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Visual Rehabilitation as a Treatment Tool for Collegiate Athletes Post-mTBI to Improve Return to Sport Outcomes

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Abstract

Introduction: Fifty percent of the 46 000 concussions seen in Canada are sports related, with post-concussive syndrome (PCS) impacting up to 30% of those patients. Individuals who experience PCS will often report headaches, dizziness, and blurred vision with visual disturbances reported in 20-85% depending on the nature of the visual deficit. A concussion is a type of traumatic brain injury (TBI) and results from an external insult leading to axonal shearing of nerve fibers, which are responsible for the signs and symptoms experienced. Current best practice in treatment involves initial rest followed by increasing aerobic activity as well as visual rehabilitation to reduce the symptoms associated with a TBI. Visual rehabilitation following TBI can take many forms with the vast majority of research focusing on convergence insufficiency (CI). CI is a condition in which the individual's eyes are unable to work together when looking at nearby objects and is a common binocular vision deficit after TBI. Near point convergence (NPC) occurs when the visual axes intersect at the maximal effort leading to blurred vision, dizziness, difficulty concentrating and reading. Clinicians should consider screening for NPC and using as a rehabilitation tool when managing TBI.

Purpose: The purpose of this literature review was to determine whether visual rehabilitation for CI and NPC is an effective treatment strategy to reduce symptoms associated with a TBI and improve athletes return to life and sport.

Recommendations: Research demonstrates that visual rehabilitation for CI and NPC deficiencies will decrease patient reported symptoms and will return NPC to normal ranges.

Conclusion: Diagnosis, assessment, and rehabilitation of a TBI should involve the visual system due to the integral connections in all aspects of the brain leading to signs and symptoms which can impair an individual's function of daily living. Further research regarding different visual markers in TBI is needed regarding treatment, specifically surrounding parameters

Key Words: concussion, visual insufficiency, convergency insufficiency, symptoms related to visual disturbances, rehabilitation tool

Introduction

In Canada 46 000 diagnosed concussions occur in children (between 5-19 years of age), and of those, 50% were sports related.[1] Individuals participating in youth, collegiate and professional level athletics have sustained a large number of traumatic brain injuries (TBI) annually with the majority of them being from concussions.[2] TBI is an overarching term used to define trauma to the brain. Within TBIs, there are subcategories which include mild traumatic brain injury (mTBI). mTBI describe structural damage to the cranium which is less severe in comparison to other categories of TBIs. Within the subcategory of the mTBI lie concussions, which have a milder form of structural damage occurring. Approximately 30-85% of people following a TBI, experience visual impairments, leading to a myriad of symptoms ranging from headaches to visual impairment such as diplopia.[3] These symptoms occur due to the integration of the visual streams within all four lobes of the brain, therefore an insult to the head causing trauma will cause disruption to the visual system.[4] Treatment for TBIs can include visual rehabilitation to improve vision, decrease symptoms, and improve overall patient function. The

aim of this literature review is to determine if visual latency rehabilitation in collegiate level athletes with TBI and milder forms such as mTBI, will improve return to sport outcomes.

Defining mTBI/Concussion

A TBI is caused by external force to the head leading to trauma, causing the brain to be bruised as it comes into contact with the unyielding cranium.[5] TBIs can result from multiple mechanisms with the commonality of a high velocity movement of the head.[5] A mild traumatic brain injury (mTBI) is a subset of traumatic brain injuries induced by mechanical forces which can lead to short term neurological impairments.[1] A concussion is a subtype of mTBI and is estimated that 1.6 – 8 million people in the USA are affected by sport and recreation related concussions annually.[5,6,7] A TBI is classified into two subcategories: primary and secondary.[5] A primary TBI occurs as a result of mechanical acceleration, deceleration or rotational force applied to the cranium.[5] Secondary TBIs are a cascade of bimolecular, biochemical and physiological events at the cellular level triggered by the primary injury.[5] mTBIs are a frequent injury with over 8 million people sustaining one per year in the United States.[5] A key physiological component of a TBI is diffuse axonal injury (DAI).[4,5] DAI is caused by mechanical forces resulting in shearing of axonal fibres occurring at the moment of impact.[4] DAI's affect the processing streams within the brain and commonly occur at white-grey matter junctions.[4,5]

Prevalence of concussions in sport participation

Concussions are of major concern for the athletic populations of all ages.[8] What makes diagnosis and treatment so challenging is the inability to see what is occurring within the cranium.[8] Out of 8 million concussions occurring annually, 10-25% of them develop prolonged symptoms which cause neurological deficits.[5,8] Gupta et al. recognized that more then 44 million youth in the USA are currently participating in organized sport, accounting for a larger percent of concussion injury burden that is currently faced today.[7] The Centre for Disease Control and Prevention have reported that three TBIs occur every minute and 5.3 million people currently live with disability related to this type of brain injury.[2] It's imperative that health care professionals quickly identify, diagnose and begin early treatment for TBIs to prevent disability. There's a need for greater understanding of the neuroanatomy to determine areas of dysfunction and provide appropriate rehabilitation for effective and timely return to sport. TBIs and milder forms such as mTBIs can be treated via non-invasive means, using therapeutic exercises.

Prevalence of visual disturbance and symptoms in individuals with mTBI

Visual involvement in mTBIs

It's common for the visual system to be impacted following a TBI as over half of the brains neuronal connections and circuits involve the visual system.[9] Post-concussion syndrome (PCS) can impact approximately 30% of people who previously suffered from a TBI with the majority of PCS symptoms persisting more than a year post injury.[4.10] The most common symptoms associated with PCS are anomalies of visual accommodation, photosensitivity, and visual field integrity to name a few.[3] Prolonged persistent symptoms prevent the individual from returning to full activities of daily living and sport.[4,10] Chang et al. reported sensorimotor deficits in mTBI patients that ranges from 20-85% depending on severity and nature of the mTBI experienced.[4]

Common visual impairments in mTBI patients include a high prevalence of convergence insufficiency (30%), saccadic deficits (19.6%) and accommodation issues (21.7%).[4] These impairments impact the bodies visual processing system, affecting how visual information is interpreted and processed within the brain.[4] The visuomotor integration system depends on effective control of eye movement and vision to bring information to the CNS and prepare the motor system to carry out a skill.[4] Binocular vision, the eyes ability to work together, provides an individual with orientation of where they are in space, and is an important component in sport performance.[9] Dysfunction that occurs in the visual system as a whole in athletes sustaining a mTBI will impact their timely return to sport and sport performance due to the visual disturbance.[9] Patients with visual deficits that go undetected in diagnosis and are not targeted within the treatment plan can be negatively impacted during their recovery time, prolonging return to sport and putting athletes at an increased risk of obtaining a secondary concussion.[9]

Causes of visual disturbances and symptoms

In a TBI, the magnitude of force occurring within the cranium results in diffuse axonal injury, which is identified as the main physiological process leading to the underlying consequences seen within patients.[4] Tearing of the brain's long connecting nerve fibres can occur in multiple regions within the brain depending on the mechanism of injury and where the trauma took place. The impact that DAI has on the visual streams has been documented in previous literature, with the consequences of this trauma best understood through understanding the neuroanatomy and the involvement that the visual system has on each stream.[4] Individuals who experience a mTBI due to DAI can experience what is known as post trauma vision syndrome (PTVS).[4] PTVS is referred to as deficits in the visual system after experiencing a concussion, whiplash, mTBI or any type of head trauma.[4] PTVS creates dysfunction within the visual system and has a magnitude of signs and symptoms that can be present due to this disruption.[4] Table 1 presents a list of symptoms that are associated with post traumatic vision syndrome and can be seen in individuals suffering with this condition.[4]

Table 1: Symptoms associated with Post Trauma Vision Syndrome

Blurred vision, Distance viewing	Face or head turn	Disorientation	Discomfort while reading	Easily distracted	Loss of balance	Dizziness
Blurred vision, Near viewing	Head tilt	Bothered by movement in spatial world	Unable to sustain near work	Decreased attention span	Poor eye-hand coordination	Poor Coordination
Slow to shift focus, near to far to near	Covering, closing one eye	Bothered by noises in environment	General fatigue while reading	Reduced concentration ability	Poor handwriting	Clumsiness
Difficulty taking notes			Loss of place while reading	Difficulty recalling what has been read	Poor posture	
Pulling or tugging sensation around eyes			Eyes get tired while reading	Easily distracted		

Impairment of function varies between individuals based on where shearing forces have occurred within the neuronal fibres leading to symptoms specific to that region of the visual field.[4] Individuals that have difficulties with visual processing are commonly mentioned in those who experience symptoms with a TBI.[4] These symptoms can be explained because the visual processing system permeates all four lobes of the brain, therefore wherever the axonal injury occurs, can impact the visual processing system.[4] Individuals symptom severity is independent of the location and magnitude of trauma and impact to the cranium.[1]

Diagnosis of concussion – current best practice

An organization such as the concussion in sports group (CISG) has created outlines and general consensuses as to what is currently known as best practice in the diagnosis of "concussions". New guidelines were created by three medical sport concussion committees in the United States.[2] These guidelines were compared with one another, and commonalities were found in athlete risk factors and symptoms scales.[2] All three guidelines found that sex and previous concussions played a role in the likelihood of sustaining further concussive episodes.[2] Females were two-fold more likely to obtain a concussion then males, and athletes who had previously obtained one or more concussions were also at a higher risk.[2]

Current best practice guidelines for concussion management indicates that athletes should be removed from play if a concussion is suspected and no same day return to play.[2,11] Diagnosis of concussions should be made by a licenced health care provider who has previous experience in the diagnosis and management of concussions.[2] There are no set guidelines for concussion testing, although a multidomain assessment is recommended for the evaluation of a concussion.[11] A list of assessments include, but are not limited to, identifying mechanism of injury, symptom scale, balance assessment (BESS), cervical screening and psychological factors.[11] Neuropsychological testing can also be performed to detect cognitive deficits after a concussion - ImPACT and the SCAT5 are the most commonly used testing measures as they are both valid and reliable tools to assess the presence of a concussion.[2]

Unfortunately, these tools to diagnose a concussion are fraught with difficulties. These tools for concussion assessment and diagnosis only record binary responses such as "yes" or "no". The effectiveness and usage of SCAT5 have not yet been validated for use on children, indicating that there is no current assessment tool for youth in sport, which is a rising population in sport participation. The terminology used within the SCAT5 symptoms scale can seem complex; with youth, and individuals with English as their second language may not understand what "foggy" or "feeling in a daze" mean and therefore misinterpret the information and alter the reliability of the assessment. From these tools there is no objective measure to help drive the course of treatment. The SCAT5 does not incorporate a biomechanical analysis and therefore does not address visual disturbances adequately. An athlete may perform the ImPACT and pass but visual dysfunctions such as saccadic intrusions, esotropia and dysfunction in binocularity are missed. These observations are what drive a patient's course of treatment and determine if they can return to play.

Defining neuroplasticity and visual involvement in neuroanatomy

Neuroplasticity is the ability for neurons to modify structurally and functionally resulting in changes in behaviour due to relearning.[12] By understanding neuroplasticity, the processes involved within it and the visual systems of neuronal integration within the cranium, therapists can create more effective rehabilitation programs.[12] It's possible to relearn behaviours lost following a TBI because the brain relies on the same neurobiological process it used prior to injury to do so.[12] Rehabilitation can use learned behaviours stored within neuronal circuits of damaged tissue to encode new behaviours through recruitment.[4,12] The primary issue after a TBI in the acute phase becomes the presence of inflammation, causing neuronal inhibition which can mask previously learned behaviours.[12]

Once the individual is out of the acute phase and inflammation has diminished, the body can now improve through recovery and compensation.[12] Neuroscientists have conflicting views on what this terminology means and how it is used to describe concepts.[12] Some argue nerves never truly recover due to the fact that once neuronal tissue is damaged, it does not return to the individuals previous quantity and therefore improvement must occur through compensation.[12] While others believe functional improvement represents recovery because patients can now perform tasks they were unable to do immediately after the injury.[12] Either way improvement is defined, through recovery or compensation, rehabilitation techniques are able to restore, recruit and retrain the brain.[12] Restoration of lost function due to inflammation and edema can improve through natural resolution.[12] Recruitment enlists areas of the cortex that can have, but haven't been making significant contributions to a behaviour and are now activated.[4,12] Retraining allows adaptation to occur within existing function, recruit neural circuits and allow additional functions for behaviour restoration.[12]

There are two major streams in the visual processing system; ventral and dorsal, both originating from the occipital cortex.[4] The ventral processing system connects to the temporal lobe and is important for object recognition.[4] The dorsal is associated with the parietal lobe and is important for understanding spatial recognition.[4] The dorsal stream, after reaching the posterior parietal cortex (PPC) trifurcates into the parieto-prefrontal, parieto-premotor and parieto-medial temporal pathways.[4] Each pathway mediates a different aspect of the visuospatial field and these associated processes help the health care provider to understand symptoms involved in those with TBI.[4] The parieto-prefrontal has two main functions, one being selective eye movement control and the other spatial working memory.[4,13] This stream relays information to the dorsal lateral prefrontal cortex (DLPFC) which directly connects to the main cortical oculomotor area in the frontal and supplementary eye fields.[4,13] The DLPFC makes several connections with the parietal eye field, cingulate eye field and the superior colliculus in the cerebellum, which acts like a conductor of a train, controlling functions within different regions of the brain.[4,13] This control includes unwanted reflexive saccades which can trigger saccadic intrusions, visual attention, goal directed behaviour and working memory.[4] The parieto-premotor pathway projects to the dorsal and ventral aspects of the cortex receiving vestibular input from the cerebellum and is responsible for maintaining coordinated map of space and the bodies position in space.[4,13] The parieto-medial temporal pathway connects with the limbic area, the most complex and least understood area, its contribution remains unclear.[4]

From cortex to brainstem, eye movement is highly interconnected to other systems allowing integration of sensory and motor information required for accurate oculomotor, cognitive processing and visuomotor feedback to occur.[13] Decline in function in even one region significantly impairs eye behaviour, which presents with symptoms a therapist may commonly see such as, double vision, motion sensitivity and spatial awareness deficits.[3,13]

Feedback integration – visual, vestibular, and proprioceptive

The central nervous system regulates postural control and stability through its ability to integrate sensory feedback from the visual, vestibular, and proprioceptive systems.[14] After a concussion, it is common to see a decline in postural control and balance as either one or multiple systems are impacted.[14] Using diagnostic testing, chronic postural control is observed and tested to determine the level of decline. Diagnostic testing can be performed through a variety of ways, these include the use of the BESS or through measurement of sinusoidal

perturbation specific to each system allowing a comparison to occur.[14] These tests are performed with the patient's eyes both closed and open to create a comparison with the lack of visual feedback to the central nervous system.[14] Since each system had a specific frequency in sinusoidal perturbation, the gain represents each systems contribution to a particular sway pattern.[14] If the individual is functioning properly, the therapist should note when the eyes are closed, that the central nervous system should increase reliance on the vestibular and proprioceptive system in order to maintain postural stability.[14] This can be seen through sinusoidal gains within the vestibular and proprioceptive systems and is called sensory reweighing.[14] Athletes who sustained a recent concussion and others with concussion history demonstrate higher gains in visual and vestibular stimuli than a control group.[14] This suggests abnormal dependence in visual and vestibular feedback mechanisms to create stability following a concussion.[14]

Visual Diagnosis and Rehabilitation to manage mTBI

Research has begun looking at ways to prevent, diagnose and treat concussions.[8] Through this process, the use of oculomotor assessment and treatment has become of interest in the ability to provide a rehabilitative technique in individuals suffering from some form of TBI.[8,9] Good vision allows athletes to use their eyes, send information to the brain to be interpreted and obtain information and react faster to their environment, with the ultimate goal of avoiding injury-causing collisions.[8] Visual system assessments should vary in the type of information being tested, including saccades, smooth pursuits, convergence and divergence.[9] Visual system impairments can be reduced with vision therapy, targeting the athletes specific deficits viewed in the assessment. The majority of visual rehabilitation research focuses on convergence insufficiency (CI), with studies showing visual therapy, such as vergence and fusion training using targets and stereograms, can reduce CI.[6] Near point of convergence (NPC) can be measured by having a target move slowly towards the patients nose until it appears double or the examiner notices exophoria in the patients eyes, which at that point the distance is measured by the therapist and compared to normative values.[9] Early onset recognition is imperative for health care providers as individuals that go unidentified can have prolonged recovery.[9] The main purpose of visual therapy for binocular vision disorders is to obtain improvement in speed and accuracy of varying oculomotor functions in order to have clear, single, symptom free binocularity.[5]

Research has observed significant improvements for visual convergence function with the Brock string and patient reported symptoms scale.[6] Divergence and saccadic abnormalities showed no significant difference but an overall improvement was reported by both clinical assessment and patient reporting when treatment targeted visual, vestibular and cervicogenic systems.[6] Although studies suggest oculomotor rehabilitation can improve visual abnormalities, specifically NPC with most of the research looking at that marker specifically, there has been no standardization in treatment exercises, frequency or duration.[5,9] Future research should look at determining standardizations in treatment techniques, exercises and frequency to provide further guidelines for implementation.

Efficacy of Treatment in decreasing symptoms

Efficacy of vision therapy and the benefits of these treatment approaches are highly anecdotal and haven't been empirically examined for patients with TBI, specifically treatment

for CI leading to improvements in NPC.[15,16] The efficacy of visual rehabilitation in terms of binocular anomalies, which include CI and NPC have been well established in the literature in the healthy population but not in post-TBI patients.[5] Therefore, studies looking at preventative measures show that vision training can decrease incidence of concussions in athletes who received vision training in comparison to those who did not.[8] Tools used as a preventative measure include dynavision (a tool used to train hand eye coordination and improve visuomotor skills), Brock string, saccadic eye movements and convergence and divergence training.[8] Vision assessments tools such as NPC are starting to be implemented in clinical concussive patients but there is still little information as to how these measures should be used in the evaluation and implementation of treatment in TBI patients.[9]

Santo et al. found statistical significance in improvements in NPC with the use of oculomotor rehabilitation in patients with impairments acutely following a concussion.[9] The results held a great deal of promise, but there was significant heterogeneity in patient population and methodology in the studies that were reviewed.[9] Methodological heterogeneity can include randomization issues, early trial termination and publication bias all impacting the reliability of study outcomes.[9] A review by Thiagarajan et al., investigated multiple studies with the use of oculomotor therapy in individuals following head trauma, including studies by Cohen, Berne and Al-Qurainy.[5] Thiagarajan et al. noted significant improvement in oculomotor function, NPC and decreased exophoria after the use of vision therapy.[5] None of the studies presented in the literature review showed negative effects but Al-Qurainy showed no statistical significance with both the vision therapy and naturally recovering groups showing improvements in accommodation and convergence after a TBI.[5] Thiagarajan et al. noted that details of Al-Qurainy's study such as diagnosis, treatment type and duration of treatment were not available and therefore makes it hard to evaluate.[5]

The lack of detail present in current studies in terms of treatment parameters is a weakness in the current literature as there are no current parameters being studied in terms of frequency and duration of visual rehabilitative techniques. Issues in providing efficacy in visual therapy treatment is that using the same procedure in mTBI population can be challenging due to complications in general factors, such as depression, memory disfunction, chronic fatigue syndrome etc.[5] The caveat to this statement is that by improving oculomotor coordination and decline abnormalities there is an ability to hasten progress in other areas of dysfunction such as cognition.[5]

Future research recommendations

Future research should investigate the effect and efficacy of vision therapy in individuals post-TBI, comparing the use of visual with no visual treatment used in a rehabilitation program to determine if there is statistical significance in the use of vision therapy.[6,9] Future research should look at different types of visual abnormalities and rehabilitation techniques including saccades, smooth pursuits and cardinal fields of gaze as those anomalies are currently not studied within the cited literature and therefore there is a lack of understanding on how to diagnose and treat these conditions when present.

Conclusion

While evidence supports the use of vision techniques for rehabilitation of TBI, further research is needed to determine the efficacy of visual therapy and its benefits. Pre-screening markers for vision should be implemented for baseline comparison if TBI occurs. Licenced professionals that administer a TBI diagnosis, should carry a multidomain approach in their treatment plans for TBIs. Even though further research is required, visual rehabilitation has shown to be a valuable tool in assessing and treating individuals following a TBI as health care providers should continue assessing vision and begin using it in rehabilitation as seen fit.

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