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Scoping review: Intervention for ocular motor disorders in children and adults with mild traumatic brain injury

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SIGNIFICANCE: Intervention strategies for post–mild traumatic brain injury (mTBI) ocular motor disorders vary across disciplines and include watchful waiting, vestibular rehabilitation, vision rehabilitation/vision therapy, and optical intervention. However, evidence supporting their effectiveness is limited, highlighting the need for high-quality randomized controlled trials with standardized testing, diagnostic criteria, and reassessment of ocular motor function after intervention.
BACKGROUND: Ocular motor disorders occur frequently after mTBI.
OBJECTIVES: This study aimed to conduct a scoping review of interventions for mTBI-related ocular motor disorders in children and adults.
DATA SOURCES: The following electronic bibliographic databases were searched: PubMed, Embase, PEDro, OVID, Clinical Key, Google Scholar, and REHABDATA.
STUDY SELECTION: Intervention studies published in English between 2003 and 2024 involving mTBI participants who had an ocular motor assessment prior to intervention were included in this study.
DATA EXTRACTION AND SYNTHESIS: Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews guidelines were followed for reporting. Study population, intervention, and outcomes were extracted and synthesized in tabular and graphical formats.
RESULTS: Sixty-seven eligible studies were included, with only three (4%) judged as low risk of bias. Intervention strategies included watchful waiting (n = 31, 46%), vestibular rehabilitation (n = 13, 19%), vision rehabilitation/vision therapy (n = 10, 15%), optical intervention (n = 4, 6%), and alternative interventions or multifaceted interventions (n = 9, 14%). Among the studies providing statistically supported results, improvements in one or more ocular motor outcome domains were reported in nearly 80% of the studies on watchful waiting (19/24) and 100% of the studies on vestibular rehabilitation (4/4), vision rehabilitation/vision therapy (7/7), or optical intervention (1/1).
CONCLUSIONS AND IMPLICATIONS: Although post-mTBI ocular motor deficits improved with watchful waiting strategy, vestibular rehabilitation, vision rehabilitation/vision therapy, and optical interventions, most studies had significant risk of bias. This review emphasizes the necessity for high-quality randomized controlled trials with standardized testing protocols and diagnostic criteria and reassessment of ocular motor functions after intervention to evaluate the effectiveness of these interventions in different age groups and recovery stages.

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Mild traumatic brain injury (mTBI) is a prevalent condition, accounting for approximately 70 to 90% of all traumatic brain injuries (TBIs).[1] Globally, it is estimated that up to and possibly more than 600 individuals per 100,000 are affected by mTBI each year.[1] mTBI has garnered considerable public health interest due to several factors, including a rise in the diagnosis of sports- and recreation-related concussions,[2] an increasing number of TBI in older adults resulting from falls,[3] and increased awareness of service personnel and veterans sustaining TBI from blast injuries.

mTBI is typically characterized by clinical sequelae of neurological dysfunction following a biomechanically plausible mechanism of injury to the brain.[4] Diagnostic criteria established by the American Congress of Rehabilitation Medicine classify an injury as "mild" TBI when the Glasgow Coma Scale score is 13 to 15 (if employed) post-injury at 30 minutes or later and, if present, loss of consciousness lasting no longer than 30 minutes and post-traumatic amnesia lasting less than 24 hours post-injury.[5] Concussion, a term often used interchangeably with mTBI by many medical practitioners,[6] will subsequently be referred to as mTBI. Different authors have characterized mTBI into various phenotypes ranging from three to six (vestibular, ocular-motor, cognitive, post-traumatic migraine,

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cervical, and anxiety/mood),[7–10] with all characterizations including an ocular motor phenotype. Investigations have shown that 69 to 84% of individuals with mTBI exhibit ocular motor disorders.[11–13] Given that a large percentage of human cortical areas and pathways are involved in visual function, the oculomotor system is particularly susceptible to the pervasive effects of mTBI.[14]

As part of the efferent visual system, ocular motor function is characterized by the ability of the eyes to focus on objects of interest, track targets, and maintain binocular alignment to ensure clear, stable, and single vision as an individual moves through space. Ocular motor function encompasses vergence (disjunctive eye movement that aligns the fovea of each eye with a visual target by rotating the eyes inward and outward), accommodation (adjusting the focus of eyes to see objects clearly at different distances), fixations (maintaining eye position on a target), smooth pursuits (tracking a slow-moving target with the eyes), and saccadic eye movements (rapidly shifting the eyes from one target to another). The ocular motor system interacts with the vestibular system through the vestibular-ocular reflex, which is an involuntary reflex that helps keep eyes focused on a target during head or body movements.[15] Ocular motor disorders in mTBI have been associated with neurocognitive impairment[16] and may prolong recovery.[17] Persistent symptoms in mTBI (e.g., blurry vision, double vision, headaches, and dizziness) affect an individual's ability to return to their daily activities, including work, sports, academic, and military duty.[18]

Intervention strategies for post-mTBI ocular motor disorders encompass a range of approaches, including watchful waiting, vestibular rehabilitation, vision rehabilitation/vision therapy, optical intervention such as lenses and prisms, and pharmacological intervention. Ocular motor disorders following mTBI have been shown to be responsive to active interventions; however, systematic reviews on the efficacy of interventions[19–21] for post-mTBI ocular motor disorders highlight the low certainty of the evidence. The goal of a systematic review is to identify and retrieve information about a specific question, appraise its quality, and synthesize the results to inform practice, policy, and future research. However, management of individuals with mTBI often involves multiple professions, and it remains unclear how the various professions approach post-mTBI ocular motor disorders. Thus, instead of a systematic review, we conducted a scoping review to determine the scope of the available literature. This broader approach helps identify existing research and uncover gaps, so more specific questions can be posed and addressed by a more targeted systematic review.[22] The objectives of this scoping review are twofold: first, to map the available evidence for intervention strategies currently used in managing mTBI-related ocular motor disorders in children and adults and, second, to identify any gaps in the current literature, informing needs for future research. Specifically, the research questions were as follows: (1) What is the natural history of post-mTBI ocular motor disorders in children and adults in studies that used watchful waiting with regular follow-up visits during the study period? (2) What intervention modalities are currently being used in the management of mTBI-related ocular motor disorders in children and adults? What is the reported response to intervention?

METHODS

We performed and reported this scoping review in accordance with our published protocol[23] and the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews,[24] respectively. We considered ocular motor disorders to include disorders of vergence, accommodation, saccades, smooth pursuits, and vestibular-ocular reflex.

Identification of relevant studies and study selection

The following electronic bibliographic databases were searched: PubMed, Embase, PEDro, OVID, Clinical Key, Google Scholar, and REHABDATA using database-specific search terms (Appendix Table A1, available at http://links.lww.com/OPX/A795).

For inclusion in this review, studies published in the last 20 years, between 2003 and 2024, were required to meet the following criteria: (1) involved participants with mTBI and assessment of their ocular motor function at the initial encounter, with no restrictions on age, race, sex, or time interval since injury; (2) described the planning, implementation, and/or results of intervention for eligible participants; and (3) were published as a full publication in English-language peer review journals. Watchful waiting with regular follow-up visits during the study period was also considered as an intervention strategy for this review. "Active monitoring" was considered as an "intervention." Editorials, review articles, book chapters, clinical guidelines, and case reports with fewer than three cases were excluded.

The initial electronic searches were performed on February 15, 2023, with a top-up search performed on January 11, 2024. Following bibliographic searches, all identified citations were uploaded into Covidence,[25] with duplicates automatically removed. Two independent reviewers screened each title and abstract against the eligibility criteria. Relevant full text reports were subsequently retrieved and assessed by two independent reviewers. Any disagreements between the reviewers were resolved with an additional reviewer or through discussion.

Data extraction

The extracted data included information on study design, objectives, participant characteristics, methods, key findings relevant to the review questions, and the professions of the authors conducting the study. We determined the professions involved in the research based on the authors' professional credentials. A third reviewer verified or adjudicated the extracted data from the first two reviewers for each study.

Risk-of-bias assessment

Based on the Cochrane Risk of Bias (RoB) tool, two independent reviewers evaluated each study in three domains: (1) involvement of unbiased comparison groups (risk of confounding), (2) whether ocular motor outcomes were measured in an unbiased way (risk of measurement bias), and (3) outcomes reported for at least 80% of enrolled participants (risk of incomplete or selective reporting). Studies meeting all three signaling questions were classified as having an overall "low" RoB; those fulfilling two of three signaling questions were judged to have an overall "moderate" RoB; and studies that met only one or zero signaling question were considered as being at "high" RoB. When it was unclear how the outcomes were measured, the study was judged to be at "unclear" RoB.

Classification of changes in ocular motor outcomes

The ocular motor outcome domains reviewed across the included studies were vergence, accommodation, saccades/smooth pursuits, vestibular-ocular reflex, and Vestibular/Ocular Motor Screening (VOMS). Vestibular/Ocular Motor Screening is a tool designed to identify the signs and symptoms of a concussion and provides a metric to assess symptom provocation. For studies that evaluated and reported changes in an ocular motor outcome domain based on single testing, we classified the overall intervention effectiveness at the study level as "successful" or "no improvement" according to the statistical analysis reported in each study. For studies that evaluated a specific ocular motor outcome domain with multiple tests (e.g., assessing vergence with near point of convergence and fusional vergence range) or multiple parameters of a test, the effectiveness of the intervention was characterized as "successful" when all tests/parameters were statistically improved or "improved" when only some of the tests/parameters were statistically improved.

RESULTS

Search results

Overall, 16,093 titles and abstracts were screened after removing duplicates. A total of 820 full text articles underwent review, resulting in the inclusion of 67 eligible studies for data extraction and synthesis in the final review. Detailed reasons for exclusion were documented for 747 studies (Fig. 1).

Study characteristics

Appendix Table A2 (available at http://links.lww.com/OPX/A812) summarizes the characteristics of the included studies. Various research designs were used across the studies reviewed: six (9%) randomized controlled trials,[26–31] three (4.5%) crossover designs,[32–39] 33 (49%) prospective cohort studies,[40–73] 22 (33%) retrospective cohort studies,[17,74–93] and three (4.5%) case series.[94–96] Fifteen (21%) studies focused exclusively on children (18 years and younger; range, 10 to 18 years),[17,26–28,40,41,74–77,87,91–94] 29 (43%) studies included only adults (range, 19 to 53 years),[29–38,42–57,73,78–82,96,97] and 23 studies (36%)[58–72,83–86,88–90,95,98] included both pediatric and adult participants (range, 13 to 71 years).

Forty-two (63%) studies were conducted in the United States; five (7%), in Canada; and the remaining 20 (30%), in other countries. Thirty-one (46%) studies utilized a watchful waiting strategy, with sample sizes ranging from 7 to 906. The median sample size across the studies was 49 participants (interquartile range [IQR], 31 to 70). Thirty-six (54%) studies used active interventions, with sample sizes ranging from 3 to 527 participants across the studies. The median sample size was 109 participants (IQR, 63 to 158) for the 13 (19%) studies that used vestibular rehabilitation, 16 participants (IQR, 9 to 33) for the 10 (15%) studies that used vision rehabilitation/vision therapy, and 43 participants (IQR, 10 to 60) across the four (6%) studies that used optical intervention.

Regarding the sex distribution of participants, 61 (91%) studies included both male and female participants, whereas two (3%) studies included only male participants.[30,72] Four (6%) studies did not report the sex of the participants.[32–37,54,63,82] The time elapsed between evaluation and onset of injury varied widely across studies, spanning from as early as 3 hours following injury[44] to as long as 30 years post-injury[83]; six (9%) studies did not indicate time since injury.[30,31,49,50,55,57,62] Of the studies that reported the etiologies of mTBI, sports-related injuries emerged as the primary etiology of the mTBI (60%) reported; other etiologies included motor vehicle accidents (27%), falls (16%), occupational or recreational accidents (10%), assault (7%), or military combat incidents (4%). Fifteen (22%) studies did not report the etiology of the mTBI.

The professions conducting the studies vary by intervention. Optometry was the primary profession conducting the studies

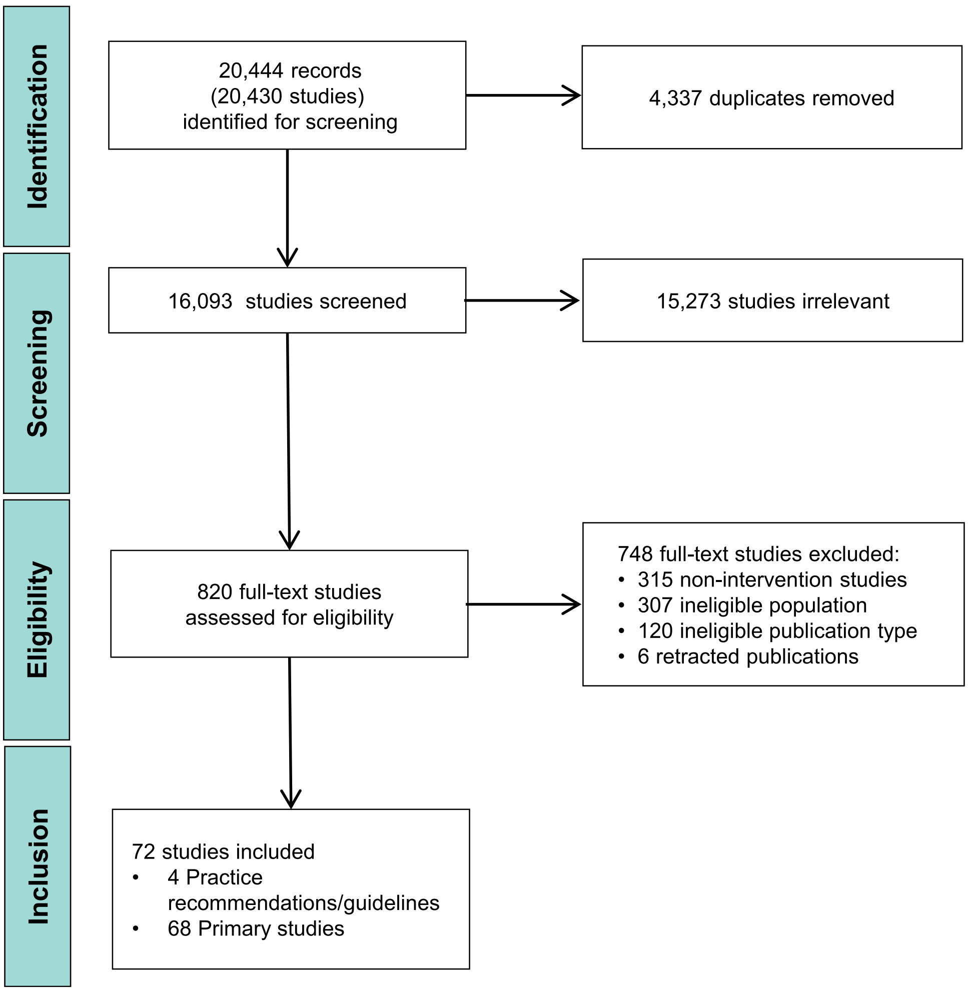

FIGURE 1. PRISMA flow diagram. PRISMA = Preferred Reporting Items for Systematic reviews and Meta-Analyses.

involving optical intervention and vision rehabilitation/vision therapy (11 of 14 studies, 79%), with 7 (50%) of these studies involving multiple professions. Physical therapy, physical medicine and rehabilitation, sports medicine, and neurology were the primary professions conducting the studies that involved vestibular rehabilitation, alternative interventions, such as hyperbaric oxygen and aerobic exercise, or watchful waiting strategy, with 44 of 53 studies (83%) involving multidisciplinary collaboration.

The RoB for confounding variables, outcome assessment, and outcome reporting is found in Appendix Fig. A1 (available at http://links.lww.com/OPX/A797). Overall, three (4%) studies were judged to have a low RoB, 22 (33%) studies have a moderate RoB, 28 (42%) studies have a high RoB, and 14 (21%) studies had an overall unclear RoB (Appendix Tables A3 to A7, available at http://links.lww.com/OPX/A813, http://links.lww.com/OPX/A808, http://links.lww.com/OPX/A814, http://links.lww.com/OPX/A810, and http://links.lww.com/OPX/A815).

Interventions

Appendix Tables A3 to A7 (available at http://links.lww.com/OPX/A813, http://links.lww.com/OPX/A808, http://links.lww.com/OPX/A814, http://links.lww.com/OPX/A810, and http://links.lww.com/OPX/A815) summarize the interventions of the included studies. Overall, 31 (46%) studies used watchful waiting strategy; 13 (19%) employed vestibular rehabilitation; 10 (15%) employed vision rehabilitation/vision therapy; four (6%) utilized optical intervention; and nine (13%) employed alternative interventions, such as hyperbaric oxygen and aerobic exercise, or multifaceted interventions.

Watchful waiting

Appendix Table A3 (available at http://links.lww.com/OPX/A813) summarizes the results from 31 studies that used watchful waiting strategy, with five studies (16%) focusing solely on pediatric participants,[17,74–77] 13 (42%) involving adults,[59,61,64–72,84,85,98,99] and 13 (42%) including children and adults participants.[42–44,46,47,49,51–53,55–57,97] These studies conducted initial assessments of ocular motor functions and repeated testing on follow-up visits at various intervals ranging from 2 days[53,55,97] to 12 months.[43,59,70,98,99] Seven (23%) studies assessed participants within 72 hours of injury,[42,46,52,53,56,66,73,97] whereas the remaining studies evaluated the participants within 3 months of injury. Seven (23%) studies did not reassess changes in the ocular motor function(s) during follow-up visits. Instead, they focused on identifying the presence of ocular motor deficits, assessing their diagnostic values, and exploring associations between ocular motor deficits and protracted recovery or cognitive dysfunction.[17,52,61,65,71,84,85]

Among the studies that reported changes in ocular motor function(s) over time, changes were categorized as "successful" in four (44%) studies[53,56,69,70,97,98] and as "improved" in one (11%) study[47] for vergence, and as "improved" in one (50%) study for accommodation.[47] For saccades/smooth pursuits, nine (53%) studies were categorized as "successful"[42,46,49,55,56,59,69,72,73,99] and two (18%) studies as "improved."[51,75] Three (75%) studies were categorized as "successful"[46,67,69] and one (25%) study as "improved"[77] for vestibular-ocular reflex, and seven (100%) studies as "successful" for VOMS scores (Fig. 2).[53,56,64,66,68,70,77,97,98]

In the five pediatric studies, only one of four (25%) studies reported improved saccades/smooth pursuits[75] over periods ranging from 1 week[75] to 6 months[74,77] post-injury. One of one (100%) study reported improved vestibular-ocular reflex and VOMS over a 6-month follow-up.[77]

In the 12 adult studies, two of three (67%) studies reported improved vergence,[69,70,98] three of three (100%) reported improved saccades,[59,69,72,99] two of two (100%) reported improved vestibular-ocular reflex,[67,69] and four of four (100%) reported improved VOMS scores.[64,66,68,70,98]

In the 13 studies involving pediatric and adult population, three of five (60%) reported improvement in vergnece,[47,53,56,97] and six of nine (67%) reported improvement in saccades/smooth pursuits.[42,46,49,51,55,56] One of one (100%) reported improved vestibular-ocular reflex,[46] and two of two (100%) reported improved VOMS scores.[53,56,97]

Vestibular (physical) rehabilitation

Eleven studies evaluated the benefits of standard vestibular rehabilitation on improving ocular motor functions and reducing symptom burden.[26,40,41,60,87,88,91–93,95,96] Two studies referred to

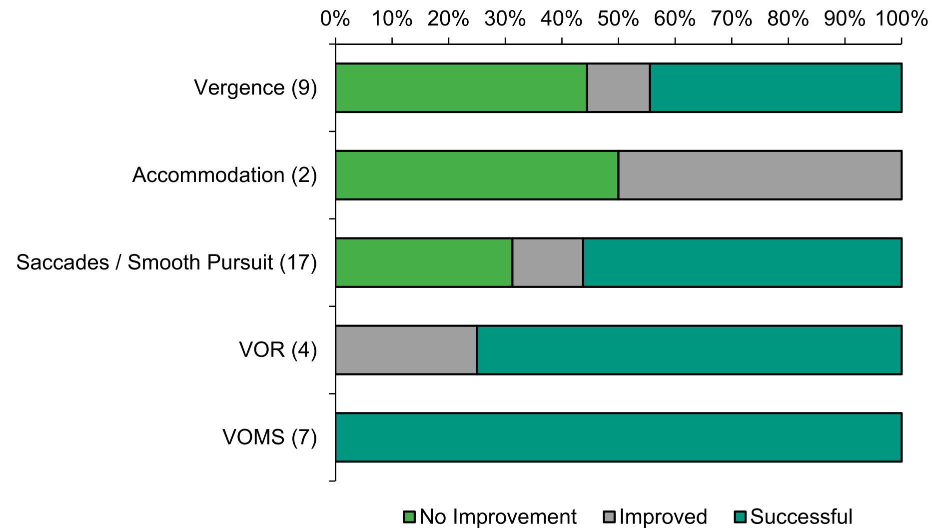

FIGURE 2. Effect of watchful waiting on ocular motor outcome domains. The intervention effect of watchful waiting is shown for each ocular motor outcome domain. Only studies reporting statistically analyzed results are included. Numbers in parentheses indicate the number of studies that evaluate the specific ocular motor outcome domain. For studies that evaluated a specific ocular motor outcome domain with multiple tests or parameters within a test, the results are characterized as "successful" if all tests/parameters improved and "improved" if only some of the tests/parameters improved. VOMS = Vestibular/Ocular Motor Screening; VOR = vestibular-ocular reflex.

the therapy as "physical therapy," but their training programs encompassed a combination of vestibular/ocular motor rehabilitation and subsymptom threshold aerobic exercise.[92,95] Therefore, these studies are also categorized under the "vestibular (physical) rehabilitation" category. Two studies used head-eye vestibular motion therapy.[81,89]

Appendix Table A4 (available at http://links.lww.com/OPX/A808) provides a summary of the findings from studies that used vestibular rehabilitation. Only one study is a randomized controlled trial comparing home-based vestibular rehabilitation exercises with behavioral management strategies.[26] Seven (54%) studies included only pediatric participants,[26,40,41,87,91–93] two (15%) included only adult participants,[81,96] and four (31%) included both pediatric and adult participants.[60,88,89,95] Eight (62%) studies involved participants within 3 months of injury.[26,40,41,60,91–93,95] Various therapy settings were used, with six (46%) studies using office-based therapy.[41,60,92,93,95,96] Most of these studies (75%) were retrospective nonrandomized intervention studies, resulting in varying therapy frequency and duration within and across studies, with therapy continuing until the patient received medical clearance.

Among the five studies that reported changes in ocular motor function(s) with intervention, changes in two (100%) studies were classified as "successful" for vergence,[41,87] two (100%) studies as "successful" for saccades/smooth pursuits,[89,93] one (50%) study as "successful,"[41] and one (50%) study as "improved"[26] for VOMS scores. None of the studies assessed accommodation or vestibular-ocular reflex (Fig. 3).

In the seven studies involving only pediatric patients, one randomized trial found more pronounced improvement in vestibular function, as measured by VOMS in the home-based vestibular rehabilitation compared with behavioral management control group.[26] Among the remaining six nonrandomized trials, two of two (100%) studies reported improved vergence,[41,87] one of one (100%) reported improved saccades,[93] and two of two (100%) reported improved VOMS scores.[26,41]

Neither of the two (0%) studies involving only adults examined post-intervention ocular motor functions.[81,96] Among the five studies including both pediatric and adult participants, one of one (100%) study reported improved saccadic amplitude, peak velocity, and latency.[89]

Vision rehabilitation/vision therapy

Appendix Table A5 (available at http://links.lww.com/OPX/A814) summarizes the results from 10 studies that used office-based or home-based vision rehabilitation/vision therapy, which is also referred to as "oculomotor rehabilitation" in the literature. Seven (70%) studies involved only adult participants,[29,32–39,45,54,82] whereas three (30%) studies involved both pediatric and adult participants.[58,63,86]

One randomized controlled trial compared "six eye exercises," a home-based oculomotor program that consisted of exercises on eye stretches, tracking, gaze stabilization, spatial localization, saccades, and vergence to "standard of care" strategy approximately 1 month after mTBI.[29] Six studies utilized office-based vision therapy programs aimed at training vergence, accommodation, saccades, and smooth pursuits,[45,54,58,63,82,86] with one of these studies also incorporating vestibular-ocular reflex stimulation.[86] Each therapy session varied from 20 to 60 minutes, with approximately 10 to 20 sessions conducted. Three studies evaluated computer-based "oculomotor rehabilitation" programs for fixation, saccades, smooth pursuits, and simulated reading,[32–39] with one study also incorporating training for vestibular-ocular reflex, vergence, and accommodation.[32–37] Six (60%) studies enrolled participants in the chronic phase of recovery (beyond 6 months) with persistent symptoms,[32–39,45,54,82] whereas three (30%) enrolled participants across a wide range of time post-injury (7 days to 5 years).[58,63,86]

Among the seven studies that reported changes in ocular motor function(s), changes in three (75%) studies were classified as "successful"[45,63,86] and in one (25%) study as "improved"[32–37] for vergence. For accommodation, one (33%) study was classified as "successful"[86] and one (33%) study as "improved."[32–37] For saccades/smooth pursuits, three (50%) studies were classified as "successful"[38,45,54] and three (50%) studies as "improved."[32–37,39,86] None of the studies assessed vestibular-ocular reflex and VOMS scores (Fig. 4).

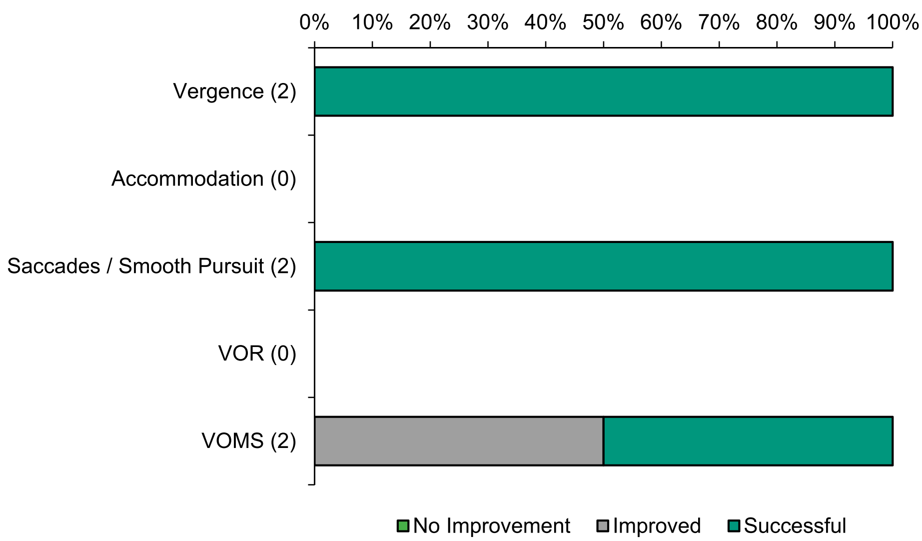

FIGURE 3. Effect of vestibular rehabilitation on ocular motor outcome domains. The intervention effect of vestibular rehabilitation is shown for each ocular motor outcome domain. Only studies reporting statistically analyzed results are included. Numbers in parentheses indicate the number of studies that evaluate the specific ocular motor outcome domain. For studies that evaluated a specific ocular motor outcome domain with multiple tests or parameters within a test, the results are characterized as "successful" if all tests/parameters improved and "improved" if only some of the tests/parameters improved. VOMS = Vestibular/Ocular Motor Screening; VOR = vestibular-ocular reflex.

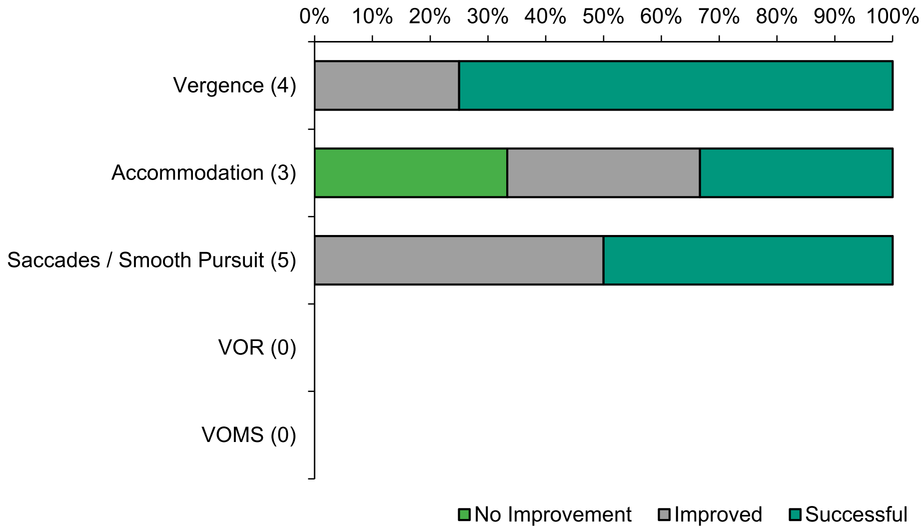

FIGURE 4. Effect of vision rehabilitation/vision therapy on ocular motor outcome domains. The intervention effect of vestibular rehabilitation/vision therapy is shown for each ocular motor outcome domain. Only studies reporting statistically analyzed results are included. Numbers in parentheses indicate the number of studies that evaluate the specific ocular motor outcome domain. For studies that evaluated a specific ocular motor outcome domain with multiple tests or parameters within a test, the results are characterized as "successful" if all tests/parameters improved and "improved" if only some of the tests/parameters improved. VOMS = Vestibular/Ocular Motor Screening; VOR = vestibular-ocular reflex.

Among the seven studies involving adult participants, two of two (100%) studies reported improved vergence functions,[32–37,45] one of two (50%) reported improved accommodation,[32–37] and five of five (100%) reported improved saccades.[32–39,45,54] Among the three studies with both children and adults, two of two (100%) studies reported improved vergence,[63,86] one of one (100%) reported improved accommodation,[86] and one of one (100%) reported improved saccades/smooth pursuits.[86] Three (30%) studies also measured changes in vergence, accommodation, and/or saccades/smooth pursuit objectively, and all three (100%) observed improvements in these outcomes with vision rehabilitation/vision therapy.[32–37,39,63]

Optical intervention

Appendix Table A6 (available at http://links.lww.com/OPX/A810) summarizes the findings from the four studies that used optical intervention.[48,62,78,83] Two (50%) studies included adults only,[48,78] and two (50%) studies included both pediatric and adult participants.[62,83] These studies included an initial vision assessment followed by a prescription of lenses or prism. Three of four (75%) studies involved prism prescription, with two specifically focusing on assessing the effect of individualized prism spectacle lenses on post-concussive symptoms in patients with vertical misalignment of the eyes post-mTBI.[62,78,83] One (25%) study prescribed spectacle lenses with or without base-in prism.[48] In the two studies that provided relevant information, the time since injury to the initial evaluation varied from 3 months to 30 years.[48,83]

Only one of four (25%) studies measured ocular motor function with optical intervention. Change in saccades with spectacle lenses was classified as "successful" in one of one (100%) study (Fig. 5).[48] No statistically supported changes for vergence, accommodation, vestibular-ocular reflex, and VOMS scores were reported in any of these studies.

Alternative or multifaceted interventions

Appendix Table A7 (available at http://links.lww.com/OPX/A815) summarizes the findings from nine studies that used various alternative interventions, including two on hyperbaric oxygen, two on aerobic exercise, and five on multifaceted interventions.

Hyperbaric oxygen

Two randomized controlled trials evaluated the effect of hyperbaric oxygen on eye movements compared with sham in adult participants with mTBI.[30,31] The frequency and duration of intervention varied between the two studies, and neither study provided information on the time interval between injury and intervention. Neither study observed improvements in objectively measured eye movements by using an eye tracker.

Aerobic exercise

Two randomized studies assessed the impact of aerobic exercise on various functions, including oculomotor function and symptom burden in pediatric participants within 1 week of mTBI.[27,28] One study compared aerobic exercise to stretching exercises,[28] whereas the other study compared aerobic exercises of two different intensities to rest.[27] Neither study reported statistically supported changes in any of the ocular motor outcome domains.

Multifaceted interventions

Five studies utilized multiple interventions. One case series evaluated the effect of gabapentin and vision therapy for saccadic intrusion in pediatric patients.[94] Three studies involved adult patients.[50,79,80] One study evaluated progressive, targeted therapy addressing behavioral, vestibular, vision, and exertion factors in chronic mTBI cases and observed statistically significant improvement in the near point of convergence and VOMS scores.[50] One retrospective study utilized decompression of the superior orbital fissure, megadose methylprednisolone, or watchful waiting strategies in patients with isolated oculomotor nerve palsy with or without sphenoid fracture.[79] In a case series, patients with post-traumatic oculomotor or trochlear nerve palsy received combination of prism correction, eye movement exercises, and galantamine (an acetylcholinesterase inhibitor to enhance regenerative process of the nerve after traumatic damage).[80] Neither study reported statistically supported changes in ocular motor outcome domains. One study integrated gaze stabilization exercises with other non–oculomotor-based training, such as neuromuscular reeducation and noninvasive neuromodulation, in both pediatric and adult

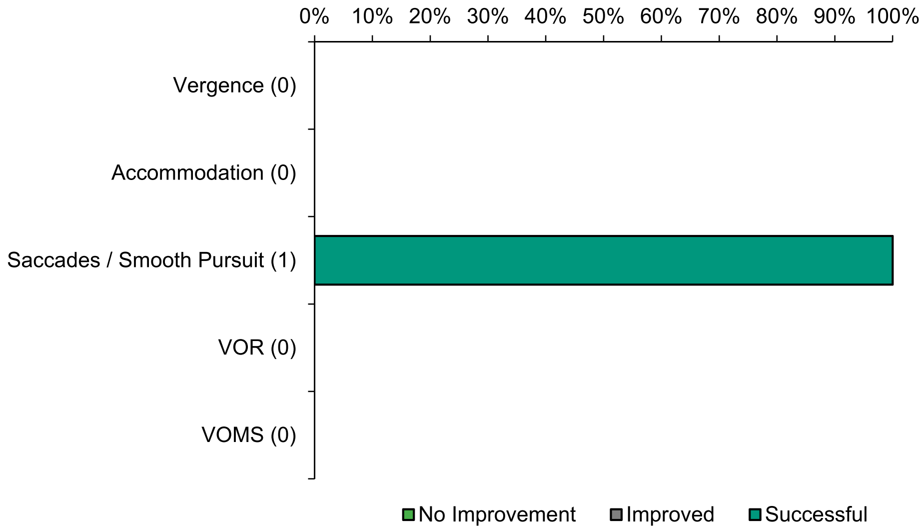

FIGURE 5. Effect of optical intervention on ocular motor outcome domains. The effect of optical intervention is shown for each ocular motor outcome domain. Only studies reporting statistically analyzed results are included. Numbers in parentheses indicate the number of studies that evaluate the specific ocular motor outcome domain. For studies that evaluated a specific ocular motor outcome domain with multiple tests or parameters within a test, the results are characterized as "successful" if all tests/parameters improved and "improved" if only some of the tests/parameters improved. VOMS = Vestibular/Ocular Motor Screening; VOR = vestibular-ocular reflex.

participants, and reported improved dynamic visual acuity, indirectly suggesting an improved vestibular-ocular reflex.[90]

DISCUSSION

This scoping review broadly examined the current literature regarding interventions for post-mTBI ocular motor disorders. The final review includes 67 articles published in the last 20 years. Eighty-five percent of these studies were published in the last 10 years, indicating a growing body of research in this area. Although many studies reported nonocular motor-related outcomes such as cognitive function and the time to return to play, work, or learn, the ensuing discussion primarily centers on the impact of interventions on ocular motor-related outcomes.

Watchful waiting

One question this scoping review aimed to address is the natural history of post-mTBI ocular motor disorders. Several studies that adopted a watchful waiting approach measured the ocular motor functions throughout the recovery phase, providing information on the natural progression of post-mTBI ocular motor disorders. However, it is important to note that evaluating the natural history of post-mTBI ocular motor disorders with watchful waiting strategy was not always the primary objective of these studies. Within 3 months of injury, various ocular motor functions improved without interventions, with most improvement occurring during the first 2 weeks after injury.[64] However, many studies lacked reassessment of ocular motor outcomes at follow-up visits, limiting the ability to assess the changes over time. In addition, only 23% of the studies (7 of 31) followed their participants beyond 3 months post-injury. Among these, four studies reported ongoing improvements in ocular motor functions over time, albeit without complete normalization of all ocular motor functions.[56,59,70,77,98,99] As such, we are unable to draw conclusions regarding the natural history of ocular motor function through the subacute into the chronic stage of injury.

Near point of convergence was the only metric used to evaluate vergence function in most studies. Although near point of convergence is a simple and rapid screening test for evaluating vergence deficits related to mTBI, and a receded near point of convergence is a common vision-related clinical finding, a receded near point of convergence is a single clinical measure of convergence ability, and it is not diagnostic of convergence insufficiency,[13] a prevalent ocular motor diagnosis following mTBI.[11–13,100,101] A receded near point of convergence can be associated with convergence insufficiency, accommodative insufficiency, or a combination of both, and an effective intervention necessitates an accurate diagnosis.[13] In addition, even though accommodative dysfunction is a prevalent ocular motor disorder post-mTBI,[11–13,100,101] accommodative function was rarely assessed in the studies that used the watchful waiting strategy.

Active interventions

One goal of this scoping review was to identify the current interventions for post-mTBI ocular motor disorders and to describe the level of evidence. Active intervention strategies identified in the literature search included vestibular (physical) rehabilitation, vision rehabilitation/vision therapy, optical intervention, and alternative interventions including hyperbaric oxygen, aerobic exercise, pharmacological intervention, and decompression of superior orbital fissure.

Vestibular dysfunction following a concussion is a prevalent phenomenon. Vestibular rehabilitation is a physical therapy program that targets dizziness and balance dysfunction to facilitate recovery, and it often incorporates exercises that improve convergence, smooth pursuits, and saccades. Vestibular rehabilitation capitalizes on the innate plasticity of the balance system to accelerate the spontaneous natural process of vestibular compensation.[102,103] Although the therapy regimen, frequency, and duration vary across the studies, the therapy generally included targeted exercises for gaze stability, postural stability, ocular-motor control, habituation, and aerobic activities with no emphasis on fusional vergence and accommodation.

Whereas much of the literature on vestibular rehabilitation involved participants within 1 month of mTBI injury, a few studies include individuals within 72 hours of injury,[60,87] highlighting a lack of standardization in terms of the rehabilitation window. Vestibular rehabilitation can be used in-office or at home; however, there is insufficient evidence on which method would be more effective.[92]

Although there seem to be positive effects of vestibular rehabilitation on near point of convergence and saccades, only 38% of the studies evaluated vergence or saccades before and after vestibular rehabilitation[26,41,87,89,93] because the primary focus of these studies was on ameliorating vestibular dysfunction and associated symptoms, and not on ocular motor disorders. Despite vestibular rehabilitation being routinely prescribed, only 1 of the 13 studies was a randomized trial,[26] indicating a lack of high-level evidence for the benefits of vestibular rehabilitation on post-mTBI ocular motor disorders.

Studies evaluating the effectiveness of vision rehabilitation/vision therapy involved pediatric and adult patients in the chronic recovery phase, occurring at least 3 months post-injury.[32–39,45,54,58,82] This timing corresponds to a common trend where many patients with visual and vestibular deficits following mTBI do not receive rehabilitation services until months following their injury.[104] A lingering question remains about the optimal timing to initiate post-concussion therapies and whether there are advantages to early intervention over watchful waiting. Post-mTBI vision rehabilitation/vision therapy encompasses various approaches, including office-based, computer-based, and home-based methods. Office-based vision therapy often utilizes therapy programs akin to those used in the Convergence Insufficiency Treatment Trial.[105] Regardless of the implementation method of the therapy procedures, the goal is to improve and normalize the accuracy, amplitude, and flexibility of vergence, accommodation, saccades, and smooth pursuits.

One randomized controlled trial compared home-based eye exercises to daily activities that integrate ocular motor skills, such as reading, and found improvement in saccadic eye movements in both groups.[29] Three studies utilized a crossover design,[32–39] with one evaluating the effectiveness of computer-based "oculomotor rehabilitation" program compared to placebo training.[32–37] The program targeted various aspects of ocular motor system and observed improvements in both clinical measures and objective measures of vergence, accommodation, saccadic eye movements, and reading rate, which persisted 6 months after the intervention. Although 80% of the studies reported improved clinical measures[32–39,45,54,63,86] and objective measures of ocular motor function,[32–37,39,63] including vergence peak velocity and accuracy via objective eye movement recording after vision rehabilitation/vision therapy,[32–37,63] only one study evaluated the short-term outcomes of the intervention,[32–37] with none assessing the long-term outcomes of the intervention.

Although most of the studies regarding vision rehabilitation/vision therapy are nonrandomized interventions or crossover studies, they used multiple tests to evaluate changes in the vergence and accommodative outcomes with intervention. This comprehensive approach contributes to a more thorough understanding of the effects of vision rehabilitation/vision therapy on post-mTBI ocular motor disorders. The results from our review align with those of other scoping and systematic reviews, which reveal a trend toward improvement of post-mTBI ocular motor deficits through vision rehabilitation/vision therapy.[21,106] Nonetheless, further studies using rigorous study designs, predefined narrow ranges of time since injury, and long-term follow-up are needed to ascertain the benefits of vision rehabilitation/vision therapy for addressing post-mTBI ocular motor deficits.

Studies that used optical intervention lacked detailed descriptions of their processes for determining the lens or prism prescriptions.[48,62,78,83] These studies also included participants with a broad range of time elapsed since injury within their cohort. In addition, only 25% of the studies measured the ocular motor function with optical intervention,[48] making it challenging to determine the benefits of optical intervention in improving ocular motor deficits and discern whether symptom improvements directly correlated with changes in ocular motor function.

Hyperbaric oxygen has been advocated for acute conditions such as carbon monoxide poisoning, crush injuries, and air embolism, as well as for the chronic management of conditions such as pressure ulcers and radiation necrosis.[107] It has also been explored for improving the long-term effects of ischemic stroke and autism.[107] There are basic science studies supporting the effects of hyperbaric oxygen on objective findings of brain recovery in animal models.[108,109] However, of the two randomized controlled trials that investigated the effects of hyperbaric oxygen on mTBI-related symptoms and eye movement abnormalities, neither study found clinically meaningful improvements on ocular motor functions associated with the exposure to hyperbaric oxygen.[30,31]

Recent studies have demonstrated that engaging in subsymptom threshold physical activity (including prescribed aerobic exercise) early after the injury can safely expedite recovery from concussion[110,111] and reduce the likelihood of adolescents developing persistent post-concussive symptoms.[112] Two randomized controlled trials that examined the acute effects of aerobic exercise found that, although aerobic exercise at low to moderate intensity within the first week of mTBI recovery was safe and well tolerated, they did not further improve VOMS scores and symptoms compared with rest or stretching exercise.[27,28]

Limitations

A few limitations to our scoping review should be acknowledged. We did not exclude studies that did not specify their diagnostic criteria for mTBI; therefore, participants in some of the included studies may not have met the current diagnostic criteria established by the American Congress of Rehabilitation Medicine. The certainty of evidence regarding various intervention strategies for improving post-mTBI ocular motor disorders is low for multiple reasons. Only six studies are randomized controlled trials (one used vestibular rehabilitation, one used vision rehabilitation/vision therapy, two used hyperbaric oxygen, and two used aerobic exercise) with relatively small sample sizes. Many studies did not report the threshold for defining ocular motor disorders, use a comprehensive evaluation with standardized diagnostic criteria, or reassess ocular motor outcomes at follow-up visits, making it challenging to draw accurate conclusions. Because intervention approaches for various ocular motor disorders differ, future studies should include a thorough examination of the vergence and accommodative systems to assess the intervention benefits more comprehensively. The involvement of eye care providers in evaluation, intervention, and reporting on ocular motor disorders following an mTBI is crucial due to their comprehensive understanding of the ocular motor system and regular interaction with patients experiencing ocular motor disorders. Standardization of testing protocols and diagnostic criteria and inclusion of reassessment of ocular motor function after intervention can promote consistency across studies and facilitate synthesis in future systematic reviews and meta-analyses.

Symptoms related to ocular motor function vary, depending on the specific ocular motor disorders. Although not the focus of this scoping review, the primary goal for improving ocular motor function is to alleviate these symptoms, as they can significantly affect an individual's ability to perform daily activities. Of the studies included in this scoping review, only 6 of 67 (9%) studies utilized surveys specially designed to track changes in vision-related symptoms, such as the Convergence Insufficiency Symptom Survey and the Binocular Vision Dysfunction Questionnaire. More research is needed to quantify symptoms and other quality-of-life domains related to ocular motor disorders in patients with mTBI and to determine the effect of intervention on those quality-of-life issues.

The age distribution of participants in the reviewed studies is predominantly skewed toward adolescent years and adults younger than 50 years. There are relatively few studies that include younger pediatric or older adult populations. Many studies included participants with a broad range of time elapsed since injury within their cohorts. The inclusion of a broad range of time since injury within a study is problematic because, often, when more than a year has passed since the mTBI, symptoms are more attributed to psychosomatic factors rather than the injury itself.[113] In addition, abnormal ocular motor functions may spontaneously improve without active interventions, and participants are likely to respond to interventions differently during subacute versus chronic recovery phases. It is possible that ocular motor disorders are best treated during the subacute recovery phase, as intervening early might facilitate faster or more complete return to baseline function. Future studies should aim to have a pre-defined narrow range of time since injury, which may shed light on optimal timing of interventions for post-mTBI ocular motor disorders.

For studies that utilized active intervention, post-intervention follow-up intervals ranged from immediately following intervention to 6 months. Most studies (34 of 37; 92%) lacked detailed information regarding long-term follow-up. This highlights the need for more studies that include long-term follow-up to assess if the benefits of the intervention are stable over time. To increase the rigor of future studies, investigators should consider larger sample sizes to address the generalizability of intervention effects, include detailed and well-described study designs, and include longer follow-up assessment periods to determine maintenance of intervention effects. All studies of mTBI-related ocular motor disorders should have an eye care professional involved in the study design and pre- and post-intervention assessments.

CONCLUSIONS

This scoping review highlights the various interventions that providers may utilize to improve abnormal ocular motor signs and associated symptoms following mTBI. This scoping review also highlights that, although post-mTBI ocular motor deficits improved with watchful waiting, vestibular rehabilitation, vision rehabilitation/vision therapy, and optical intervention, most studies had a significant risk of bias. The review demonstrates the need for high-quality randomized controlled trials to evaluate the effectiveness of these interventions for patients with post-mTBI ocular motor disorders in various age groups as well as various time points in recovery.

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