

The Effects of Mild Traumatic Brain Injuries (mTBIs) on Oculomotor Functions and Effective Treatments

André Kurahashi Dantas

American School of Campinas, R. Cajamar, 35 - Jardim Alto da Barra, Campinas, São Paulo, 13090-860, Brazil; 360andre.dantas@gmail.com

ABSTRACT: Traumatic brain injuries (TBIs) occur following external impacts, altering brain functions, such as visual processing and cognitive abilities. Of 1.7 million individuals affected by TBI, 70-80% have mild TBI (mTBI). In 90% of mTBI cases, individuals experience oculomotor dysfunctions. To date, there is no known comprehensive review that evaluates the effects of oculomotor dysfunctions following mild TBIs and the effectiveness of specific treatments to improve these conditions. As such, this review aims to provide a comprehensive overview of how mTBI influences oculomotor functions and visual processing. Mild TBI can affect multiple oculomotor functions, including vergence, accommodation, and version. Oculomotor dysfunctions resulting from mTBI can hinder daily activities, such as reading. Four different studies employed distinct, effective oculomotor training designs: Thiagarajan and colleagues employed effective oculomotor neurorehabilitation for reading; Cade and Turnbull utilized effective chiropractic intervention for oculomotor dysfunctions; Thiagarajan and Ciuffreda implemented effective oculomotor rehabilitation for vergence responsivity; and Smaakjær and colleagues trialed effective vision therapy for binocular vision and ocular motility. Overall, this review contributes to raising medical awareness surrounding oculomotor dysfunctions following mTBI and appropriate treatments for such impairments.

KEYWORDS: Medical and Health Sciences, Mild Traumatic Brain Injury (mTBI), Oculomotor; Traumatic Brain Injury (TBI), Vergence, Version, Accommodation, Effective Treatments.

■ Introduction

Traumatic brain injuries (TBIs) are the result of external impacts (blows/jolts) that directly alter brain functions, such as visual processing and cognitive functions, producing a concussion-like condition in the individual affected.¹ TBIs can occur at any age. However, the severity of the symptoms varies from young to elderly. For example, individuals 75 years and older have higher TBI-related hospitalizations and deaths than younger individuals, who tend to recover faster and more efficiently following TBI.² This widespread injury (TBI) affects nearly 1.7 million individuals in the United States of America annually, of which 70-80% are mild TBIs (mTBI).³ As such, due to this commonality, mTBIs will be the main injury addressed in this paper.

Additionally, of the 1.7 million cases of mTBIs, 90% of individuals experienced oculomotor dysfunctions as a result.³ Oculomotor dysfunctions are common results of mTBIs. Given that oculomotor functions are related to all four brain lobes, in a 2020 clinical trial conducted by Berryman *et al.*, experts revealed how mTBI can produce symptoms that impair an individual's regular oculomotor function.⁴ For example, oculomotor functions impaired following mTBIs include pursuits, saccades, convergence, fixations, and vestibular ocular reflex, which consequently negatively impact the day-to-day routines of affected individuals.⁴ A daily activity examined in a 2014 study by Thiagarajan and Ciuffreda was reading. These researchers conducted a crossover study to evaluate the effects of oculomotor-based vision rehabilitation (OBVR) on visual impairments following mTBIs.⁵ To evaluate the effects of OBVR treatments (which included oculomotor training (OMT) and

sham training (ST), reading exercises were administered. These readings consisted of a combination of saccadic eye movements, coordination of the individual's vergence eye movements, constant synchrony between ocular accommodation and vergence, along with continuous visual attention elements to process text.⁵ The authors found that after the OMT, 80% of patients improved in the abnormal parameters measured, such as reading rates and amplitudes of vergence and accommodation.⁵ Hence, when mTBIs impact the brain's standard processing of these functions, the individual's ability to read becomes compromised, and OBVR appears to be effective in treating oculomotor dysfunctions.

In addition to reading, there are other daily activities hindered by visual impairments in individuals who have experienced mTBIs. Dysfunctional oculomotor functions (pursuits, saccades, etc.) can hinder an individual's academic performance when required to extensively engage cognitive functions.⁶ This means that one will demonstrate poor effectiveness in computer-related tasks, taking notes in class, and head movements in dynamic sports activities.⁶ Ultimately, it is critical to stress the importance and severity of visual dysfunctions following mTBIs, as they can negatively impact daily activities regularly performed by other individuals.

Although there is a 2017 review of visual impairments following TBIs, the severity of the conditions addressed remains unknown. Additionally, a 2025 review addresses oculomotor dysfunctions following mTBI; however, it lacks evaluations of effective treatments regarding oculomotor dysfunctions. To date, there has yet to be a comprehensive review evaluating the impacts of oculomotor dysfunctions following mild TBIs

and effective treatments to improve such conditions. Taken together, the existing literature reviews lack recent relevance, as one was published eight years ago, and the other does not comprehensively evaluate effective solutions to visual impairments. Therefore, a review incorporating more recent evidence is needed to examine oculomotor dysfunctions following mTBIs and evidence-based treatments.

As such, this literature review aims to provide a comprehensive review of how mild traumatic brain injuries affect oculomotor functions and visual processing, and the methods that have been shown to improve such conditions. A thorough review of the literature may provoke further discussion, leading to an increase in medical awareness of mTBIs' influence on visual impairments. Once medical providers are more aware of this relationship, more efficient treatment protocols for patients with ocular dysfunctions following mTBI can be developed to minimize the harmful effects of visual impairments following mTBIs.

■ Discussion

Oculomotor Dysfunctions Following mTBI:

Following a mTBI, the four brain lobes are damaged, meaning that oculomotor functions become hindered as a result. In general, visual impairments are caused by the hindrance of vergence, accommodation, or version functions, all of which are key elements required to perform many acts done by the eye in an individual's daily activities.³ Due to the complication of such key elements, the eye has further difficulties with fixation, saccades, and pursuit, resulting in the affected individual experiencing difficulty in performing normal vision-related acts.^{7,8} Such hindered acts, as mentioned previously, include athletic activities, note-taking, sleeping, and tracking any moving objects;⁶⁻⁹ all of which ultimately reduce one's quality of life.

Vergence is a key oculomotor function where the eyes perform the function that tracks objects as they move in depth over the range of an individual's binocular view, effectively aiming to maintain a constant focus and singleness of the targeted object.^{3,10} Additionally, the vergence operating system comprises multiple neuronal pathways susceptible to damage from mTBIs,¹⁰ effectively producing an oculomotor dysfunction that hinders one's daily activities. The neuronal pathways, where discharge of neurons occurs during vergence, include the cerebellum, the pons, and areas of the cerebral cortex, including the frontal eye field, middle temporal, and medial superior temporal visual areas, as well as the parietal lobe.³ Hence, when mTBI occurs in an individual, these neural systems are impacted and ultimately impaired, which translates to further negative consequences on the vergence of the mTBI-affected individual. Vergence abnormalities, moreover, can be inferred to be among the most common dysfunctions following TBIs, as seen in the 2007 study by Ciuffreda *et al.*, in which 56.3% of individuals placed in the TBI subgroup were identified as having vergence dysfunctions.¹¹ However, Ciuffreda and colleagues did not specify the type of TBI; therefore, it is unclear the percentage of individuals with mTBIs that would have vergence dysfunctions.

Convergence insufficiency is arguably the most common type of vergence dysfunction, as 42.5% of individuals with vergence abnormalities suffer from convergence insufficiency.^{10,11} More specifically, convergence insufficiency is an oculomotor vergence abnormality where the individual experiences a binocular vision disorder, with a receded near point of convergence and reduced positive fusional vergence at near.¹² This impairment is caused by the nerves surrounding the six eye muscles—superior and inferior rectus muscles, the lateral and medial rectus muscles, and the superior and inferior oblique muscles¹³ not firing the proper signals for ocular movement.¹⁴ Figure 1 illustrates improper nerve signaling and how convergence insufficiency occurs, using content from Parker E. Ludwig and colleagues' book as a reference for the simple visualization of the eye muscles.¹⁵ As such, this improper functioning of nerves can be caused by mTBIs, and as these neuronal pathways become impaired, they consequently impact the convergence system of the eyes.

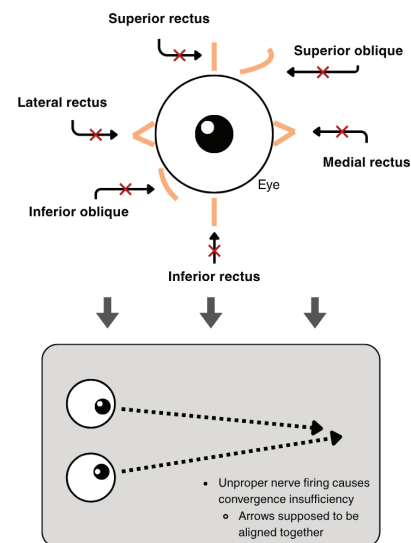


Figure 1: Illustration of where the six ocular muscles are located and their improper signaling (indicated by the red "X"). The grey box below illustrates the effects of convergence insufficiency on ocular function, demonstrating how the individual's ability to fixate at a near object is limited due to drifting outwards from the eyes.¹⁶ Made using Canva.

Accommodation is an understudied oculomotor dysfunction that involves the eyes' ability to change focus between objects at different distances, altering the shape of the eye's lens.¹⁷ Often, individuals who experience mTBI later develop accommodative impairments.¹⁸ Accommodative insufficiency refers to the impaired dynamics of accommodation, which is the reduced capability of sustaining focus on specific targets at short distances;¹⁹ impaired dynamic accommodation includes reduced amplitude, lower peak velocity, and an increased accommodation time constant, potentially causing headaches, double vision, eye strain, and intermittent blur.¹⁸ A 2019 meta-analysis by Natalya Merezhinskaya and colleagues emphasized the occurrence of individuals with accommodative dysfunction following traumatic brain injury (TBI, not to be confused with mTBI), sharing a 42.8% prevalence (95% confidence interval: 31.3 to 54.7) across the 1,271 TBI patients screened primarily in the United States, but also from Asia,

Africa, and Europe.²⁰ It is critical to note that the majority of studies reviewed by Merezhinskaya *et al.* included TBI patients, while the remaining reported on mild TBI.²⁰ This limits the validity of the prevalence of accommodative dysfunction in individuals following mTBI.

Version is another oculomotor function that is impaired following a mTBI. Version, not to be confused with vergence, refers to the synchronous, symmetrical movement of both eyes to interpret a designated element and is composed of saccadic and pursuit movements.^{7,19} More specifically, versional eye movement dysfunction refers to delayed and incorrect saccadic eye movements, along with the impaired optical ability to pursue target elements.²² Interestingly, version and vergence are quite related, as these ocular functions operate using similar neural pathways, operating with precision and synchrony to track the target element.³ Evidence suggests that versional eye movement dysfunction is caused by diffuse axonal injury, which is a downstream effect of mTBI.²² Diffuse axonal injury occurs when acceleration forces induce a rapid stretch of the axon, disrupting microtubules and producing focal breaks.²³ Diffuse axonal injury severely impairs the relay of the occipital lobe to execute visuospatial information in the frontal and parietal lobes, known as the saccadic center.²² Figure 2 visualizes and summarizes the pathways of oculomotor impairments following mTBIs.

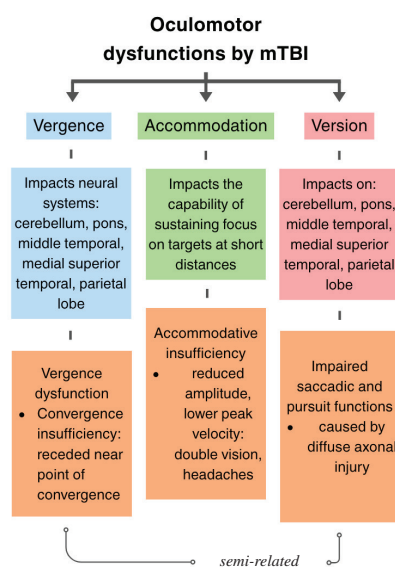


Figure 2: Oculomotor dysfunctions caused by mTBI and their related impacts flowchart. Made using Canva.

Effects of mTBI on Reading:

Following mTBIs, affected individuals can experience several visual impairments.⁵ These visual dysfunctions can lead to many daily functions being disrupted due to mTBIs. One general visual impairment associated with mTBI symptoms is difficulty reading. For an individual to read text, precise coordination of versional eye movements, synchrony with vergence and ocular accommodation, and a constant, advanced attentional state are required. Specifically, the automatic saccadic eye movements during reading involve shifting the eyes left and right, lasting 30–60 milliseconds and having an amplitude of 1–3 degrees.⁵ These are followed by around 250 milliseconds

of fixations for text processing, with occasional regressions to re-read information.⁵ As such, for reading to occur efficiently, all these complex ocular mechanisms must occur synchronously to achieve a truly efficient and functional reading.

These complex oculomotor mechanisms, however, are susceptible to the effects of mTBIs. As such, mTBIs can significantly affect the precise functions that comprise reading. The impairments caused by a mTBI are oculomotor-based, meaning that the eye's motor functioning and capability are hindered due to this injury. For example, since saccadic eye movements are primarily processed in the frontal lobe and the superior colliculus region of the midbrain,¹³ if mTBIs affect these areas, the individual's reading ability will ultimately become difficult due to the dysfunctional saccadic eye movement. Hence, the precision of the saccadic eye movements is severely reduced (due to mTBIs). From this reduction in saccadic precision, affected individuals tend to make inaccurate saccades with varying amplitude degrees, ultimately producing slower reading rates as they experience difficulty fixating words and maintaining focus within the line currently being read.²⁴ Additionally, precision and ease of reading are further affected by vergence changes resulting from mTBIs. Since the precise simultaneous movement of both eyes is impaired, diplopia, or partially overlapping images, can occur intermittently, resulting in difficulty for the individual in organizing and identifying words in the text.^{5,25} For better visualization, Figure 3 illustrates side-by-side the comparison between normal readers and readers affected by visual impairments. Overall, this can limit the learning and comprehension rate of the individual, due to a longer period of time being needed to understand the information given in the text.²⁴

Comparison of reading processes

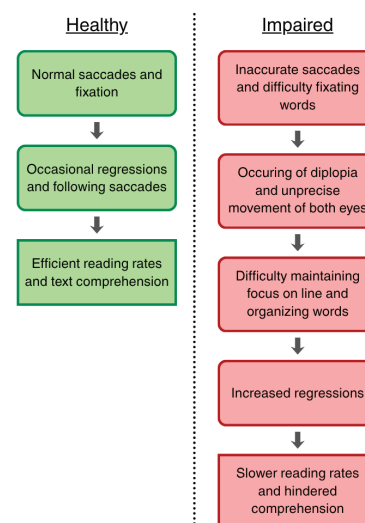


Figure 3: Comparison of occurrences in reading between normal individuals and mTBI-affected individuals. Made using Canva.

Effective Treatments for the Oculomotor Dysfunctions:

In addition to the oculomotor dysfunctions explained previously, numerous researchers and colleagues have undergone multiple trials to evaluate the efficacy of their specific treatment in improving visual impairments and optical abilities.

This section will critically review and analyze four studies that employed various treatments for oculomotor dysfunctions, providing a final overview of the effectiveness of the methodological design.

In *Effects of mTBI on Reading*, Thiagarajan and colleagues conducted experiments in 2014 to identify more efficient methods to improve recovery in patients with impairments in the vergence, version, and accommodative systems. This was a crossover, interventional study that utilized oculomotor training (OMT) and sham training (ST) over 6 weeks (2 sessions per week, each lasting 1 hour).⁵ The OMT group had three training sections, designed to train the version, vergence, and accommodative systems.⁵ The ST group also underwent these three training sections; however, they received a sham version/vergence/accommodation training.⁵

The parameters measured by Thiagarajan and colleagues were actions performed during reading and tests (to evaluate nearvision-related symptoms) that included the Convergence Insufficiency Symptom Survey (CISS) and the Visual Search Attention Test (VSAT). Overall, the visagraph parameters collected post-OMT improved, although some differences were not statistically significant. Specifically, a significant 25% increase in reading rate (wpm) occurred post-OMT, increasing from 142 (baseline) to 177 (post-OMT); the number of fixations per one hundred words decreased significantly, from 164 (baseline) to 135 (post-OMT); and the grade level efficiency increased significantly by two levels, also considered clinically significant, from 4.1 (baseline) to 6.3 (post-OMT).⁵ Evidently, the data collected demonstrate a significant difference between baseline and post-OMT ocular abilities, with visagraph parameters post-OMT all demonstrating positive improvements, although some parameters had p-values that made the data statistically insignificant.⁵

As such, this OMT design to improve oculomotor function in affected individuals can be considered to be efficient. Across all visagraph parameters, the post-OMT data demonstrated improvements in oculomotor functions, with one limitation being the statistical significance of the results, as half of the presented data were not statistically significant.⁵ However, Thiagarajan and colleagues explain this insignificance clearly, such as the possible relatively high inter-subject variability.⁵ In conclusion, the OMT designed by Thiagarajan and colleagues was shown to be effective, with improvements across all visagraph parameters measured by the specialists.

Another study, conducted in 2024 by Alice E. Cade and Philip R. K. Turnbull, in which such experts evaluated the efficacy of chiropractic intervention on oculomotor and attentional visual outcomes in young adults with mTBI.⁷ This unique treatment originated from an observed correlation between convergence insufficiency/saccadic deficits, which altered proprioceptive drives, a function related to spinal joint dysfunction; hence, the inclusion of chiropractic intervention became a possibility.⁷

In this experiment, Cade and Turnbull conducted a single-blind, randomized controlled intervention study comparing a group receiving chiropractic intervention with a control group, where the chiropractic group received care

from four chiropractors instructed to utilize the best practice guidelines and scope of chiropractic practice.⁷ The data collection consisted of recording baseline computerized eye-tracker assessment (CEA) results in 40 young adults experiencing persistent postconcussion syndrome (PPCS) following mTBI.⁷ The assessment in the CEA included egocentric localization, fixation stability, pursuit, saccades, vestibulo-ocular reflex, and the Stroop Test.⁷

As a result, the collected data revealed that the chiropractic group significantly improved dynamic and static gaze stability, improved performance in the Stroop test (split into two parts, the first involved reading, and the second involved matching font colors), and reduced saccadic latency.⁷ Specifically, gaze stability improved following chiropractic intervention, with a previous value of 3.26 and a posterior value of 3.16 (expressed in $\log_{10}$ minarc²), in comparison with the control group, which worsened from a value of 2.94 to 3.12 ($\log_{10}$ minarc²).⁷ The chiropractic group revealed significant performance improvements in the first part of the Stroop test ($X^2[1, N = 40] = 3508.64$); however, the second part's performance remained the same in both the control and chiropractic group.⁷ A significant reduction in saccadic latency was observed in both groups, but the reduction was greater in the chiropractic group.⁷ Prosaccade reduced from 366.9 to 317.0 ms, and antisaccade reduced from 350.3 to 317.0 ms.⁷

In summary, participants in the chiropractic group scored higher than participants in the control group on the Stroop test, showed improved gaze stability in the vestibulo-ocular reflex and fixation stability test, and a decreased vertical error in egocentric localization (p-values indicating statistical significance).⁷ As such, chiropractic intervention proved beneficial and effective for oculomotor dysfunction following mTBI. This is due to observations of differences in data results between the chiropractic group and the control group, where some parameters measured in the control group worsened or did not change, whereas the chiropractic group showed improvements (e.g., Stroop test of selective attention).⁷ The importance of this finding is a new form of treatment for visual impairments, which increases medical awareness of new potential treatments to alleviate oculomotor dysfunctions and provides a better quality of life to affected individuals in different (potentially easier) methods.

Furthermore, in another experiment conducted by Thiagarajan and Kenneth J. Ciuffreda in 2013, these researchers addressed the impact of oculomotor training on vergence responsivity and nearwork-related symptoms in individuals following mTBI (not to be confused with the previous 2014 article focused on reading capabilities).³ The design of this experiment was a crossover, interventional study with single-blind allocation, with a total duration of 15 weeks, with two separate groups: the oculomotor training (OMT) group and the Placebo training group (P training).³ Similar to previous studies mentioned, the OMT group underwent three separate training sessions that included version, vergence, and accommodation training. However, only the results of the vergence training were reported, as it was the primary objective emphasized by Thiagarajan and Ciuffreda. Additionally, to specifically report

on the effects of OMT on vergence responsivity, some of the visual parameters addressed by Thiagarajan and Ciuffreda include the near point of convergence (NPC) break and recovery, positive fusional vergence (PFV) break and recovery, negative fusional vergence (NFV), horizontal near phoria, peak velocity ($^{\circ}/s$), and evaluations from both the CISS and VSAT tests.³

Following OMT, Thiagarajan and Ciuffreda recorded a significant increase in the peak velocity for convergence and divergence. Although peak velocity did not normalize, a significant benefit from OMT was revealed.³ The NPC break and recovery data showed improvement following OMT, as the values recorded decreased significantly for both the NPC break (4.07) and recovery (3.64).³ The PFV values also showed significant improvements, with the PFV break value significantly increasing by 2.80 and the recovery significantly increasing by 4.71.³ The NFV break and recovery also improved significantly, evidenced by the increase in the NFV break (3.40 and normalized) and recovery (2.04).³ Additionally, regarding the CISS and VSAT tests, the CISS resulted in a significant decrease in score (37 ± 4 to 28 ± 3) following OMT, and the VSAT percentiles significantly increased in 80% of the participants (32nd (± 9) to 50th (± 10) percentile).³ It is important to note that not all visual parameters recorded by Thiagarajan and Ciuffreda were mentioned in this paper.

As such, the results reported by Thiagarajan and Ciuffreda indicate the effectiveness of their methods and study design to perform OMT. As indicated by the recorded visual parameters, the OMT designed by Thiagarajan and Ciuffreda improved most laboratory and clinical vergence measures that were abnormal at baseline.³ For instance, the significant decrease/increase in CISS/VSAT scores following OMT indicates that the overall vergence oculomotor system improved and recovered efficiently. Therefore, the OMT design used in this experiment, conducted by Thiagarajan and Ciuffreda, is considered highly efficient for individuals experiencing vergence-related abnormalities following mTBI. Furthermore, a critical difference to note is the duration between this experiment (2013) and the one conducted in 2014: the 2013 experiment spanned 15 weeks, compared to 6 weeks in 2014. This can be associated with the greater number of significant results in the longer experiment (2013) and the greater number of insignificant results in this shorter experiment, thereby suggesting that time duration may be a critically influential variable for researchers when designing efficient OMT.

Additionally, another differentiated 2022 experiment was conducted by Peter Smaakjær and colleagues, aiming to specifically address the positive outcomes of binocular vision and ocular motility training in patients with oculomotor dysfunctions following mTBI.²⁶ Unlike the previous experiments discussed, this investigation was designed as a single-group study without randomization, meaning there were no control groups for comparison. This spanned 10 weeks, with 1-hour training sessions and a minimum of 20 minutes of at-home training each day (except on days when patients received the training session), investigating the effects of their OMT on 28 mTBI patients aged between 25 and 61.²⁶ These patients were previously examined and selected by a neuro-optometrist

and a speech and language pathologist to deduce if individuals fell in the exclusion criteria, giving an unblinded design to the experiment.²⁶ The specific OMT consisted of multiple tests, which were a modified Canadian Occupational Performance Measure (COPM) interview (relevant and important three self-selected activities), the Groffman Visual Tracking Test (GVT) (evaluating pursuit movements), the King-Devick test (K-D test) (testing saccadic eye movement), the Multidimensional Fatigue Inventory (MFI-20) questionnaire (measuring fatigue), and a Danish reading test utilizing a readability index used in Scandinavia (measuring reading rates).²⁶

In the final results collected from the trials, the data acquired and compared indicated overall improvements in the parameters analyzed by the researchers. COPM results at the end of the treatment, for example, indicated significant improvement in performance and satisfaction for the important self-selected chore, with one parameter (not the only one) being COPM2 Performance and Satisfaction, significantly increasing from 3 (2.5 - 4) to 6 (5 - 8) and 2 (1-3) to 7 (2 - 8), respectively.²⁶ More objective improvements were also reflected in data from the GVT and the K-D test, which changed significantly from 28 (20 - 33) to 34 (25-45) and from 83 (63 - 110) to 65 (53 - 85), respectively.²⁶ It is important to note that the increase in the GVT scores is considered an improvement, while a decrease in the K-D test is considered an improvement. The final data parameter presented in this review is the MFI-20 questionnaire, which also indicated significant positive evolution. This parameter significantly decreased from 73 (62 - 78) to 67 (50 - 74), indicating that patients experienced less fatigue (general, physical, and mental) and reduced activity/motivation following Smaakjær and colleagues' OMT design.²⁶

Based on the significant improvement data collected in this investigation, the OMT design used by Smaakjær and colleagues in 2022 can be considered effective and consistent with previous experiments. This is evidenced by changes in baseline test scores administered after the treatment period ended, indicating improvements in ocular functions, such as pursuit and saccades. Nonetheless, the true effectiveness of such OMT remains unknown, as the authors do not specify or guarantee that the patient was consistent and compliant with the required home training, nor do they provide means to verify this. This would be critical to include in this experiment, as patient adherence is not always guaranteed and tends to decline with increasing treatment duration.²⁷ Overall, aside from the limitations identified by the authors themselves, such as potential bias in COPM results and the uncontrolled, nonrandomized design,²⁶ the experiment itself is considered efficient and effective, providing an uncommon experimental design that ultimately produced a positive impact on oculomotor function. This is also supported by the uncommon inclusion of patients at a more advanced age,²⁶ allowing for a broader study of the effects of this vision therapy on that age group.

Overall, in close relation to all studies analyzed in this section, the 2013 study by Thiagarajan and Ciuffreda reported the strongest effect of their OMT design, as most visual parameters normalized and showed significant improvements post-OMT, with the longest trial duration among all studies:

15 weeks. Nonetheless, the study by Smaakjær and colleagues collected data on a broader, more comprehensive set of parameters, including not only oculomotor parameters but also fatigue and personal opinions on self-selected treatments. Furthermore, the 2014 study by Thiagarajan and colleagues can be considered more clinically accessible due to its relatively short 6-week duration and holistic OMT of vergence, accommodation, and version, all measured and tracked using commonly used visual parameters, such as the CISS and VSAT.^{5,28,29} However, the least replicable study can arguably be Smaakjær and colleagues' investigation, which is due to the lack of clarity and detailing of the procedures and specific actions/treatments done in the vision therapy employed, making it difficult for future researchers to access potential gaps in the methodology to possibly improve the OMT design. Finally, the four studies analyzed complement and contribute to one another by addressing features and elements not covered by the others and by revealing, directly and indirectly, critical limitations for future assessment and research. This ultimately highlights the understudied state of oculomotor dysfunctions post-mTBIs, underscoring numerous key areas that remain to be comprehensively investigated by future research.

■ Strengths and Limitations

A major strength of this review is its extensive evaluation of effective treatment options. Of the existing literature, none emphasized the importance of evaluating and reporting the effectiveness of specific oculomotor training in improving visual impairment outcomes in patients. Including this aspect enhances the article's analytical depth by allowing the audience to access not only a recent review of oculomotor dysfunctions but also a recent review of efficient treatments. Another strength of this review is that it revisits oculomotor dysfunctions, drawing on more recent literature in an effort to provide a more robust understanding of this topic, given that more empirical studies on this topic have been published. Thus, this updated review informs scientists about more recent understanding and effective treatments, which can lead to improvements in treatments for individuals with oculomotor dysfunction following mTBI.

A primary limitation of this article is that the effective treatments cannot be generalized across the elderly population, as the clinical trials employed a limited age range from 18 to 35 years old. The severity and impact of mTBI vary across age groups,² so excluding older age groups leaves more specific implications of mTBI unknown.

■ Conclusion

In conclusion, this review aimed to provide an understanding of how mild traumatic brain injuries affect oculomotor functions and visual processing, and to evaluate oculomotor training interventions that have been effective in improving oculomotor dysfunctions. Mild traumatic brain injury (mTBI) can hinder vergence functions when neural systems utilized in vergence are impacted, which ultimately impairs them. Mild TBI can further disrupt the accommodative function of the eyes, resulting in reduced ability to maintain focus on close

targets. Additionally, mTBI causes versional eye movement dysfunction, characterized by impaired pursuit of target elements and incorrect, delayed saccadic movements.

Furthermore, in this review, four clinical trials were chosen for evaluation on their effectiveness. Thiagarajan and colleagues' 2014 study employed effective oculomotor training (OMT), as post-OMT data on visagraph parameters showed improvements. In Cade and Turnbull's 2024 study, they utilized a unique OMT that included chiropractic interventions. This OMT design was also shown to be effective, as parameters in the chiropractic group improved compared with the control group, although some parameters did not improve. The 2014 study analyzed by Thiagarajan and Ciuffreda was also considered effective due to improvements in most laboratory and clinical vergence measures. Finally, the 2022 investigation by Smaakjær and colleagues was shown to be effective, with improvements across all parameters and significance in the majority of the parameters.

Given the limitations previously stated, it would be critical for future literature reviews on this topic to include details on the effects of oculomotor impairments and related treatments in the elderly population. This is crucial to include, as severity varies according to age.² Thus, with broader inclusion of age ranges in this topic, a more holistic and comprehensive understanding of the health consequences of mTBI would be available worldwide.

As such, all studies reviewed in this work indicate the intricate complexity of visual impairments and implications post-mTBIs. Despite extensive literature reviews and numerous clinical trials aimed at identifying new, effective treatments, oculomotor dysfunctions following mTBIs remain an understudied medical topic. This is due to existing literature reviews lacking the scope to encompass what was addressed here and to investigate these implications across a wider age range. Hence, to finalize, this review tackles such gaps (except age ranges), increasing medical awareness of the severity of oculomotor dysfunctions following mTBI and of effective treatments for these dysfunctions.

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■ Authors

André Kurahashi Dantas is a Brazilian high school student born in Campinas, São Paulo. With an aspiring goal to pursue medicine internationally, André has been actively participating in various extracurricular opportunities to strengthen his academic profile, such as olympiads, internships, research, and excelling in resilience, reflection, and analytical skills.