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Original research

Persistent vestibular-ocular impairment following concussion in adolescents

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ABSTRACT

Objectives: The current study investigated the role of persistent vestibular-ocular symptoms and impairment following sport-related concussion on recovery time and clinical outcomes among adolescents.
Design: Prospective cohort.
Methods: 50 (F-22/M-28) adolescents aged 12–20 years completed a vestibular-ocular motor screening, neurocognitive assessment, and the Post-Concussion Symptom Scale (PCSS) at clinical assessments conducted at 0–10 and 11–21 days after concussion. Participants were assigned to: 1) persistent vestibular-ocular (PERSIST), 2) vestibular-ocular improvement (IMPROVE), or 3) no vestibular-ocular impairment (NONE) groups based on vestibular-ocular motor screening conducted during each assessment. A 3 (GROUP) X 2 (TIME) ANOVA was performed on neurocognitive and symptom scores, and a between-subjects ANOVA was performed for recovery time.
Results: 49 subjects were identified among the PERSIST (n = 17), IMPROVE (n = 12) and NONE (n = 20) groups. There were no neurocognitive performance differences between groups at 0–10 days post-concussion, but groups differed on PCSS at 11–21 days ($p = .001$), with the PERSIST (29.0 ± 24.9) group reporting higher symptoms than the NONE (5.45 ± 10.0; $p = .005$) group. The PERSIST group took significantly longer to recover (34.9 ± 11.6 days) than the NONE (22.9 ± 14.9 days) group ($p = .03$). All groups improved on verbal ($p < .001$) and visual memory ($p = .028$), visual motor speed ($p = .005$), and reaction time ($p = .004$) from 0–10 to 11–20 days following SRC and no significant group by time interactions for cognitive scores identified.
Conclusions: Persistent post-concussion vestibular-ocular symptoms and impairment may influence neurocognitive performance and clinical recovery following sport-related concussion.

Practical implications

- Vestibular Symptoms are common following sport-related concussions among adolescents.
- Repeated screening of vestibular impairment may improve identification of persistent vestibular profiles.
- Persistent vestibular impairment is associated with worse neurocognitive performance, greater symptom burden, and longer recovery than those with absent vestibular impairment.

1. Introduction

The assessment of the vestibular and ocular motor system is emerging as an important component to the recommended multifaceted evaluation of sport-related concussion (SRC). Vestibular impairment has been identified as a prognostic factor for worse symptom burden, decreased cognitive performance[1,2] and longer recovery[3–5] following SRC. Vestibular impairment after SRC is common among adolescents[3,4,6] and up to 81% of athletes exhibit vestibular-associated signs, (e.g., vomiting, balance insufficiencies), symptoms (e.g., dizziness, nausea, fogginess), or other deficits (e.g., visual gaze instability, hearing loss) after injury. Moreover, these aforementioned clinical findings are also associated with greater likelihood of post-concussion syndrome[4]

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and longer return to academic performance[3] in concussed adolescents. Vestibular impairment may result from isolated or concurrent disruption to the vestibular-spinal or vestibular-ocular afferent pathways. Vestibular-spinal signals transmits peripheral somatosensory information to maintain postural stability[7] and related symptoms have been reported to resolve in the first 3–5 days after SRC.[8] In contrast, the vestibular-ocular afferent pathway pertains to visual gaze stability and visual focus during head movements[9] which is previously reported resolve after postural stability.[10] A screening of the vestibular system may identify insufficiencies otherwise overlooked from neurocognitive, symptom, and clinical interview components of the multifaceted assessment. Moreover, serial evaluations of the vestibular system may improve identification of concussion clinical profiles.[11]

Until recently, the evaluation of the vestibular and ocular motor system involved sophisticated equipment (i.e., video nystagmography) not readily available to clinicians. The Vestibular Ocular Motor Screening (VOMS) tool is a brief, clinical screening tool intended to identify vestibular or ocular motor impairments after SRC.[9] The VOMS is cost-effective as it requires readily available materials (e.g., tape measure, metronome, and a target with 14 point) and takes less than 10 min to complete. The VOMS has been reported to have good reliability[11] and high internal consistency among control ($\alpha = 0.95$) and concussed ($\alpha = 0.92$) individuals.[9] Sufrinko et al reported that the VOMS was a sensitive measure of vestibular impairment and concussion diagnosis within 10 days of injury,[1] vestibular-ocular screening can be a cost-effective and stable measure within a multifaceted concussion evaluation.

To date researchers have classified patients as having vestibular and ocular motor impairment as abnormal VOMS scores exhibited within the first week of injury.[1,12] These studies have documented the VOMS as a sensitive screening tool for vestibular dysfunction using cross-sectional categorization by examining the presentation of vestibular-associated symptoms at 1 time-point (i.e., 0–10, 11–21, or >21 days after concussion).[3,4,9] However, symptom presentations associated with SRC resolve over the course of recovery[13,14] and there is limited prospective evidence of serial VOMS assessments among adolescents with vestibular impairment recovering from SRC. More recently, Elbin et al compared VOMS scoring methods among an adolescent cohort across 14 days[12] and reported the symptom change scores (VOMS component symptoms minus pretest symptoms[11]) and total scores may be appropriate interpretation strategies to identify vestibular impairment following concussion. Of the sample, 56% (35/63) exhibited vestibular impairment ≤7 days of SRC, whereas 30% (19/63) were impaired 8-14-days after injury; and concluded that most patients resolve vestibular-impairments within 14 days of SRC. These findings support the utility of VOMS screening following SRC but did not evaluate neurocognitive performance or other clinical outcomes (i.e., recovery). There is a need to identify the demographic characteristics, clinical presentation, and outcomes associated with persistent vestibular impairment among adolescent athletes recovering from SRC. This consideration is important because symptom burden, cognitive deficits, and outcomes associated with vestibular impairment after SRC very amongst individuals and a prospective investigation of vestibular impairment may elucidate important clinical information derived from repeated VOMS administration.

A multifaceted assessment comparison between adolescents that have absent-, initial but improve-, and persistent- vestibular impairment during the subacute phase of SRC recovery has not been conducted. The purpose of the current study is to examine the effect of persistent vestibular impairment on clinical outcomes and recovery time among adolescents with SRC. This study is needed as it would provide prospective, empirical evidence of the clinical presentation during serial evaluations and clinical outcomes of those that develop persistent vestibular impairment following SRC.

2. Methods

A prospective, repeated measures design was used for the current study whereby sixty-three adolescents (28 female, 36 male) aged 12–20 years seeking care at an outpatient clinic between October 2014 and March 2017. To be included in the study, athletes were required to (a) complete a clinical assessment within 10 days of injury, (b) second clinical visit at 11–21 days after concussion, and (c) medical clearance evaluation as determined by treating physician. Each visit consisted of a clinical interview, vestibular-ocular screening, demographics, and neurocognitive assessment. Any athlete with a concurrent cervical spine injury, or positive neuroimaging was excluded from study participation.

All concussions were diagnosed by neuropsychologists or sports medicine physicians in accordance with international consensus.[15] Specifically, a temporary neurological injury (1) induced by a biomechanical force applied to the head or body followed by (2) clinical signs (e.g. balance difficulties, unconsciousness, disorientation, etc.) or symptoms (e.g., migraine, nausea, photophobia, etc.) and (3) presence of any impairment identified from the sideline assessment (e.g., Sport Concussion Assessment Tool) by a team physician or other healthcare professional (i.e., athletic trainer, physical therapist).

Demographic information including sex, age, and concussion history were obtained as part of demographic section of the com-

Table 1
Descriptive statistics between vestibular impairment groups (n = 49).

	None N = 20	Improve N = 12	Persist N = 17	Total N = 49	X^2 (p-value)[a]
Age	14.3 (1.9)	15.8 (2.3)	15.6 (2.1)	15.1 (2.1)	
Female	4 (20.0)	7 (58.3)	10 (58.8)	21 (42.9)	6.56 (.038)*
Previous concussions	6 (12.2)	1 (2.0)	7 (14.3)	14 (28.6)	12.3 (.015)*
0	14 (70.0)	11 (91.7)	10 (58.8)	35 (71.4)	
1–2	6 (30.0)	–	4 (23.5)	10 (20.4)	
3 or more		1 (8.3)	3 (17.6)	4 (8.2)	
Sport					24.195 (.450)
Basketball	4 (20.0)	–	5 (29.4)	9 (18.4)	
Football	3 (15.0)	1 (8.3)	2 (11.7)	6 (12.2)	
Hockey	3 (15.0)	2 (15.4)	–	5 (10.2)	
Soccer	6 (30.0)	4 (33.3)	2 (11.7)	12 (24.5)	
Other	4 (20.0)	5 (41.7)	8 (47.1)	17 (34.7)	
Motion sickness	3 (15.0)	6 (50.0)	6 (35.3)	15 (30.6)	3.14 (.208)
Migraine	3 (15.0)	–	5 (29.4)	8 (16.3)	6.93 (.031)*

Values presented as frequency (%); or mean (M) and standard deviation (SD).
[a] (2, N = 49).
* Significant ($p < .05$).

puterized neurocognitive evaluation. Motion sickness and migraine history were obtained from the clinical interview and coded dichotomously (yes/no).

The VOMS tool was conducted at each clinical visit to determine vestibular impairment. Patients report on a Likert scale ranged from 0 to 10 (0 is not present, 10 is severe) for headache, dizziness, nausea, and fogginess prior to screening and after each component: (1) smooth pursuits, (2) horizontal saccades, (3) vertical saccades, (4) near point convergence, (5) horizontal vestibular-ocular reflex (VOR), (6) vertical VOR, and (7) visual motion sensitivity (VMS). Vestibular-ocular impairment was operationally defined as the VOMS change scores.[11,12] Specifically, a total symptom worsening of ≥2 on the horizontal VOR, vertical VOR, or VMS components compared to the pretest symptoms or a mean NPC convergence (of 3 measurements) greater than 5 cm were classified as exhibiting vestibular-ocular impairment. Patients that did not report a total symptom worsening of ≥2 on the VOR and VMS components were classified as no vestibular-ocular impairment.

Participants were administered the Immediate Post-concussion Assessment and Cognitive Test (ImPACT)[16]; a computer-based neurocognitive test battery composed of six domains which compile to four composite scores: verbal and visual memory, visual motor speed, and reaction time. The Post-Concussion Symptom Scale (PCSS) is a computerized self-report symptom inventory within the ImPACT test and incorporates 22 itemized symptoms. Participants rate each symptom on a 7-point Likert scale from 0 (none) to 6 (severe) and individual symptom ratings are summated to provide a total symptom severity score.

Recovery time was defined as the total number of days from concussion injury to medical clearance for resuming full sport participation. In accordance with international consensus,[17] adolescents were required to (1) be symptom free at rest and following exertion; (2) neurocognitive performance within normative or baseline reliable change indices (RCI); and (3) resume pre-injury levels for sleep and physical activity tolerance. When asymptomatic at rest, athletes were scheduled for a clearance appointment which consisted of ImPACT, PCSS, VOMS and a standardized exertion assessment. As per clinic policy, athletes seeking medical clearance were seen within 72 h of request to ensure that appointment availability did not hinder opportunity to be evaluated for medical clearance.

Patients provided consent and when appropriate, assent with parental consent; all procedures were approved by the University of Pittsburgh's institutional review board. Evaluations consisted of the Vestibular/Ocular Motor Screening tool (VOMS), Immediate Post-concussion Assessment and Cognitive Testing (ImPACT), and Post-concussion Symptom Scale (PCSS) by a neuropsychologist or trained assistant. Assessments were conducted during 2 time points: 0–10 days and 11–20 days after SRC. Participants that demonstrated vestibular-ocular impairment at 0–10 days, but not at 11–20 days were classified into the vestibular improvement group (IMPROVE), and participants that demonstrated vestibular-ocular impairment at both the 0–10 and 11–20 days post-injury clinical evaluations were assigned to the persistent vestibular group (PERSIST). Participants that did not report vestibular-ocular symptom scores over clinical cutoffs at either clinical evaluation time point were grouped as having no vestibular impairment associated with their SRC (NONE). The investigation was externally funded, but there was no additional role pertaining to data collection or analyses.

Descriptive statistics (i.e., frequencies, means, standard deviations, etc.) were used to describe the participant demographics. A series of one-way analysis of variance (ANOVAs) and chi-squared analyses were performed to examine between-group differences on continuous (age) and categorical (i.e., sex, and prior concussion, migraine, and motion sickness histories) demographic variables to

Table 2
Means and standard deviations for vestibular-ocular motor screening components total and change symptom scores among vestibular impairment groups (n = 49).

	None				Improve				Persist			
	Total		Change		Total		Change		Total		Change	
VOMS components	1–10	11–20	1–10	11–20	1-10	11–20	1–10	11–20	1–10	11–20	1–10	11–20
Baseline symptoms	2.68 (2.33)	.947 (1.65)	–	–	6.83 (4.13)	2.67 (3.70)	–	–	9.23 (6.46)	5.93 (4.36)	–	–
Smooth pursuits	2.21 (1.96)	1.05 (1.65)	–.47 (1.26)	0.11 (0.31)	7.00 (4.00)	2.33 (3.37)	0.17 (1.11)	–0.33 (0.65)	9.86 (6.35)	6.07 (4.57)	0.20 (1.01)	0.13 (0.64)
Horizontal saccades	2.37 (2.06)	1.00 (1.67)	0.16 (0.50)	0.53 (0.23)	8.50 (4.87)	2.50 (3.87)	1.50 (1.78)	–1.67 0.58(.)	9.53 (6.13)	7.00 (4.02)	0.27 (1.58)	1.00 (1.00)
Vertical saccades	2.37 (2.00)	1.00 (1.67)	–0.32 (0.95)	0.5 (0.23)	8.67 (4.98)	2.42 (3.63)	1.83 (1.80)	–0.25 (0.452)	10.36 (6.27)	7.43 (4.33)	0.67 (2.02)	0.47 (1.46)
Convergence (Sx)	2.00 (2.13)	0.95 (1.61)	–0.68 (1.67)	0.00 (0.33)	9.0 (4.18)	2.58 (3.87)	2.17 (1.47)	–0.83 (0.67)	9.33 (7.60)	6.73 (4.81)	0.27 (2.31)	0.93 (1.28)
Horizontal VOR	2.16 (2.03)	0.89 (1.63)	–0.53 (1.58)	–0.53 (0.52)	9.91 (5.20)	2.42 (3.12)	3.08 (1.73)	–0.25 (0.97)	11.14 (7.44)	8.36 (4.58)	1.40 (2.61)	2.40 (1.45)
Vertical VOR	2.11 (2.21)	0.89 (1.63)	–0.58 (1.81)	–0.05 (0.52)	9.50 (4.83)	2.25 (3.14)	2.67 (1.67)	–0.42 (0.90)	11.50 (7.72)	8.21 (5.18)	1.67 (2.50)	2.33 (1.54)
VMS	2.11 (2.21)	.790 (1.65)	–0.58 (1.71)	–0.16 (0.50)	10.58 (4.71)	2.75 (3.82)	3.75 (2.38)	0.83 (0.67)	12.50 (8.35)	9.00 (5.07)	2.73 (3.06)	3.13 (2.17)
NPC (cm)	3.52 (3.43)	1.84 (2.10)	–	–	1.78 (1.95)	.667 (0.93)	–	–	7.41 (11.75)	7.88 (12.14)	–	–

Values presented as Mean (SD); VOR, vestibular ocular reflex; VMS, visual motion sensitivity; NPC, near point convergence; Sx, symptoms.

ensure group equivalence. A series of 3 group (PERSIST, IMPROVE, NONE) X 2 time (0–10 days and 11–21 days after SRC) repeated measures ANOVAs were performed on verbal memory, visual memory, visual motor processing speed, reaction time, and total concussion symptoms. An additional one-way ANOVA was performed to compare the PERSIST, IMPROVE, and NONE groups on clinical recovery time. Statistical significance was set at Bonferroni-corrected $p = .05$ and all statistical analyses were conducted with IBM SPSS (IBM Corp. Released 2017.Version 25. Armonk, NY.).

3. Results

Sixty-four athletes were recruited for study and 50/64 (79.3%) completed the 1–10 and 11–20 post-injury clinical visits. One participant from the IMPROVE group was an outlier for concussion recovery (188 days) and was excluded from analysis, resulting in a final sample of 49 subjects (age range 12–20; M = 15.10 ± 2.13). There were 20 (F = 4, 20%) participants in the NONE, 12 (F = 7, 58%) in the IMPROVE, and 17 (F = 10, 59%) in the PERISIST groups (Table 1). The PERSIST group contained more females (10 vs 4; X^2=6.56, $p = .038$) than the NONE group and more individuals with a history of previous concussions (7 vs 1; $X^2 = 12.39$, $p = .015$) and migraine history (8 vs 0; $X^2 = 6.93$, $p = .031$) than the IMPROVE group. VOMS results for both total and change scores are depicted in Table 2.

The results from a mixed model ANOVA revealed a significant between-subjects main effect for vestibular impairment group. Post-hoc analyses indicated no between-group differences for any neurocognitive outcome or total symptom severity 1–10 days after concussion ($p > .05$). However, there were significant differences between vestibular-ocular impairment groups 11–21 days after concussion. Verbal memory differed between groups ($F_{2, 44} = 3.256$, $p = .048$ $\eta_p^2 = .129$) and a post-hoc pairwise comparison revealed the PERSIST group performed worse than the IMPROVE group ($p = .046$). Total symptom severity also differed between groups ($F_{2, 44} = 8.01$, $p = .001$, $\eta_p^2 = .267$); the PERSIST group reported greater symptom severity than NONE group ($p = .001$). There were no observed differences between groups for remaining neurocognitive outcomes (visual memory, visual motor speed, and reaction time) at 11–21 days after concussion (Table 3).

There were several significant within-subjects effects among all vestibular-ocular groups for the neurocognitive outcomes. Specifically, there was a significant within-subjects effect for verbal memory ($F_{1, 44} = 20.452$, $p < .001$, $\eta_p^2 = .317$) and post-hoc analyses revealed an improvement between time points improvement for the NONE ($p = .042$), IMPROVE ($p = .004$), and PERSIST ($p = .027$) groups (Table 3). A significant within-subjects effect was observed for visual memory ($F_{1, 44} = 5.176$, $p = .028$, $\eta_p^2 = .105$), but was only observed as an improved performance among the IMPROVED group ($p = .049$). Visual motor speed performance increased ($F_{1, 44} = 8.890$, $p = .005$, $\eta_p^2 = .168$) for the IMPROVED group ($p = .022$). Reaction time decreased (better performance) between time points ($F_{1, 44} = 9.174$, $p = .004$, $\eta_p^2 = .173$), but was observed in only the IMPROVE group ($p = .026$). Symptoms improved across time ($F_{1, 44} = 31.880$, $p < .001$, $\eta_p^2 = .420$) among the NONE ($p = .001$) and IMPROVE ($p < .001$) groups. No interactions were present between vestibular-ocular impairment groups and time with any neurocognitive or symptom outcome. Lastly, there was a significant difference among vestibular-ocular impairment groups in days to medical clearance ($F_{2, 46} = 3.771$; $p = .03$, $\eta_p^2 = .141$). Specifically, the PERSIST group took more days to recover than the NONE ($p = .028$) group (Fig. 1).

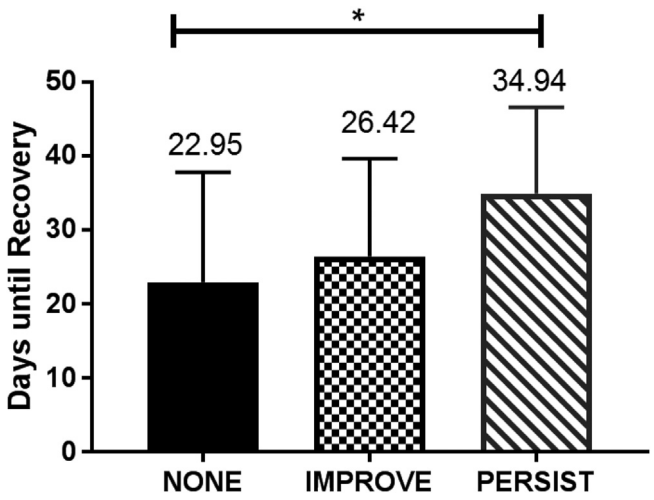

Fig. 1. Mean days until recovery between vestibular groups; *Significant difference ($p = .028$).

4. Discussion

The current study identified recovery time and other clinical outcomes among adolescents that either improved or experienced a persistence in vestibular impairment following SRC. We hypothesized that concussed patients with persistent vestibular-ocular impairment would perform worse on a neurocognitive assessment than those without vestibular-ocular impairment after SRC. Our primary hypothesis was partially supported as the PERSIST group reported greater symptoms and had worse verbal memory scores 11–21 days after concussion, but this finding was significant only compared to the IMPROVE group. Interestingly, the PERSIST group also experienced a longer recovery than the NONE group (34.9 ± 11.6 VS 22.9 ± 14.9, $p = .028$).

Our findings contribute to the current knowledge surrounding vestibular impairment following concussion.[3,4] Corwin et al. identified adolescents with vestibular deficits 12 days after SRC were associated with worse neurocognitive performance and longer clinical recoveries than their counterparts.[3] Similarly, Ellis et al conducted initial evaluations a median seven and twelve days after injury for the concussion (recovery within 30 days) and PCS (recovery beyond 30 days) groups respectively; and reported higher odds of PCS in those with vestibular impairment during the initial evaluation.[4] Our results complement both findings and identified vestibular impairment associated with prolonged recovery. Nevertheless, previous investigations identified vestibular impairment at one time-point[3,4] and had varied procedures to operationalize vestibular impairment. The current study identified vestibular-ocular impairment among a large percentage (59%) of adolescents within 10 days of SRC and a majority (58%) with initial vestibular-ocular impairment experienced persistent vestibular-ocular impairment and delayed symptom resolution. Concussion injuries are recognized as temporary injuries with individualized responses and recent evidence suggests symptom and impairments resolve within diversified trajectories.[1] The current findings provide further support as we identified subsets of adolescents with vestibular-ocular impairment that (1) improve symptom burden and neurocognitive performance or (2) experience persistent vestibular-ocular symptoms beyond 10 days following SRC.

Our results are also consistent with previous reports of vestibular complaints associated with higher total symptom severity.[17,18] We observed that females were more likely to experience persistent vestibular-ocular symptoms than males. Females were also more likely to report provoked symptoms on VOMS than males which is also consistent with reports that identified females as reporting higher symptoms on vestibular assessments[19] and self-reported symptoms than males.[20] However, our findings cannot confirm if the higher symptom reports are socially or physiolog-

Table 3
Means and standard deviations for neurocognitive performance among vestibular impairment groups.

Assessment	Group					
	None N = 20		Improve N = 12		Persist N = 15	
Time point	1–10	11–20	1–10	11–20	1–10	11–20
Days after injury	7.26 (1.82)	14.11 (3.13)	7.17 (1.70)	16.08 (3.80)	7.21 (3.19)	15.29 (3.69)
Neurocognitive testing						
Verbal memory	80.37 (14.62)	86.42[a] (9.99)	82.92 (8.24)	91.50[a] (5.32)	72.60 (16.62)	79.27[a,b] (18.41)
Visual memory	68.90 (15.58)	73.95 (12.22)	66.08 (12.80)	74.67[a] (12.66)	64.80 (17.41)	66.71 (14.51)
Visual motor speed	36.14 (8.42)	38.21 (7.51)	37.15 (6.06)	41.03[a] (7.14)	32.94 (9.71)	35.79 (11.50)
Reaction time	0.688 (.157)	0.651 (.111)	0.647 (.100)	0.585[a] (.067)	0.764 (.256)	0.641 (.127)
Total symptom severity	19.00 (16.16)	5.45[a] (10.03)	33.08 (17.22)	13.00[a] (15.48)	36.20 (25.69)	29.00[c] (24.89)

Values presented as Mean (SD); VOR, vestibular ocular reflex; NPC, near point convergence.
[a] Improvement compared to 1–10 days after concussion.
[b] Lower score than Improve group ($p = .046$).
[c] Greater than None group ($p = .001$).

ically dependent as vestibular impairment may be reflective of reporting behavior and/or unresolved neurobiological homeostasis.

Persistent vestibular impairment in our adolescent population was identified by aggregating information from serial vestibular-ocular screening. Repeated evaluations throughout recovery is advocated to identify potential complications, provide patient education, facilitate interventions, and determine return to activity or duty following concussion.[17,21,22] As such, our results confirm the benefits of serial evaluations after injury to identify individualized impairment after injury. Repeated evaluations with cognizance towards symptom provocation may provide additional utility for serial vestibular-ocular screening.

A thorough understanding of persistent vestibular impairment may contribute to improved prognosis and differential diagnosis. The vestibular system synchronizes visual and somatosensory feedback to maintain postural control and visual equilibrium in relationship with the perceived environment.[23] Symptom provocation during maneuvers that enact the vestibular-ocular or vestibulo-spinal afferents may elucidate a concussion subtype with a disruption to this system.[9] An objective evaluation augmented by symptom provocation may delineate ideal information for prognosis and differential diagnosis purposes as post-concussion symptoms alone may be non-specific to concussion and overlap other comorbidities.[24–26] A dynamic assessment of the vestibular system is recommended to discern deficits following SRC[27] and a focalized evaluation (i.e., vestibular-ocular) of the system may improve identifying those at risk for greater injury burden or prolonged recovery.

Though our findings are novel and contribute to the knowledge around vestibular impairment after concussion, there are several limitations worth recognizing. Firstly, our results are limited by a small sample size and may increase the likelihood for erroneous findings. For instance, the PERSIST group contained more females than the NONE group and more individuals with self-reported migraine history and previous concussions than the IMPROVE groups, Prior concussions have previously been associated with worse neurocognitive performance[28] and prolonged clinical recovery,[29] but a recent report suggests a moderate prevalence of vestibular-ocular dysfunction among healthy adolescents-regardless of previous concussions.[30] Future investigations should incorporate a larger sample to elucidate vestibular impairment development and evanescence among a large and diverse population. Secondly, although the VOMS screening is an objective measure for vestibular impairment following concussion,[9] group assignment was based on subjective responses during assessment. Future research in this area would benefit from a multifaceted assessment of other objective measures to delineate vestibular impairment or predict persistent vestibular impairment. Lastly, concussion clinical profiles are aimed to improve concussion management practices by stratifying subjective and objective findings to identify individualized interventions (i.e. vestibular, exertional, or cognitive therapies). In the current study, all participants received recommendations regarding self-care to facilitate symptom recovery and all received similar instructions to self-manage symptoms as tolerated. The effects of concussion-specific treatment impose to symptom resolution or persistence is uncertain.

5. Conclusion

Clinicians and researchers should be aware of the differences between patients with and without vestibular symptoms and impairment following concussion. Based on the high percentage of vestibular impairment that recovered within 10 days, identifying persistent vestibular profiles may be more challenging until the sub-acute period following concussion. Persistent vestibular symptoms and impairment was associated with worse neurocognitive performance on visual memory, symptom burden, and longer recovery than absent vestibular impairment.

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