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Neuro-Optometric Rehabilitation Using a Multisensory-Based Bottom-Up to Top-Down Paradigm for Post-Concussion Syndrome – A Retrospective Case Series Study

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ABSTRACT

Background

Optometrists are becoming increasingly involved in the rehabilitation management of concussion patients who experience prolonged recovery of symptoms, often referred to as post-concussion syndrome (PCS). Literature pertaining to this population provides ample evidence that neuro-optometric rehabilitation is effective for oculomotor (OM) vision dysfunctions, but lacks the same for non-oculomotor vision (NOM) dysfunctions. Many PCS patients suffer NOM vision dysfunctions whereby they are foundationally too sensory-fragile to tolerate a traditional top-down therapy approach early in their treatment process. This study provides a review of PCS patients receiving a multisensory-based bottom-up to top-down neuro-optometric rehabilitation paradigm that targets NOM, as well as, OM vision dysfunctions.

Methods

The participants are mild traumatic brain injury (mTBI) patients with persistent symptoms. The design is a retrospective chart review of clinical measures one week before and an average of 38 days after initiation of neuro-optometric rehabilitation. The main measures reviewed are the Sports Concussion Assessment Tool 5 (SCAT5) symptom survey, the Dizziness Handicap Index (DHI), the Test of Information Processing Skills (TIPS), and the FCFTester kinetic color visual fields. A secondary measure is near point of convergence (NPC).

Results

The patient group averaged an improvement of 50% in SCAT5 symptoms survey score and a 48% improvement in the DHI total score. The TIPS revealed a group average improvement in visual modality, auditory modality, and delayed recall of 231%, 123%, 172%, respectively. Kinetic color visual fields increased an average of: green OD 51%, OS 47%, red OD 27%, OS 26%, and blue OD 21%, OS 23%.

Conclusion

The clinical findings and treatment of 56 PCS patients are described. Neuro-optometric rehabilitation utilizing a specific paradigm provided substantial improvement in both OM and NOM vision measures and symptoms for the group in 38 days of therapy. The paradigm began with a multisensory-based passive, input-only, bottom-up therapy accompanied by gradual addition of active, output-based, top-down techniques.

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BACKGROUND

Neuro-optometric rehabilitation (NOR) is a therapy service provided by specially trained optometrists which utilizes therapeutic prisms, lenses, filters, occlusion, and vision therapy to help stimulate and reorganize visual pathways of the brain which are not functioning properly due to brain injury. NOR differentiates itself from other optometric specializations through extensive collaboration with other professions. This is particularly seen in management of concussion, also referred to as mild traumatic brain injury (mTBI). According to the American Association of Neurological Surgeons, the formal medical definition of concussion is a clinical syndrome characterized by immediate and transient alteration in brain function, including alteration of mental status and level of consciousness, resulting from mechanical force or trauma.[1] In many cases, there are no external signs of head trauma nor loss of consciousness. However, a wide constellation of symptoms can result including vision disturbances. Literature reveals that more than 70 percent of concussion patients suffer related vision dysfunctions.[2] Since no system provides more neurosensory input to the brain than vision, optometry is best equipped and has an obligation to provide rehabilitation of vision to this patient population.

Incidence rates for concussion range widely from a conservative 300,000 per year to a more liberal and recent estimate of 3.8 million cases in the United States annually.[3] A recently signed bill, The Traumatic Brain Injury Program Reauthorization Act of 2018, has directed the CDC to implement a National Concussion Surveillance System. This will allow for more accurate determination of the incidence and cause of concussions (children and adults).[4]

Symptoms of a concussion include, but are not limited to, blurred vision, fatigue, dizziness, headache, irritability, insomnia, inattention, photophobia, vertigo, and cognitive difficulties.[5-9] Symptoms largely reflect a functional disturbance rather than a structural injury and, as such, no abnormality is seen on standard structural neuroimaging (CT scans and MRI). However, several studies have revealed existence of brain damage in mTBI's using functional imaging techniques such as Diffusion Tensor Imaging, a more advanced variation of MRI.[10] Unfortunately, this imaging technology remains expensive and is often reserved for research purposes rather than clinical patient evaluation. Therefore, a patient with an isolated concussion commonly receives a CT scan and if negative, emergency room physicians are advised that the patient may be safely discharged. Although most patients do recover from a concussion within three weeks,[11] others suffer persistent symptoms leading to a diagnosis of post-concussion syndrome (PCS).

While a number of definitions for PCS have been proposed in the literature, generally it refers to concussion symptoms that persist for weeks, months, or more than a year after a concussion.[12,13] The incidence of PCS varies, but most studies report that about 15% of individuals with a history of a single concussion develop persistent symptoms associated with the injury. Premorbid risk factors for PCS include prior concussions, mental health problems, physician-diagnosed migraine, vestibulo-ocular dysfunction, hyperacusis, and ADHD/learning disabilities.[14-17]

There remains a lack of evidence-based treatment strategies for PCS, however, some individuals benefit from several interventions depending on the particular presenting signs and symptoms. The most common treatment options that are considered to be effective consist of medications, early education,[18,19] cognitive behavioral therapy,[20] aerobic exercise therapy,[21] and physical therapy.

Many of the symptoms of PCS are, in part, a result of compromised processing of sensory inputs, including visual.[22] Research has shown that optometric vision therapy should be included in the overall treatment as it provides improvement in post-concussion vision problems.[23] However, optimal human perception is dependent upon the combined processing of multiple sensory inputs more so than unisensory processing. Neuroscience research has long-established that there is widespread distribution of brain pathways dedicated to multisensory integration and processing. And multisensory plasticity has strong implications for successful rehabilitation of mTBI patients. This case series provides a retrospective review of PCS patients receiving a neuro-optometric rehabilitation paradigm with multisensory processing training at its core with adjunctive optometric vision therapy. This author considers this a bottom-up to top-down therapeutic approach and has experienced it to be uniquely effective when non-oculomotor-based vision dysfunctions are diagnosed at the patient's initial evaluation.

METHOD

This study was a retrospective chart review of 66 consecutive PCS patients who presented with both OM and NOM vision dysfunctions to the author's clinic during the period of August 2017 to June 2019. Reviewed were clinical measures performed one week before and an average of 38 days after initiation of treatment. Six patients were excluded due to their concussion occurring greater than three years prior to evaluation. Controversy in literature proposes the further out a patient is from his/her injury, persistent symptoms could be strongly associated with conditions other than the head injury.[24] Four patients were excluded due to already receiving optometric vision therapy elsewhere. Patient exposure to all other prior interventions was included. This resulted in an "N" of 56. Each patient was de-identified via meeting safe harbor requirements under section 164.514(a) of the HIPAA Privacy Rule.[25] Patient ages ranged from 15 to 73 with a median age of 45. The time between most recent concussion and initiation of treatment ranged from 48 to 1010 days with a median time of 134 days. Fifteen were men and 41 were women. The number of previous concussions ranged from zero to four. No patients were excluded based on socioeconomics nor method of payment (i.e. insurance, private pay, etc.) factors. Since physical therapy (PT) is commonly considered a standard of care recommendation for post-concussion, the study made note that thirty-seven patients had received (PT) at some point since their injury and before receiving our treatment.

The neuro-optometric rehabilitation protocol utilized consisted of 12 consecutive days of in-office visits each lasting 75 minutes followed by 18 days of home therapy. The treatment consisted of a blending of 1) multi-sensory integration via simultaneous application of optometric phototherapy, vestibular stimulation, auditory stimulation, and 2) gradually applied sensorimotor output activities such as versional and vergence oculomotor therapy and balance tasks. See Figure 1 for an example. Many patients were also provided weighted proprioceptive sensory support (e.g. weighted blankets/toys, ankle weights) per their gravity-based sensitivity.

Optometric Phototherapy, also known as Syntonic Optometry, is the application of light through the pupil to the retinal blood supply and to retinal photoreceptors. It is a method of neuromodulation using photo-transduction – photons of light activating a graded change in membrane potential and a corresponding change in the rate of transmitter release onto postsynaptic neurons.[26] It is a noninvasive use of prescribed light frequencies to treat visual dysfunction, brain injury, and imbalanced autonomic nervous systems.[27,28] As the photonic energy of the light stimulates the retinal ganglion cells of the retina, it can subsequently re-energize many neural structures including, but not limited to, the thalamus, hypothalamus, superior colliculus, pineal gland, and the pituitary gland. The optometric phototherapy in this treatment protocol consisted of 12 days of a progression through magenta, ruby, yellow-green, yellow-

Day	Bottom-up Passive therapy (in-office)	Bottom-up Passive therapy (in-office)
1	Optometric phototherapy (OP) using one color, lateral canal vestibular stimulation, auditory training	monocular and binocular horizontal pursuits
2	OP using three colors, posterior and anterior canal vestibular stimulation, auditory training	monocular and binocular vertical pursuits
3	OP using three, lateral canal vestibular stimulation, auditory training	monocular and binocular horizontal pursuits
4	OP using three colors, posterior and anterior canal vestibular stimulation, auditory training	monocular and binocular vertical pursuits monocular 4-corner wall saccades, clock dial saccades, Percon mazes level 1
5	OP using four colors, lateral canal vestibular stimulation, auditory training	monocular horizontal pursuits monocular arrow wall saccades, clock dial saccades, Percon mazes level 1
6	OP using four, posterior and anterior canal vestibular stimulation, auditory training	monocular and binocular vertical pursuits, monocular 4-corner wall saccades, clock dial saccades, Percon mazes level 1
7	OP using six colors, lateral canal vestibular stimulation, auditory training	binocular horizontal pursuits binocular arrow wall saccades, clock dial saccades and peripheral awareness, Percon mazes level 1
8	OP using six colors, posterior and anterior canal vestibular stimulation, auditory training	binocular vertical pursuits binocular 4-corner wall saccades, clock dial saccades and peripheral awareness, Percon mazes level 2 +/-.25 lens flipper at near 2 BO and BI loose prism fusion at 15 ft
9	OP using six colors, lateral canal vestibular stimulation, auditory training	binocular horizontal pursuits binocular arrow wall saccades with tandem stance, clock dial saccades and peripheral awareness, Percon mazes level 2 +/-.50 lens flipper at near 4 BO and 2 BI loose prism fusion at 15 ft
10	OP using six colors, posterior and anterior canal vestibular stimulation, auditory training	binocular vertical pursuits binocular 4-corner wall saccades with tandem stance, clock dial saccades and peripheral awareness, Percon mazes level 2 +/-.50 lens flipper 6 BO and 2 BI loose prism fusion at 15 ft
11	OP using six colors, lateral canal vestibular stimulation, auditory training	binocular horizontal pursuits binocular arrow wall saccades balancing on one foot, clock dial saccades and peripheral awareness, Percon mazes level 2 +/-1.00 lens flipper 8 BO and 4 BI loose prism fusion
12	OP using six colors, posterior and anterior canal vestibular stimulation, auditory training	

HOME THERAPY ONLY BEGINS

13-30	home OP twice daily using one color; NO further vestibular or auditory training	head rotation pursuits and 4-corner saccades

Figure 1: Example of the OMST protocol with adjunctive active vision therapy. The left column represents the passive, bottom-up therapy and the right column represents the active, top-down therapy. Note, many PCS patients will not tolerate the above "rapid" active schedule in this example and modification to this would be left up to the practitioner's professional judgement. The optometrist well trained in syntonics is able to make modifications to the left column on a daily basis but within the boundaries of the above protocol.

blue, violet, and magenta again. The order, exposure time, and combination of filters was determined based on integration of principles taught by the College of Syntonic Optometry, the Sensory Learning Institute, and readings from the works of Dr. Edwin Babbit and Dr. Dinshah Ghadiali, 19th and 20th century pioneers in the use of light therapeutically.[29]

Vestibular stimulation is provided by movement of the patient whereby the vestibular system in the inner ear registers motion, both linear and rotational, and sends this sensory information via the eighth cranial nerve to the vestibular nuclei of the brainstem. Here it engages with sensory inputs from the visual, somatosensory, and auditory systems. Efferent fibers proceed from here to provide motor output to extraocular muscles for appropriate oculomotor response and the spinal cord for balance. The vestibular nuclei also send sensory information to the cerebellum so it can modify and further control the motor responses.[30] The vestibular stimulation in this treatment protocol was achieved by slow and gentle 7" circular rotation of the patient in supine position on a trochoidal motion table. The supine position provides favorable neck support, gravity-induced somatosensory/proprioceptive input, and comprehensive stimulation of the various vestibular apparatuses. The patient's horizontal position is alternated daily so that stimulation of both the anterior/posterior and the lateral semicircular canals is achieved.

The auditory stimulation was comprised of tracks of unfamiliar music that is randomly attenuated and has pre-determined frequencies filtered out. The specific program utilized is The Sensory Learning Acoustic Training program created by Mary Bolles based on the work of French physicians Alfred Tomatis and Guy Berard.

OMST Active Therapy Log

Day	Date	PP	FS	4CS	AS	CDS	PM1	PM2	CDPA	25LFN	50LFN	100LFN	11FPFD	21LPFD	42LPFD	MD	ATS	A1F	AV	MD2
1																				
2																				
3																				
4																				
5																				
6																				
7																				
8																				
9																				
10																				
11																				
12																				

PP – Pencil Pursuits
FS – Figurine Saccades
4CS – 4 Corner Saccades
CDS – Clock Dial Saccades
PM1 – Percon Mazes, Level 1
PM2 – Percon Mazes, Level 2
CDPA – Clock Dial Peripheral Awareness
AS – Arrow Saccades

25LFN – +/- .25 Lens Flipper @ Near **(M or B)**
50LFN – +/- .50 Lens Flipper @ Near **(M or B)**
100LFN – +/- 1.0 Lens Flipper @ Near **(M or B)**
11FPFN – 2 BO/ 2 BI Flip Prism Fusion @ 10 ft
21LPFD – 4 BO/2 BI Flip Prism Fusion @ 10 ft
42LPFD – 8 BO/4BI Flip Prism Fusion @ 10 ft
MD – Modified ____________________

ATS – Add Tandom Stance
A1F – Add 1 Foot Balance
AV – Add Visualization
MD2 - Modified ____________________

Notes:

M= Monocular B = Binocular

Figure 2: Log sheet for administering and tracking of the active, top-down therapy that is adjunctive to the passive, bottom-up therapy.

Oculomotor therapy is commonly prescribed for remediation of oculomotor (eye movement) deficits prevalent in brain injured patients. It has also been proven to improve visual attention.[31] The patient is guided through saccadic and pursuit eye movement tasks to improve visual fixation accuracy and smoothness. It also includes vergence training to enhance efficiency and stamina of maintaining clear and single binocular fixation. The oculomotor therapy in this treatment protocol was initially minimal, consisting of five to ten minutes of monocular (progressing to binocular) saccadic and pursuit activities. Then convergence therapy was gradually introduced as tolerated without aggravating patient symptoms. These activities increased in difficulty during the in-office phase of treatment. Balance and other sensorimotor output activities were gradually added to further rehabilitate integration of sensorimotor pathways. See Figure 2.

The primary clinical measures reviewed were the symptom survey of the Sports Concussion Assessment Tool 5 (assessment of both OM and NOM), the Dizziness Handicap Index (assessment of NOM), FCFTester kinetic visual fields (assessment of NOM), and the Test of Information Processing Skills (assessment of NOM). A secondary measure was near point of convergence (assessment of OM). These measures were administered one week prior to the initiation of the therapy and an average of 38 days post-initiation of the therapy.

The Sports Concussion Assessment Tool, 5th edition (SCAT5) symptom survey, measures a global range of self-reported concussion symptoms. The patient rates 22 symptoms on a scale from zero to six.[32] According to the Consensus statement on concussion in sport—the 5th international conference on concussion in sport held in Berlin, October 2016, the SCAT5 symptom survey demonstrates clinical utility in tracking recovery.

The Dizziness Handicap Inventory (DHI) measures the self-perceived level of handicap associated with the symptom of dizziness with high test-retest reliability and internal consistency.[33] The DHI has 25 items with 3 response levels, sub-grouped into three domains: functional, emotional, and physical. The patient has a response option for each symptom of 0, 2, or 4. The total score is the sum of the responses. Possible total score range is 0–100; a higher score indicates a worse handicap. Whitney et al. propose that a total score of 0–30 indicates mild, 31–60 moderate, and 61–100 severe handicap, and that scores correlate well to levels of functional balance impairment.[34]

The kinetic color fields (green, red, and blue) were measured monocularly utilizing the FCFTester computerized program. The parameters for each patient were the following: 1.6-2.2 mm diameter target size; target presentation speed of 24-36mm/second; target brightness setting for each color was 176 (no unit); random order of presentation of the three colors; each target presentation began at 30 degrees from center; twelve meridians were tested at 30-degree intervals; central fixation target was a single digit that randomly changed and flashed at a frequency of once per 1500ms. Although there was a range of target size and target presentation speed throughout the group, the same settings were repeated at follow-up testing for each patient.

The Test of Information Processing Skills (TIPS) represents an assessment of attentive cortical (cognitive/executive function) processing. The TIPS is a norm-referenced test developed by neuropsychologist, Dr. Raymond Webster, that assesses information processing skills in children and adults between age 5 and 90. Performance on the TIPS represents a top-down assessment since it measures cortically based visual processing, auditory processing, executive functioning, working memory, and delayed recall.

Near point of convergence (NPC) is a clinical measure utilized to assess a patient's ability to maintain alignment of the eyes on a near object. Inability to sustain convergence

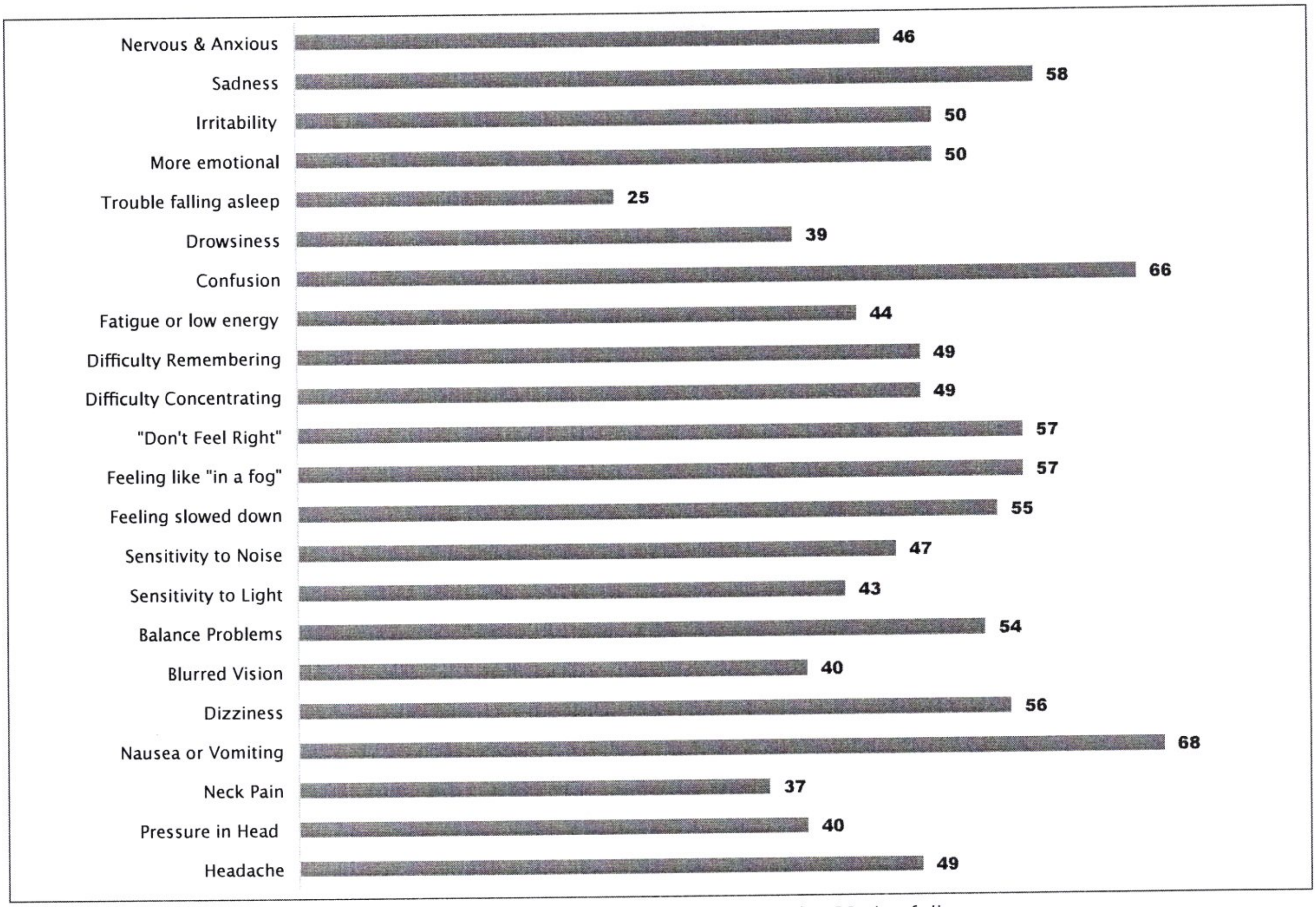

Figure 3: Percent improvement of the group for each SCAT5 symptom at the 38 day follow up.

at near may cause a person to fixate with one eye at a time, or to experience diplopia. A reduced NPC is commonly found in post TBI patients and has been found to be a good objective marker in acute mTBI.[35]

RESULTS

The patient group averaged an improvement of 50% in SCAT5 symptom survey total score. See Figure 3 for improvement averages specific to each symptom of the SCAT5 survey. The majority of patients (30/56) reported greater than 50% improvement. See Figure 4. All 56 patients completed the survey before and after therapy. The group averaged an improvement of 48% in their DHI total score. All patients completed the survey before and after therapy. Ninety-one percent of patients had an improved score and 9% had a worsened score. Kinetic functional color visual fields increased

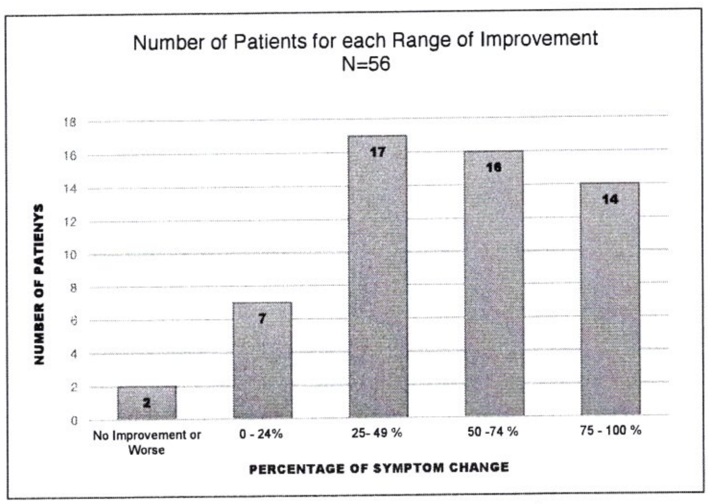

Figure 4: Number of patients in each range of improvement in SCAT5 symptom survey. Note: the majority of patients (30) reported greater than 50% improvement at the 38-day follow up evaluation.

an average of: green OD 51%, OS 47%, red OD 27%, OS 26%, and blue OD 21%, OS 23%. All patients performed the test. The TIPS revealed a group average improvement in visual

Table 1. Summary of clinical measure results at the 38-day follow up.

	SCAT5 Survey	Dizziness Handicap Index	Kinetic Fields Green OD/OS	Kinetic Fields Red OD/OS	Kinetic Fields Blue OD/OS	TIPS Visual Modality	TIPS Delayed Recall	NPC
Average Percent improvement of the group	50	48	51/47	27/26	21/23	231	172	21.6
Percentage of subjects that improved	95	91	71/64	71/75	79/74	56	79	84
Percentage of subjects that worsened	3.5	9	29/36	29/25	21/26	38	10	9
Percentage of Patients with no change	1.7	0	0/0	0/0	0/0	6	11	6

modality, auditory modality, and delayed recall of 231%, 123%, 172%, respectively. Five of the 56 patients did not complete the TIPS due to being too symptomatic to finish it. The group averaged an improvement of 21.6% in NPC measurements. Thirty-two of the 56 patients were included in the NPC data results. Patients not included were those with normal (less than 8cm) baseline measures (18/56) and five patients who did not receive the test measures at one or both visits. See Table 1 for summary.

No appreciable difference in SCAT5 symptom survey and DHI measures were found when taking into consideration whether or not PT occurred prior to the neuro-optometric rehabilitation. The group that received PT prior to our treatment had an average improvement of 51.0% and 48.8% in SCAT5 and DHI scores, respectively. The group that did NOT receive PT prior to our treatment had an average improvement of 49.2% and 47.05% in SCAT5 and DHI scores, respectively.

DISCUSSION

The PCS patients in this case series received neuro-optometric vision rehabilitation that was based on a bottom-up to top-down therapeutic protocol. All included patients presented with both non-oculomotor based and oculomotor based vision disturbances. Non-oculomotor (NOM) based vision disturbances include motion sensitivity, mental fogginess, photophobia, dizziness, nausea, and visual information processing deficits,[36] whereas, oculomotor (OM) based vision disturbances refer to vergence, accommodative, saccadic, and pursuit dysfunctions. The literature has a significant amount of evidence that optometric rehabilitation is effective for OM based vision dysfunctions, but lacks the same for NOM based vision dysfunctions. The outcome of this study suggests that PCS patients who present with NOM based vision symptoms recover efficiently and globally when a bottom-up to top-down therapeutic approach is employed. Therefore, this protocol is appropriate to consider. Concussed patients who present with primarily OM based vision dysfunctions should continue to be provided with a traditional top-down model as described by D'Angelo and Tannen.[37]

Top-down therapy requires conscious and intentional mental processing at the level of the cerebral cortex.[38] It employs an attentional mechanism of voluntarily orienting toward relevant stimuli, objects, events, or locations based on one's goals, motivation, or expectation. In contrast, a bottom-up therapy approach more likely targets automatic, pre-attentive[39,40] neural mechanisms that are based on responding to stimuli and environmental events which may be salient, counter to, or irrelevant to the individual's

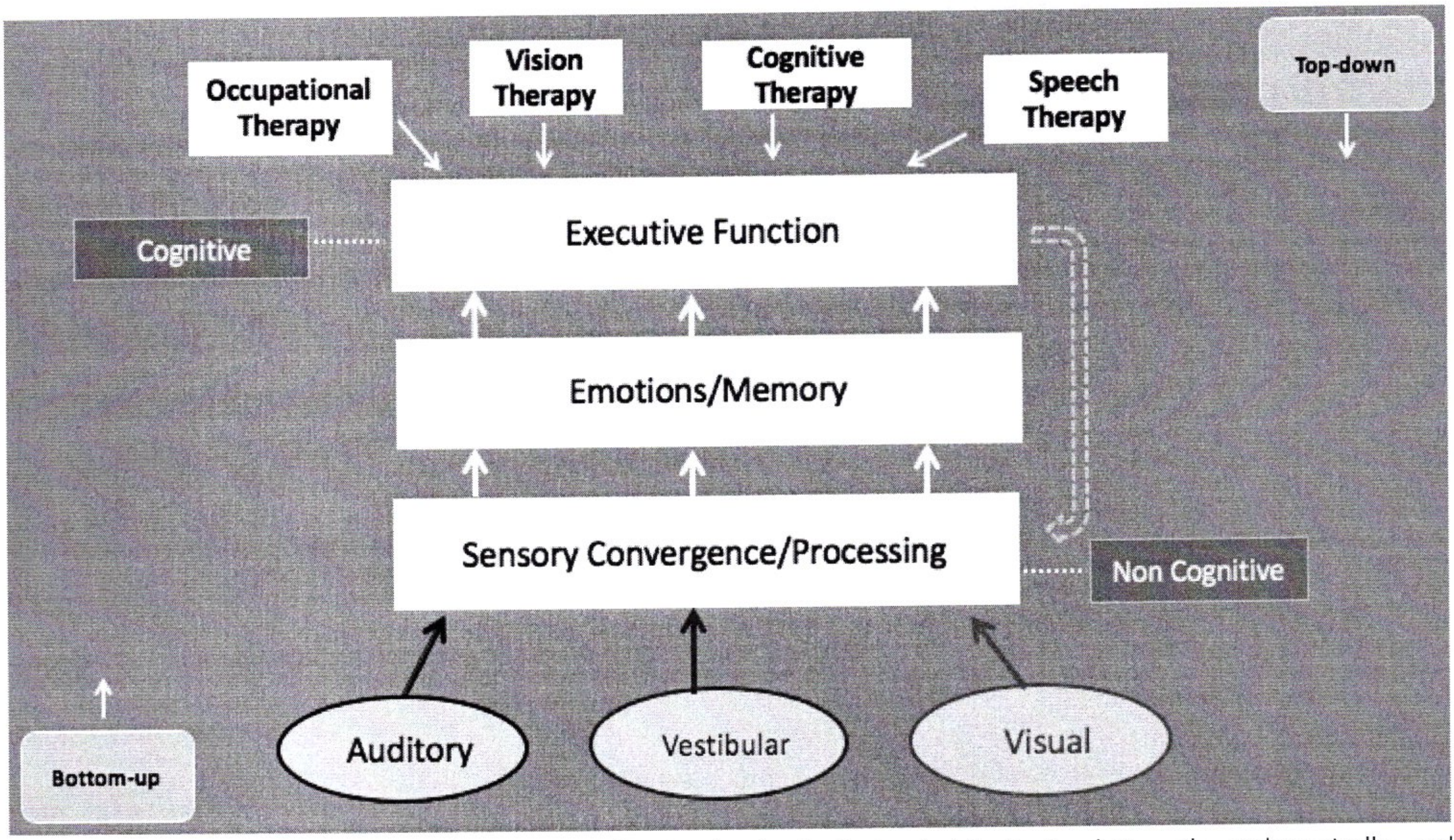

Figure 5: Sensory convergence and processing begins in the brainstem/midbrain (evolutionarily, embryonically, and developmentally after birth), and ideally becomes an efficient process on "autopilot". This provides momentum for higher "new" (cognitive/cortical) processing skills to be learned, which can then further enhance brainstem processing. Head injury can cause dysfunction at brainstem/midbrain areas (especially whiplash) causing information processing to get stuck in "first gear". This results in difficulty with cognitive perception (mental slowness, foggy headedness, sequencing difficulties, etc). Therefore, many PCS patients benefit from therapeutic interventions that begin with a passive, bottom-up approach such as OMST that is initially targeted at the brainstem/midbrain areas, before or adjunctive to top-down therapeutic approaches.

goals or expectations.[41] Despite the existence of these two "directions of processing", there is evidence that they influence each other and synergistically interact to provide optimal perception.[42]

Bottom-up therapy mechanisms influence central neural processing activities via ascending pathways from the periphery to the brainstem and then the cerebral cortex.[38] Bottom-up processing is reactive and involves the brain's initial reception of information from sensory inputs, whereas, top-down processing is strategic and planned.[43] See Figure 5 for this author's diagrammatic representation.

Peachy and Peachy refer to bottom-up and top-down visual pathways as subconscious/subcortical and purposeful/cortical, respectively. They state that initially, vision rehabilitation in traumatic brain injured patients may need to address dysfunctional subcortical colliculi and multisensory pathways. Then oculomotor deficits can benefit from therapeutic procedures that require visual direction, followed by perceptual accuracy treatment.[44]

As most optometrists have experienced, PCS patients are sometimes too sensitive to tolerate an approach that begins with attention driven techniques (i.e. active/output based, high complex vision therapy). This top-down therapy approach assumes the patient is ready for motor output demands such as saccades, pursuits, vergences, and accommodation. Often the patient with PCS is too sensory-input "fragile" and "pulls back", contorts their face, breaks into a cold sweat, alters their breathing, or completely resists the sensory-motor activity. This type of patient needs to first be provided with an opportunity to establish improved automaticity and efficiency in pre-attentive processing, particularly, multisensory integration processing. This can then provide sensory regulation that is foundationally essential before attempting top-down therapy such as instructional oculomotor skill activities.

Multisensory processing describes the ability of an intact, well-developed brain to receive information from multiple sensory pathways and modulate these inputs for optimal identification of and reactivity to environmental events. This is a biological example of the "whole being greater than the sum of its parts".[45] This ability of the brain to simultaneously process information from multiple independent sensory channels has significantly contributed to our survival. Studies including the midbrain have shown that the development of this process is not predetermined.[46] Neurons in a newborn's brain are not capable of multisensory integration, but as their brains are given the cross-modal experiences, their brains learn and engage this strategy at multiple levels of the neuraxis.[47]

Most researchers believe multisensory processing begins in the thalamus[48] and midbrain regions. For example, the superior colliculus houses the initial regions that are involved in receiving converged sensory inputs (structural) from numerous ascending and descending unisensory afferent sources[49] before multisensory processing (functional effect) even occurs.[50] Information from here projects to the multisensory region of the thalamus, namely the pulvinar. This complex of nuclei has extensive connections to cortical areas, see Figure 6.

Correspondingly, several cortical areas contribute to multisensory integration. For instance, Cappe, Morel, Barone, and Rouiller explain that the premotor cortex is a polymodal integration area, with convergence of visual, auditory, and somatosensory inputs, creating intention used for preparation of voluntary movements. Extensive multisensory interplay also occurs from many other cortical sources of inputs, such as multisensory parietal areas.[51] The success of these cortical influences on perception relies on efficient multisensory convergence and integration that originates in the thalamus and brainstem. Any or all of these pathways are susceptible to the diffuse damage a concussion can cause.

The patients in this study received a bottom-up to top-down protocol that is foundationally built on early efforts to establish enhanced multisensory processing. This author refers to it as optometric multisensory training (OMST). It involves simultaneous application of optometric phototherapy, vestibular stimulation, auditory stimulation, proprioceptive input as needed, and gradually introduced and applied oculomotor therapy as tolerated. This multisensory training encourages the neural activity of one sensory input to influence that of others. It spreads the therapeutic effect amongst several sensory systems creating opportunity for the stronger systems to support the weaker systems until

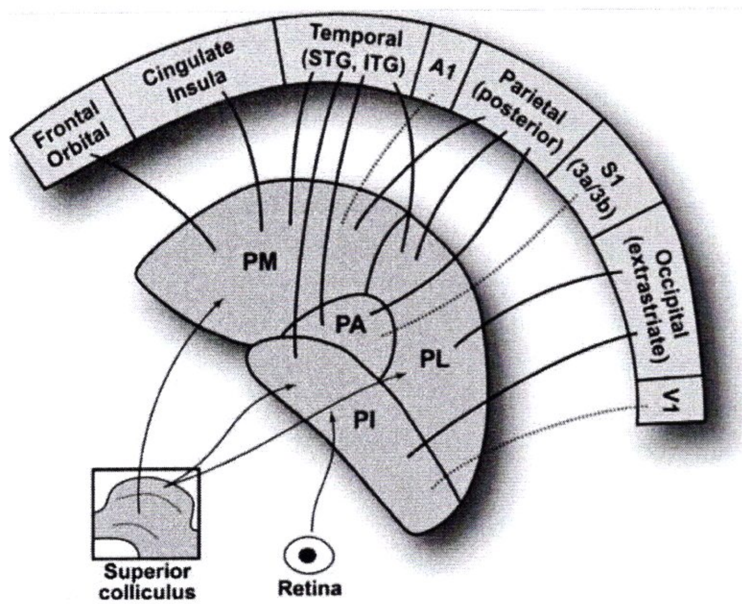

Figure 6: A topographical representation of connections to cortical areas from subcortical inputs (pulvinar of the thalamus) arising from multiple sensory inputs that the superior colliculus receives, including non-lateral geniculate vision paths. The retina component in the figure is small representing the retinal ganglion cell input that directly goes to the LGN. *Stein, Barry E., The New Handbook of Multisensory Processing, figure 3.2, page 53, copyright 2012 Massachusetts Institute of Technology, by permission of The MIT Press.*

all reach the balanced and synergistic status that ideally existed before the brain injury. This study supports that this bottom-up to top-down neuro-optometric rehabilitation approach using OMST provided patients with relatively quick and comprehensive gains. It therefore prepared them for higher complex neuro-optometric rehabilitation activities that would follow in a more traditional clinical manner.

This author hypothesizes that the primary catalyst for the efficacious improvements that this protocol provides is the influence of the optometric phototherapy on the multisensory processing. Retinal ganglion cells (RGC) are the primary driver of the LGN of the thalamus.[52] And recent studies of mammalian retina circuitry confirms that a number of RGC types innervate the superior colliculus independent of these thalamic tracts.[53] Therefore, optometric phototherapy naturally has a great effect on both thalamic and superior colliculus activity. As a result, the optometric phototherapy energizes transmission along visual-based pathways at the same time that energized oculomotor, auditory, and vestibular inputs arrive. The optometric phototherapy also likely improves the flow of neural energy through the magnocellular pathway and dorsal stream enhancing parietal lobe function. This poly-regional access of the optometric phototherapy potentiates improved spatial awareness of and anchoring in the environment. This subsequently prepares the brain to attend to cortical visual processing and thereby receive top-down therapy.

Moreover, as the multisensory networks of the brain repetitively receive this energized information while simultaneously receiving the oculomotor and vestibular input, the brain has an opportunity to be retrained in the modulation and integration of multiple sensory signals while doing this in a safe and controlled clinical situation. This provides a foundation for development of more accurate and efficient production of motor output including posture, balance,[54] and eye movements thereby reducing related PCS symptoms, both oculomotor-based and non-oculomotor-based.

CONCLUSION

This case series presents a paradigm for neuro-optometric rehabilitation when NOM vision dysfunctions are included in the PCS patient presentation; the initial phase of therapy is heavily weighted with a multisensory based bottom-up technique. It is accompanied by a gradual addition of top-down based techniques as tolerated such as oculomotor, accommodative, and vergence activities. There is an initial emphasis on rehabilitation of pre-attentive multisensory processing to better prepare the patient for optimal engagement in attentive output activities. The results indicate that this paradigm provided the PCS patients broad resolution of symptoms in a relatively short period of time.

The majority of the patients in this study continued further neuro-optometric rehabilitation after the 38 days that shifted into a more traditional approach (weekly one-hour visits) with top-down emphasis yet further bottom-up support as needed such as yoked prism, binasal occlusion, filters, plus-lens therapy, isolated optometric phototherapy, and if indicated, new spectacle lenses. This author frequently delays prescribing of glasses for PCS patients who present with NOM based vision issues until the 38 day follow up evaluation. This is because they are often too sensory "fragile" to refract reliably and adapt easily to the refractive change initially. Moreover, blurred vision is the lowest rated presenting symptom on the SCAT5 symptom survey in this study. See Table 2. Further noteworthy is the significant improvement in blurred vision at the 38 day follow up likely due to the improved visual-vestibular integration achieved from this paradigm. Additionally, determination of the appropriate lens filter/tint for photophobia to be included is more accurate at the 38 day follow up due

Table 2. Self-rating scores (average of the group) 1 week prior and at 38-day follow up in order of highest to lowest severity rating. Note: blurred vision is not a highly rated symptom, therefore a general eye exam may not be adequate for the PCS patient population. Note: blurred vision symptom improved 41% in absence of prescribing spectacle lens changes.

Symptom	Pre-treatment self rating	38-day self rating	Percent change
1: Don't Feel Right	3.7	1.6	57
2: Fatigued or low energy	3.6	1.8	50
3: Feeling slowed down	3.4	1.4	59
4: Feeling in a fog	3.3	1.6	52
5: Difficulty Concentrating	3.1	1.4	55
6: Nervous or Anxious	3.0	1.6	47
7: More Emotional	2.9	1.4	52
8: Sensitivity to the Light	2.9	1.5	48
9: Difficulty Remembering	2.9	1.6	45
10: Sensitivity to Noise	2.8	1.4	50
11: Irritability	2.7	1.4	48
12: Trouble Falling Asleep	2.6	1.5	42
13: Drowsiness	2.6	1.3	50
14: Sadness	2.5	1.2	52
15: Pressure in the head	2.5	1.4	44
16: Headache	2.5	1.3	48
17: Neck Pain	2.3	1.6	30
18: Balance Problems	2.2	1.0	55
19: Confusion	2.1	0.8	62
20: Dizziness	1.9	0.9	53
21: Blurred Vision	1.7	1.0	41
22: Nausea or Vomiting	1.1	0.4	64

to change in status of photophobia that often occurs from the OMST.

This case series study substantiates pursuit of higher evidence-based, prospective studies. Future studies should include follow up for several months to assess whether the reported improvements were retained by the patient. However, an advantage of reporting clinical changes in only 38 days is that it lessens the argument that spontaneous recovery was heavily involved.

Future studies should include additional optometric clinical measures that have been supported in literature for post-concussion monitoring. For example, this author finds value in utilizing the Distance Fusional Facility Test, developed by Barry Tannen, OD,[55] and the King Devick Test at the initial evaluation, but due to time constraints at the 38-day follow up, often defers retesting of these until the three month follow up evaluation.

Finally, results of this study indicate that neuro-optometric rehabilitation using this paradigm is effective for PCS patients regardless of whether or not the patient has already received PT. Therefore, physicians who manage PCS patients should be encouraged to also include referral for neuro-optometric rehabilitation in their patient plans. Future studies comparing outcomes between PCS groups receiving neuro-optometric rehabilitation versus physical therapy, versus both, would be informative for future patient care.

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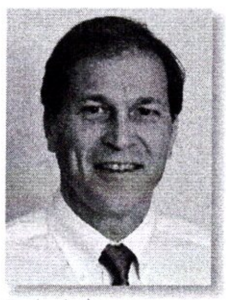

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