0%)	1 (1.6%)	4 (5.5%)	0 (0%)
Divergence deficit	0 (0%)	1 (1.6%)	0 (0.0%)	0 (0%)
Nonspecific vergence dysfunction	1 (2.6%)	2 (3.2%)	6 (8.2%)	1 (3.3%)
Overall vergence deficits (total)	3 (16.7%)	26 (41.9%)	25 (34.2%)	1 (3.3%)
Accommodative diagnosis				
Accommodative insufficiency	6 (33.3%)	27 (43.5%)	21 (28.8%)	3 (10%)
Accommodative excess	2 (11.1%)	7 (11.2%)	11 (15.1%)	0 (0.0%)
Accommodative infacility	1 (5.6%)	1 (1.6%)	2 (2.7%)	1 (3.3%)
Accommodative dysfunction	3 (16.7%)	6 (9.7%)	8 (28.8%)	0 (0.0%)
Accommodative insufficiency and infacility	0 (0.0%)	3 (4.84%)	0 (0.0%)	0 (0.0%)
Overall accommodative deficits (total)	12 (66.7%)	44 (71.0%)	42 (57.5%)	4 (13.3%)

Data are presented as frequency (percentage).

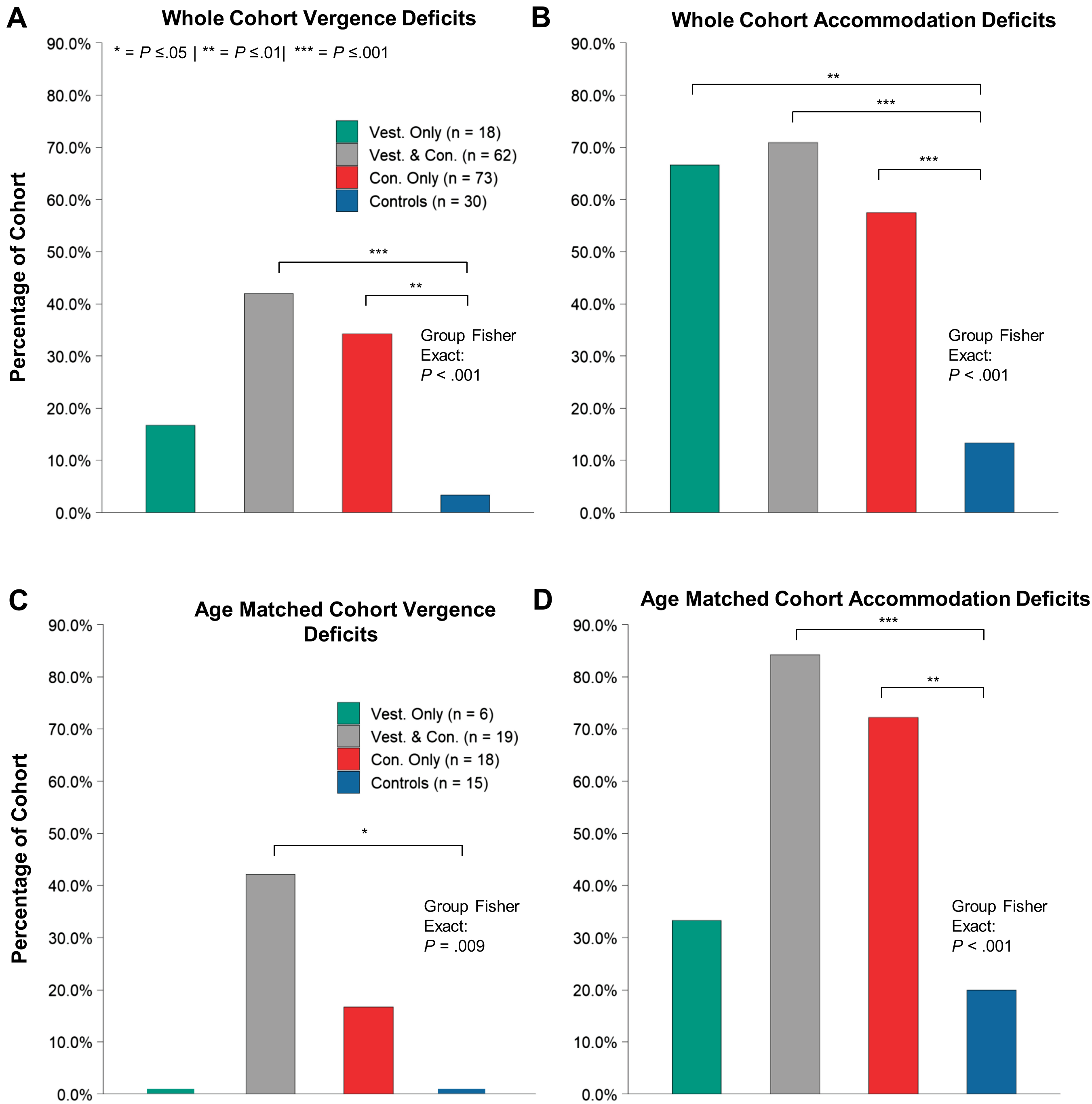

FIGURE 2. Whole cohort comparison of frequency of (A) vergence deficits and (B) accommodative deficits. Age-matched cohort comparison of frequency of (C) vergence deficits and (D) accommodation deficits. Group Fisher exact test compared deficit frequency across all four subgroups with significance reported in boxes. Brackets represent significant Fisher exact test difference between two individual groups. Con. = concussion; Vest. = vestibular.

groups analyzed previously overlapped. Dividing patients by individual vestibular diagnoses and specific combinations of vestibular diagnoses and concussion yielded groups too small for analysis, except for concussed patients diagnosed with only vestibular migraine (21) or only benign paroxysmal positional vertigo (20). We compared these groups to the concussion-only group. Patients with only vestibular migraine and a concussion had significantly lower positive fusional vergence measures (20 Δ [14 to 20 Δ]; $P = .04$) and failed testing at a higher rate (16 [76%]) than the concussion-only group ($P = .02$). Overall, concussed patients with only vestibular migraine had significantly more vergence deficits (13 [62%]) compared with the concussion-only group (25 [47%]; $P = .02$). This group also failed amplitude of accommodation testing (14 [67%]; $P = .03$) and met the criteria for accommodative insufficiency (11 [53%]; $P = .04$) at significantly higher rates compared with the concussion-only group. Patients with only benign paroxysmal positional vertigo and a concussion

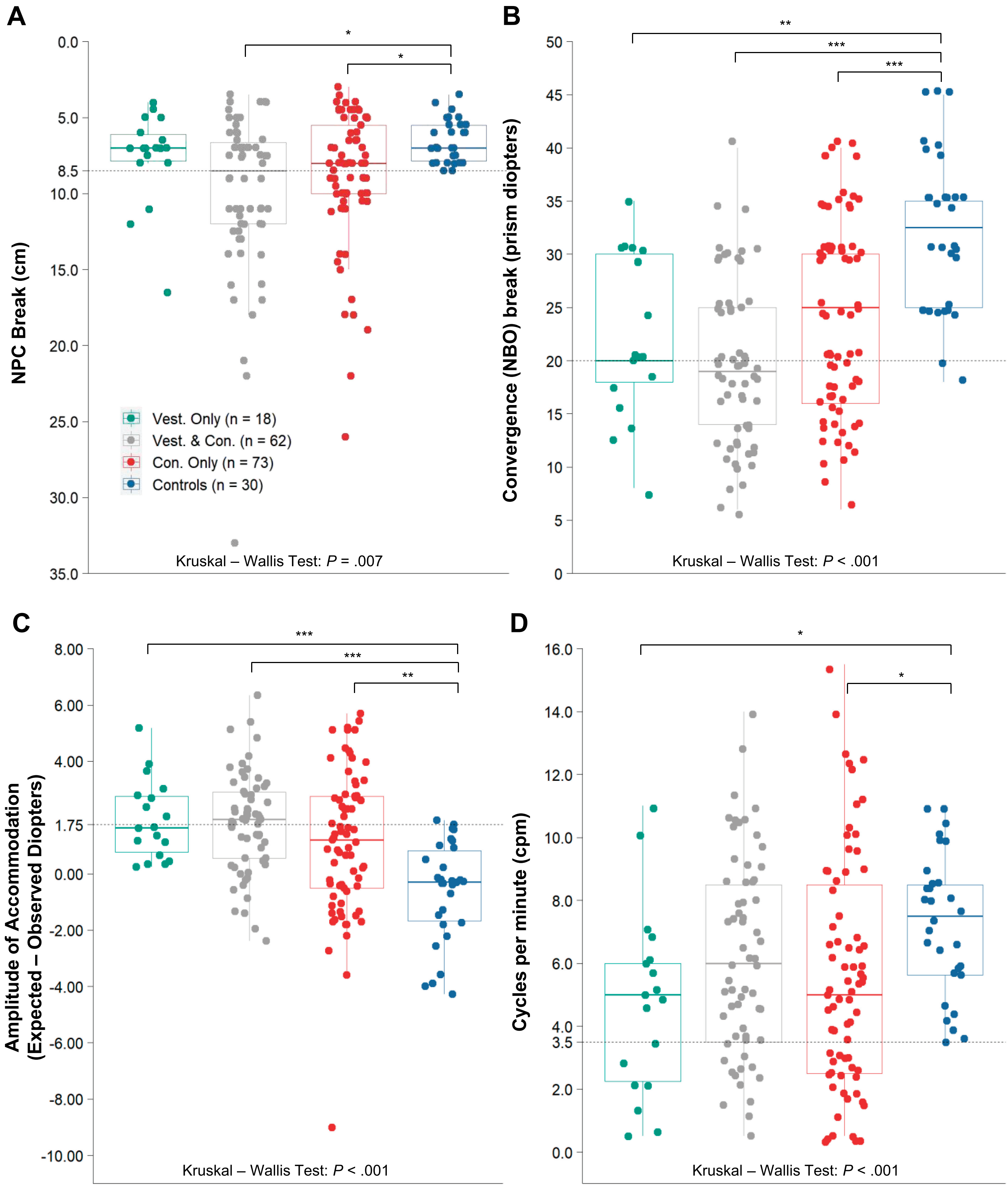

FIGURE 3. Group comparison of (A) near point of convergence, (B) convergence break, (C) amplitude of accommodation, and (D) accommodative facility measures. Box plots describe the median (horizontal line in the box) and 25th and 75th percentiles (lower and upper ends of the box), with tails representing all other data. All individual measures are displayed as individual data points. Dashed red line represents clinical test criteria based on whole cohort measures. Kruskal-Wallis test compared measures across all four subgroups with significance reported in boxes. Brackets represent significant Wilcoxon rank sum test difference between two individual groups. Con. = concussion; Vest. = vestibular.

TABLE 4. Subgroup frequency of failing vergence and accommodative measures based on whole cohort criteria

Clinical measures	Vestibular diagnosis only (n = 18)	Vestibular and concussion diagnosis (n = 62)	Concussion diagnosis only (n = 73)	Controls (n = 30)	*P**
Vergence measures					
Frequency of NPC failure	3 (16.7%)	31 (50.0%)	34 (46.6%)	2 (6.7%)	<.001†
Frequency of NBI failure	2 (11.1%)	7 (11.3%)	10 (13.7%)	0 (0.0%)	.15
Frequency of NBO failure	10 (55.6%)	42 (67.7%)	35 (47.9%)	2 (6.7%)	<.001†
Frequency of NVF failure	3 (16.7%)	18 (29.0%)	10 (13.7%)	2 (6.7%)	.03†
Accommodation measures					
Frequency of AA failure	8 (44.4%)	36 (58.1%)	29 (39.7%)	2 (6.7%)	<.001†
Frequency of MAF failure	7 (38.9%)	17 (27.4%)	25 (34.2%)	2 (6.7%)	.01†

**P* value is row Fisher exact test. †Statistically significant. AA = amplitude of accommodation; MAF = monocular accommodative frequency; NBI = near base in; NBO = near base out; NPC = near point of convergence; NVF = near vergence facility.

had significantly lower positive fusional vergence measures (18 Δ [14 to 25 Δ]; *P* = .04) but did not fail the clinical test at a significantly higher rate. In addition, these patients failed near vergence facility testing at a higher rate (7 [35%]) compared with concussion-only patients (10 [16%]; *P* = .03).

DISCUSSION

The authors observed an increased frequency of accommodative and vergence deficits in patients with vestibular migraine, benign paroxysmal positional vertigo, or persistent postural-perceptual dizziness (70 and 36%) compared with patients with only a concussion diagnosis (58 and 34%) and controls (13 and 3%). Within the group of patients who had a vestibular diagnosis, those with a preceding concussion had higher rates of vergence deficits (42%) compared with those with only a vestibular diagnosis (17%); however, the small number of patients with only a vestibular diagnosis and no concussion (18) limited the generalizability of our analysis. When examining individual vestibular diagnoses, we found that patients with vestibular migraine or benign paroxysmal positional vertigo had more abnormal vergence measures compared with concussion-only patients and controls. Patients with vestibular migraine also had increased frequency of abnormal accommodative measures. These trends were maintained when comparing concussed patients who had been diagnosed with only vestibular migraine or only benign paroxysmal positional vertigo to concussion-only patients; this is a useful comparison because it showed that these vision deficits were more frequently associated with vestibular migraine and benign paroxysmal positional vertigo.

There are multiple possible mechanisms by which vestibular migraine and other vestibular disorders such as benign paroxysmal positional vertigo could impact convergence and accommodative function. Although it is tempting to consider a relationship between vestibulo-ocular reflex impairment and visual function dysfunction, this connection seems unlikely, as there is little overlap between these pathways, and most patients with vestibular migraine have a normal vestibulo-ocular reflex response.[16] The most likely mechanism is via autonomic dysregulation in patients with chronic and/or recurrent dizziness. Stimulation of the sympathetic nervous system has been shown to inhibit the accommodation response by reducing ciliary muscle contraction.[17] Vestibular migraine and other chronic vestibular disorders have been associated with excessive stimulation of the sympathetic nervous system, likely as a stress response to chronic and/recurrent dizziness[18] Yildiz and colleagues[19] found that migraine patients had impaired accommodative function relative to controls, particularly during migraine attacks. Prior studies have also suggested that vergence deficits could be attributed to issues with motion processing in vestibular disorders.[20,21] Additional mechanisms have been proposed for the increased prevalence of visual function dysfunction in concussion patients, including shearing injury to central pathways in the brain that mediate convergence and accommodative function, although such a mechanism is not applicable to patients with vestibular disorders without concussion.[22]

This retrospective study has limitations that should be acknowledged. The control group was significantly younger and separately assessed from the study group. Many of the study group patients had multiple vestibular diagnoses and/or a concussion, thus obscuring the relationship between an individual vestibular diagnosis and visual function deficits. The study group largely comprised patients with a concussion diagnosis. Most vestibular patients without a concussion were referred specifically for vision symptoms, so the findings from this small cohort might not be generalizable. Furthermore, concussion-related vestibular diagnosis etiology could be different from primary vestibular diagnosis and affect binocular vision function differently. The small sample size limited the statistical power for detecting differences among the three patient groups and controls, including differences that might have led to confounding factors and necessitated the use of nonparametric statistical methods to analyze nonnormally distributed data. Uneven diagnostic groups also limit generalizing the results to the general population.

Despite these limitations, we observed an increased prevalence of vergence and accommodation deficits in adolescent patients with vestibular diagnoses and/or concussion compared with control participants. Understanding the mechanisms underlying these observed deficits would require a larger sample size of patients with vestibular disorders. Assessing patients with a single vestibular diagnosis or grouping patients with multiple diagnoses by self-reported symptoms could provide more clarity as to which specific vestibular issues are associated with vergence and accommodation deficits. Our study posits the need for prospective studies to address the interaction between the vergence, accommodation, and vestibular systems. The high frequency of vergence and accommodation deficits coexisting in patients with a vestibular diagnosis merits a detailed visual function examination, and management of deficits could affect time course of symptom resolution.

ARTICLE INFORMATION

Supplemental Digital Content: Appendix Table A1, available at http://links.lww.com/OPX/A582, lists the clinical measures and diagnostic criteria for corresponding vergence and accommodation deficits assigned to study participants. Whole cohort diagnostic criteria were calculated using values outside the 95% of the total control group (n = 30). Age-matched diagnostic criteria were calculated using values outside of the 95% of the age-matched control group (n = 15).

Appendix Table A2, available at http://links.lww.com/OPX/A582, compares the frequency of vergence and accommodation deficits of the age-matched cohort by patient group based on age-matched control group–based criteria.

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