Optometric Phototherapy-Based Multi-Sensory Training Facilitates Reduction of Symptoms in Post-Concussion Syndrome

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Key words: neuro-optometric rehabilitation, post-concussion syndrome, multisensory integration, multisensory training, optometric phototherapy, oculomotor therapy, vestibular stimulation, auditory training.

ABSTRACT

Background: The objective of this article is to present the effectiveness of a multi-sensory training method that utilizes optometric phototherapy, oculomotor therapy, vestibular stimulation, and auditory stimulation, on reducing the symptoms of post-concussion syndrome. The setting is my neuro-optometric clinic.

Methods: The participants are 25 consecutive adult patients presenting to the clinic with post-concussion syndrome. The design is a comparison of symptoms and objective tests one week before and one week after treatment. The main measures are an acquired brain injury symptom survey, visual evoked potential, and Test of Information Processing Skills.

Results: 84% of patients reported improvement in a majority of their PCS symptoms; the patient group exhibited an average visual evoked potential (VEP) increase of 35% in low contrast amplitude; the patient group demonstrated an average increase in visual processing of 60%; auditory processing increased an average of 27%; delayed recall improved an average of 206%; all results were measured after an average treatment period of 38 days.

Conclusions: multi-sensory training utilizing optometric phototherapy, oculomotor therapy, vestibular stimulation, and auditory stimulation provides most post-concussion syndrome patients significant reduction in symptoms in a relatively short period of time. These patients were not making further appreciable progress in recovery prior to this treatment…they "hit a plateau". In addition to subjective improvements, patients also demonstrated significant improvement in objective testing.

Introduction

A review of the literature reveals that there is not a well-established, broadly-accepted treatment for post-concussive syndrome (PCS) symptoms. There remains a lack of evidence-based treatment strategies. However, some individuals benefit from several interventions depending on the particular presenting signs and symptoms. The most common treatment options that are effective for certain patients consist of medications, physical therapy, early education (1, 2), cognitive behavioral therapy (3), and aerobic exercise therapy (4).

The purpose of this article is to introduce a particular multisensory training method that has been an effective treatment of PCS symptoms when utilized within my neuro-optometric rehabilitation services. **Neuro-optometric rehabilitation** is a therapy service provided by specially trained optometrists which utilizes therapeutic prisms, lenses, filters, occlusion, and vision therapy to help stimulate visual pathways of the brain which are not functioning properly due to brain injury. Depending on the particular history presentation and clinical results of my neuro-optometric evaluation, I prescribe one or more of these "tools". However, none of them have been as efficacious in reducing PCS symptoms as the multi-sensory training this paper presents.

The impetus for presenting this paper is the uniquely quick, relatively consistent, and comprehensive results I obtain on patients who have hit a plateau in their recovery. Further uniqueness is the fact that it is a more passive than active therapy. Therefore, it is usually receptive by symptom-sensitive patients who might otherwise "shut down" on us when traditional output-based active therapy approaches are attempted. I will provide both supportive scientific research references and my preliminary clinical study results.

Background

Concussion is a mild traumatic brain injury, usually occurring after a blow to the head. It can produce anything from loss of consciousness to impaired cognitive or physical abilities. Estimated incidence rates for this condition, according to the Centers for Disease Control and Prevention, range from a conservative 300,000 per year to a more liberal and recent estimate of 3.8 million cases in the United States annually (5).

Post-concussion syndrome, or PCS, is a set of symptoms that may continue for weeks, months, or more than a year after a concussion (6, 7). Predictive factors for PCS are poorly understood. In fact, PCS does not appear to be associated with the severity of the initial injury (8). The rates of PCS vary, but most studies report that about 15% of individuals with a history of a single concussion develop persistent symptoms associated with the injury. Research indicates that many of these symptoms are, in part, a result of compromised processing of sensory inputs, including visual, vestibular, and auditory.

Researchers have found that efficient visual processing and sensory integration are essential to day-to-day functioning (9, 10). In a study measuring visuo-perceptual performance in children, mild traumatic brain injury was shown to induce prolonged visual processing deficits (11). Auditory processing disorders can also be compromised in PCS patients. Turgeon, et al, found that concussions can disrupt the neurological mechanisms implicated in several auditory processes, including monaural low-redundancy speech recognition, tone pattern recognition, and dichotic listening (12).

If sensory processing is disrupted due to brain injury, one can intuitively conclude that **multisensory integration** is likely to be compromised in PCS patients. Multisensory integration describes a process by which an intact, well developed brain is able to integrate information from multiple senses and modulate these inputs for optimal identification of and reactivity to environmental events. All brains engage this strategy at multiple levels of the neuraxis (13), and its impact on cognition and behavior has been repeatedly demonstrated. Multisensory integration has been shown to enhance and speed up the detection, localization, and reaction to biologically significant events (14).

In recent decades, researchers have made advances in understanding the physiology of multi-sensory neurons and networks that provide the relationship between cellular responses and our perception and behavior. Prior to this, rehabilitation therapy did not focus on the multisensory networking of the brain but rather on the musculoskeletal system; neurologists limited their attention to central or peripheral nervous system disorders, and otologists confined their focus to the peripheral vestibular apparatus and inner ear (15).

During the past couple decades, success has been seen in **multisensory training** - combining sensory systems during therapy, such as in rehabilitation of brain-injured patients. A common example is when a physical therapist incorporates both head and eye movement during advanced stages of vestibular/balance therapy. The vestibular and visual systems are therefore both stimulated creating a multisensory training activity. Brain injury can cause disruption of visual-vestibular integration centers in the midbrain. Although damage to these areas of the brain cannot be measured with the imaging tools readily available today, we can infer these areas are negatively affected because positive results occur during rehabilitation that incorporates the pairing of these systems.

Moreover, this interaction of the vestibular and visual systems provides clear and stable vision during movement. The integration of vision and vestibular inputs also contributes to the maintenance of balance. When there is a compromise to this interaction, which often occurs in head injury, patients can suffer a constellation of symptoms and deficits including blurred vision, oscillopsia, decreased dynamic visual acuity, oculomotor deficits, poor depth perception, imbalance, nausea, dizziness, and vertigo. Since many of these symptoms exist in PCS patients, one might embrace the notion that PCS patients could have their symptoms improved with multisensory training that involves simultaneous visual and vestibular stimulation. The clinical results discussed later in this paper support this.

Jiang, Stein, and McHaffie recently demonstrated that multisensory training reverses midbrain lesion-induced changes and improves hemianopia. They found that cross-modal (auditory–visual) training reestablishes visuomotor competencies in animals rendered hemianopic by complete unilateral visual cortex ablation. This visual responsiveness occurred in deep layer neurons of the ipsilesional superior colliculus allowing these midbrain neurons to once again transform visual cues into appropriate orientation actions. The findings underscore the inherent plasticity and functional capacity of phylogenetically older visuomotor circuits that can express visual capabilities thought to have been replaced by more recently evolved brain regions. These observations suggest that multisensory training should be further considered as strategies aimed at ameliorating trauma-induced visual deficits in humans (16).

Research out of Boston University found that using multisensory training programs helps adults improve their performance of low-level perceptual tasks significantly faster than methods that use only one stimulus. These tasks included visually detecting the motion of an object, discriminating differences in highly similar objects, and finding an item in a cluttered scene (17).

Methods

The multisensory training method utilized in my neuro-optometric rehabilitation simultaneously uses optometric phototherapy, oculomotor therapy, vestibular stimulation, and auditory stimulation in an intensive repetitive fashion. The training consists of 12 in-office visits lasting 75 minutes each and two to three weeks of daily home therapy.

The goal of this multisensory training method is to access the neuroplasticity inherent in the patients' nervous system augmented by the potential of dormant idling neurons (18). Neural connections are created and altered by the novel experience during the training (19). This multi-modal approach encourages improved connectivity between brain areas (20). The repetitive component of the training fosters automaticity in the neural pathways. I will provide a brief explanation of the individual sensory stimulations that are combined during this multisensory training method.

Patient #	Age	Days Start to Follow up	Days Injury to Start	% of All Symptoms Improved	% of V/V-V Symptoms Improved	VEP OD L_c % Δ	VEP OD H_c % Δ	VEP OS L_c % Δ	VEP OS H_c % Δ	TIPS Visual Pro % Δ	TIPS Auditory Pro %Δ	TIPS Delayed Rec %Δ
1	24	36	1461	80.0	100.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2	45	43	940	53.3	62.5	n/a	0.0	n/a	n/a	n/a	n/a	n/a
3	40	36	39	73.3	87.5	n/a	n/a	n/a	31.0	-84.9	78.9	177.8
4	58	35	54	93.3	100.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
5	58	36	340	46.7	50.0	n/a	25.8	39.3	29.3	172.0	-26.5	368.8
6	38	36	119	86.7	87.5	-53.2	-19.0	43.2	-59.8	n/a	n/a	n/a
7	38	38	207	80.0	100.0	n/a	n/a	n/a	29.6	31.5	10.0	-9.0
8	69	38	532	73.3	75.0	n/a	32.1	n/a	n/a	n/a	n/a	n/a
9	54	36	244	86.7	100.0	n/a	n/a	n/a	n/a	n/a	n/a	n/a
10	45	36	75	73.3	75.0	n/a	51.7	n/a	0.0	n/a	n/a	n/a
11	46	43	1096	35.7	28.6	n/a	206.9	n/a	66.7	35.1	-42.1	70.3
12	21	36	577	50.0	66.7	-41.0	-30.3	22.6	7.8	24.0	63.6	833.3
13	22	34	35	60.0	75.0	-16.7	17.3	12.0	-1.8	138.1	32.7	57.1
14	34	43	94	66.7	50.0	43.6	22.2	61.1	9.8	-55.3	200.0	900.0
15	71	36	159	86.7	75.0	-56.3	n/a	n/a	n/a	n/a	n/a	n/a
16	53	38	101	86.7	100.0	-62.6	-44.4	93.1	n/a	n/a	n/a	n/a
17	21	38	470	46.7	50.0	n/a	-81.5	-27.3	-24.0	36.4	0.0	26.7
18	51	36	111	83.3	83.3	151.7	-17.9	100.0	0.0	0.0	4.3	-10.7
19	55	38	807	69.2	71.4	47.4	106.3	n/a	51.9	97.3	7.6	525.0
20	45	43	120	35.7	28.6	68.8	60.8	187.1	163.5	79.4	-12.7	50.8
21	56	38	223	92.9	87.5	44.0	-41.8	1.1	32.3	-29.1	10.0	-10.7
22	34	36	54	75.0	60.0	-0.9	32.8	10.1	38.6	83.8	8.8	68.0
23	22	37	147	78.6	85.7	135.1	-25.0	24.1	-28.6	84.0	68.1	26.7
24	66	43	101	73.3	75.0	n/a	-13.6	n/a	33.3	-2.0	10.7	9.9
25	30	36	420	53.3	37.5	79.4	-9.4	-1.6	-30.2	354.5	23.3	212.5
Ave	43.8	37.8	341.0	69.6	72.5	26.1	14.4	43.5	19.4	60.3	27.3	206.0

Table 1 summarizes age, injury and therapy time-frame, symptom improvement, VEP (visual evoked potential) and TIPS (Test of Information Processing Skills) data per patient.

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 (21). It is a noninvasive use of prescribed light frequencies to treat injury and diseases of the nervous system including visual dysfunction, brain injury and imbalanced autonomic nervous systems (22), (23). As the photonic energy of the light stimulates the biochemistry of the brain, it can re-energize many neural pathways including visual, vestibular, auditory, brainstem nuclei, and glands including the hypothalamus, the pineal, and the pituitary, just to name a few. As a result, a patient becomes primed to be more neurologically receptive to clinical treatments and stimulations. I believe this is why the optometric phototherapy component appears to be the primary driving force behind the synergistic results of the multisensory training that we use in our clinic.

ABI Symptom Survey

NAME________________________ DATE________________

Please complete this questionnaire. After each symptom listed, circle the number that best describes how often you currently experience that particular problem.

0 = never, 1 = (not very often) infrequently, 2 = sometimes, 3 = fairly often, 4 = always.

		Never	infrequently	sometimes	often	always
1.	**Reading difficulties** (*fatigue, blur, loss of place, headaches, limited endurance, pain, shuts you down, nausea*)	0	1	2	3	4
2.	**Difficulty with concentration on tasks** (*difficulty multi-tasking disconnected feeling foggy-headed hazed-over feeling difficulty thinking or processing, general confusion*)	0	1	2	3	4
3.	**Photophobia** (sensitivity to lights or glare)	0	1	2	3	4
4.	**Headaches** (NOT associated with reading)	0	1	2	3	4
5.	**Spatial misjudgements** (*disorientation, clumsiness, poor eye-hand coordination, falls, bump into things*)	0	1	2	3	4
6.	**Imbalance**	0	1	2	3	4
7.	**Dizziness**	0	1	2	3	4
8.	**Writing difficulties**	0	1	2	3	4
9.	**Word/Name retrieval difficulties**	0	1	2	3	4
10.	**Phonophobia** (sensitivity to sounds)	0	1	2	3	4
11.	**Become "shut-down", or a nap needed to recover from excessive fatigue**	0	1	2	3	4
12.	**Double vision or eyes feel out of sync**	0	1	2	3	4
13.	**Sleep pattern difficulties**	0	1	2	3	4
14.	**Anxiety**	0	1	2	3	4
15.	**Visually busy environments or motion exacerbates or induces any of the symptoms listed above**	0	1	2	3	4
	Total Score	__	__	__	__	__

This survey was developed by Steven J Curtis, OD, FCOVD

Figure 1. ABI Symptom Survey.

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 (24). 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 specific oculomotor therapy activities used during the multisensory training are based on those commonly used in optometric vision therapy.

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 (15).

The **auditory stimulation** included in this multisensory training is attenuated obscure music with customized sound frequencies, volume, lateralization, and modulation presented through headphones. After a thorough history is taken to rule out the need for a referral to an ENT, customization is accomplished via a listening profile taken on the patient using an audiometer.

Subjective and objective clinical results were obtained on 25 consecutive PCS patients before and after receiving this multisensory training. Tests were administered approximately one week prior to and then again 38 days after the start of their multisensory training. Patient ages ranged from 21 to 71with a median age of 43.8. The time since their most recent concussion to the start of training ranged from 35 to 1461 days with a median time of 341 days.

The tool utilized for subjective measurements was an acquired brain injury (ABI) symptom survey I developed. The questions in the survey were chosen based on a review of the presenting history of the previous 25 consecutive PCS patients that were treated. The symptom survey is shown in figure 1. All participants completed the symptom survey.

Objective clinical results were obtained using two tests: visual evoked potential (VEP) and Test of Information Processing Skills (TIPS). These tests reliably paralleled the patient improvement in symptoms and they have evidence-based research credibility. An advantage of using these tests is because one (VEP) represents visual processing physiologically along a subcortical-cortical (non-cognitive) neural pathway, and the other (TIPS) represents an assessment of higher level cortical (cognitive/executive function) processing. Due to scheduling limits, eight of the patients did not receive the TIPS. Due to unacceptable reliability and/or scheduling limits, some or all of the VEP results of several patients is not available. Prioritization of these tests is now in place in our scheduling protocol and is represented in table 1 when reviewing patients 11 through 25.

All Symptoms	%Δ
Reading Difficulties	-44
Concentration Difficulty	-37
Photophobia	-39
Headaches	-17
Spatial Misjudgments	-36
Imbalance	-48
Dizziness	-50
Writing Difficulty	-38
Retrieval Difficulty	-30
Hyperacusis	-41
Shut Down from Fatigue	-26
Double Vision	-59
Sleep Difficulty	-47
Anxiety	-36
Environmental Trigger	-36
Ave	-39

Table 2 summarizes the percent change of each symptom for the patient group.

A VEP objectively measures the functional responses of the visual pathway including the retina, optic nerve, optic radiations, and visual cortex. Electrical signals are measured from the electrophysiological activity ("brain waves") at the visual cortex. VEP recordings have been used for a variety of applications that involve neuro-visual disorders such as glaucoma, amblyopia, multiple sclerosis, diabetic retinopathy (25, 26, 27, 28) and traumatic brain injury (29). VEP tests provide the clinician with objective data, as no response is required from the patient.

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 reflects visual processing, auditory processing, executive functioning, working memory, and delayed recall.

Results

Improvement in a <u>majority</u> of symptoms was reported by 84% of patients – 21 of 25 patients improved in at least half of their presenting symptoms (see column 5 of table 1). The average amount of improvement in all 15 symptoms for the entire group was 39% (see table 2).

Figure 2 is a graph showing the percentage of patients reporting improvement for each symptom. Eight of the most responsive symptoms to the multisensory training were reading difficulties, writing difficulties, photophobia, imbalance, dizziness, double vision/"eyes out-of-sync feeling", spatial mis-judgements, and busy visual environment sensitivity. These are all vision and visual-vestibular (V/V-V) based symptoms, often referred to in the brain-injury medical community as "visual disturbances".

When considering only the eight V/V-V based symptoms, 88% of patients (22 of 25) reported improvement in a majority of them (see column 6 of table 1). Twenty percent (5 of 25) had improvement in 100% V/V-V symptoms. The average amount of improvement of the eight V/V-V based symptoms in this group was 44% (calculated from table 2 data).

More specifically, 83.3% of patients (20 of 24) reported improvement in reading difficulties. The amount of improvement the group reported in reading was an average of 44%. Seventy nine percent of patients (19 of 24) reported improvement in photophobia with an average improvement amount of 39%. Ninety percent of patients (17 of 19) reported improvement in double vision/ "eyes feel out of sync" with an average improvement amount of 59%. About 82% of patients (18 of 22) reported improvement in balance with an average improvement amount of 48%. Substantially improved non-visual symptoms worth noting were concentration difficulties (83.3%), sleeping difficulties (75%) and hyperacusis (81%).

Upon further review, dizziness was the symptom that resulted in the most patients reporting a 100% improvement from the multi-sensory training. Thirty six percent (9 of 25) patients stated that their symptom of dizziness had completely resolved. Traditionally, dizziness is treated primarily as a vestibular dysfunction but these results indicate that this multi-sensory training should also be considered especially if the patient has "hit a plateau" in recovery with vestibular therapy. Collaboration with local vestibular therapists is most appropriate for serving these patients well.

Although the symptom improvement is very satisfying and welcomed, as clinicians we feel more justified in our efforts if there is objective testing data that parallels the subjective improvements. The following section will review the objective clinical results for the same group of patients that were represented in the symptom data above.

VEP measurements were obtained using the Diopsis NOVA 32 spatial frequency configuration with multi□ contrast stimulus pattern at both low contrast and high contrast to test the integrity of the magnocellular (primarily peripheral vision) and parvocellular (primarily central vision) pathways, respectively. The patient group exhibited an average increase of 35% in low contrast amplitude and 17% in high contrast amplitude (average of OD and OS). The magnocellular pathway plays a much greater role in balance than the parvocellular pathway. I believe that the significantly greater improvement that occurred to the low contrast amplitudes compared to the high contrast amplitude means that these PCS patients gained needed improvement in neurotransmission throughout the magnocellular pathway including its integration with vestibular and motor areas. As a result, balance symptoms improved.

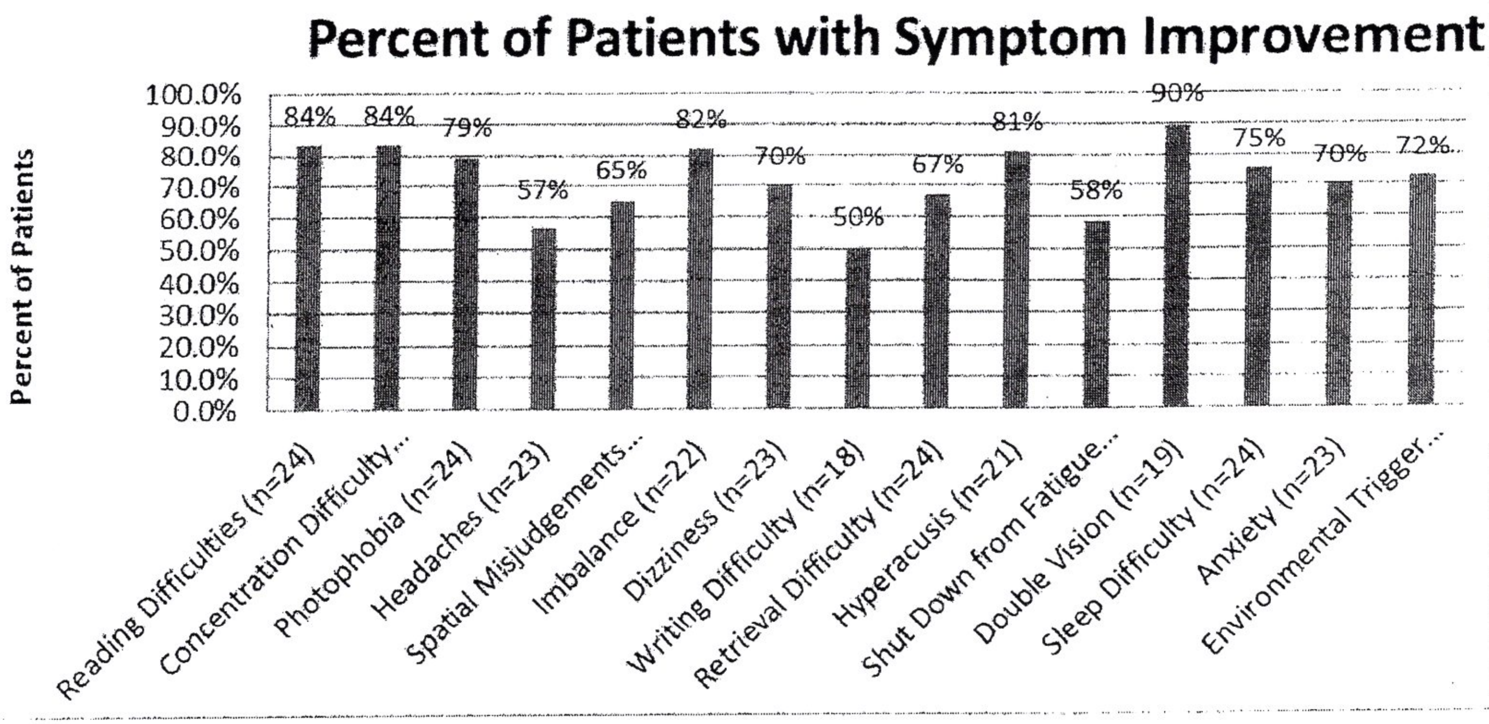

Figure 2.

In addition to improved amplitudes, patient reliability on the test improved likely indicating improved visual attention. Research that helps us understand this observation is present in a study by Ciufredda, et al. They studied the effect of oculomotor therapy on VEP amplitudes and visual attention. They found that visual attention improved as measured objectively via alpha band activity embedded in the VEP. The VEP amplitudes increased and the variability decreased. Latencies, both high and low contrast, exhibited no statistically significant change (24).

Using the TIPS, the patient group demonstrated an average increase in their visual processing score of 60%. Auditory processing increased an average of 27 %. Most notably, delayed recall improved an average of 206%.

Patients who reported an average improvement in all symptoms of greater than 50% had an average time between injury and start of treatment of 126 days. Those with average improvement below 50% had an average of 424 days between injury and start of therapy. This indicates that delaying treatment negatively affects the effectiveness of treatment. Age of the patient did not show influence in outcomes.

Discussion:

So why do these patients respond to this multisensory approach when single-sensory based rehabilitation methods such as physical therapy or vision therapy failed? Consider that while physical therapy often improves overall function in patients by improving the use of vestibular inputs, it may unfortunately decrease the dependency on visual information; likewise, vision therapy aids patients by enhancing visual input at the risk of decreasing dependency on vestibular inputs. In contrast, this multisensory integration training spreads the processing therapy amongst all the systems creating opportunity for the stronger systems to support the weaker systems until all reach the balanced and synergistic status that existed before the brain injury.

Anatomically, what are the neural mechanisms behind these positive changes for PCS patients who receive the multi-sensory training? The process of sensory integration occurs at several levels of the brain including the cerebellum, brainstem nuclei, the superior and inferior colliculi, the thalamus, the hypothalamus, the reticular system, anterior ectosylvian sulcus (31) and the intraparietal sulci of the cortex (32). The peripheral sensory organs provide individualized neural information from our environment to these areas. For example, the optic nerve has a path consisting of the chiasm, lateral geniculate nucleus (LGN), and optic radiations before terminating in the occipital cortex. But near where it junctures at the LGN, it sends collateral neurons to the superior colliculus. The superior colliculus is a major component in sensory integration. In addition to input from the retina, the superior colliculus receives inputs from the visual cortex along with sensory and motor structures including the hypothalamus, thalamus, and inferior colliculus (33).

Specific to visual-vestibular integration, the neuroanatomy begins with the vestibular nerve providing neurons from the inner ear to the vestibular nuclei of the brainstem. From here, fibers proceed to the oculomotor nuclei and to the spinal cord. Vestibular fibers are also sent to the cerebellum along with input from the visual cortex. This extensive interplay of sensory information provides for effective motor outcomes including saccadic eye movements, vergence eye movements, and balance maintenance (34).

An excellent example of this is represented by a patient I just saw for follow-up a few days prior to finishing the writing of this paper (thus, she is not included in the 25 patient group). K.A., a 54 yowf, presented with a history of several concussions throughout her life. Her most recent one (six months prior to her treatment) caused severe post-concussion syndrome symptoms. The most debilitating symptom for her was the constant sensation of being on a boat on the ocean. This case was one of my most interesting because binocular vision dysfunctions are often at the core of our neuro-optometric rehabilitation efforts yet, she is monocular, having a prosthetic right eye since age one. However, based on her symptoms and one particular clinical test I performed on her, I was confident she would respond to the visual-vestibular training effects of the optometric phototherapy-based multisensory training. Bi-nasal occlusion, or in this case, mono-nasal occlusion provided her with instant significant improvement in balance. I repeated the test three times both in the exam room and having her stand in our busy dispensary. Her husband witnessed the profound effects as well. This demonstrates to me that she is unable to integrate the entire amount of ambient visual information with her vestibular information thus causing her the visual-vestibular symptoms of "being on a boat". The nasal occlusion allowed for a manageable amount of ambient visual input to integrate more efficiently.

At her follow-up appointment with me 36 days after beginning the treatment, she reported that "I am off the boat" and "this is the first day I have driven my car this far". Clinically, her ABI symptom survey improved from a score of 40/60 to 17/60. Her low contrast VEP's only improved from 9.05 microvolts to 9.64 microvolts, however her reliability improved from 78% to 98% indicating improved visual attention. TIPS scores for K.A. improved from 61st to 75th percentile in visual processing and from 63rd to 91st percentile in delayed recall. This explains why she reported her concentration abilities were significantly improved and stated "I'm out of the quicksand".

Why is this optometric phototherapy-based multisensory integration training predominantly providing improved PCS symptoms that are visual and visual-vestibular based? Three likely reasons are: 1) patients presented with these disturbances as their primary symptomology, while other symptoms were secondary; 2) since vision is considered the most dominantly used sensory system in humans, it will be the most influential one in symptom recovery; 3) this multisensory training targets visual-vestibular integration pathways in the brain. As a result, most patients reported improvement in reading, writing, photophobia, balance, dizziness, double vision/"eyes feel out-of-sync", spatial judgement, and busy visual environment sensitivity.

Furthermore, neural mechanisms are compromised when brain injury disrupts integration processing between the auditory and visual systems. The superior and inferior colliculi are key structures in maintaining coherence between vision and audition. For example, a visual stimulus takes much longer to arrive at the colliculus than a sound does. The colliculus performs the critical function of maintaining a memory for these varying responses and merges the differing lengths of time to provide temporal fusion (35).

It is my prediction that this multisensory training is uniquely more effective compared to other multisensory training methods. My hypothesis for this is based on the inclusion of optometric phototherapy. It is capable of energizing neural transmission throughout the integrative pathways in the midbrain **at the same time** that oculomotor and vestibular inputs arrive. Additionally, optometric phototherapy likely improves the flow of neural energy through the magnocellular pathway and dorsal stream enhancing parietal lobe function. This, in turn, provides the patient with improved spatial awareness of their environment creating improved cortical visual input available for integration.

In other words, as the sensory integration and spatial localization areas of the brain repetitively receive photo-transduced energy while simultaneously receiving the vestibular and auditory inputs and performing oculomotor output, 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 resultant improvement in sensory integration provides more accurate and efficient production of motor output including posture, balance, and eye movements thereby reducing related symptoms such as in PCS. When neurons fire in sync with one another, they are more likely to form new connections and grow stronger through repeated stimulation (30).

Further and more sophisticated study is needed to provide validity and expansion to these clinical results. For example, a much larger pool of subjects is needed. Ideally, future research should utilize fMRI to compare changes in the brain. I also propose comparing this multi-sensory training to other multisensory trainings or to single-sensory trainings.

Neuro-optometric rehabilitation is comprised of many other techniques that are sometimes effective in reducing PCS symptoms. Studies comparing this optometric phototherapy-based multi-sensory training to other techniques might help the provider understand when it is appropriate to choose one or the other during treatment planning. One of the most compelling factors that influence me to prescribe this multi-sensory training is when a patient presents with a history of intolerance to traditional active/output-based therapies. This multisensory training is primarily a passive and input only-based therapy thereby being more receptive by the easily overwhelmed patient.

Multi-sensory stimulation should be considered in the rehabilitation of PCS patients. This is because the foundation of essential human functions of daily living depends on the interaction of information transmitted from the various peripheral sensory systems to the brain. In promoting their PhD programs in multisensory neuroscience, Wake Forrest University states this on their website:

> "*Despite traditional emphasis on individual senses, there is growing appreciation that brains are inherently multisensory ... multisensory therapeutic regimens may better ameliorate the sensory deficits associated with acute brain trauma (e.g., neglect following stroke), and training programs emphasizing interactions among senses are essential to pro-*

mote a better understanding of the debilitating effects of disease and the strategies necessary to ameliorate them."

Sue Barry, professor of neuroscience at Mt Holyoke College, once stated "one of the most important functions of our brain is to integrate the information from all our senses into a perceptual whole. Only then can we perceive the world as single, integrated, and stable. Brain injury shatters this wholeness" (36).

Finally, PCS has socioeconomic repercussions because it often prevents patients from returning to work, play, and enjoying family relationships. When PCS patients deal with their constant symptoms, they become irritable, anxious, depressed, and display a personality to their loved ones and public that does NOT reflect their pre-injury persona. They are less efficient at work with some losing their jobs. They become a medical expense drain for the insurance companies and their own out-of-pocket resources. If rehabilitation of these patients can be facilitated using interventions such as this multisensory training method, the patient, family, employers, providers, and insurance companies all win.

REFERENCES

1. Mittenberg W, Canyock E, Condit D, Patton C. Treatment of post-concussion syndrome following mild head injury. J Clin Exp Neuropsychol. 2001;23 (6):829-836 [PubMed].
2. Wade D, King N, Wenden F, Crawford S, Caldwell F. Routine follow up after head injury: a second randomized controlled trial. J Neurol Neurosurg Psychiatry. 1998;65(2):177-183 [PMC free article] [PubMed].
3. Al Sayegh A, Sandford D, Carson AJ. Psychological approaches to treatment of postconcussion syndrome: a systematic review. J Neurol Neurosurg Psychiatry. 2010;81(10):1128-1134 [PubMed].

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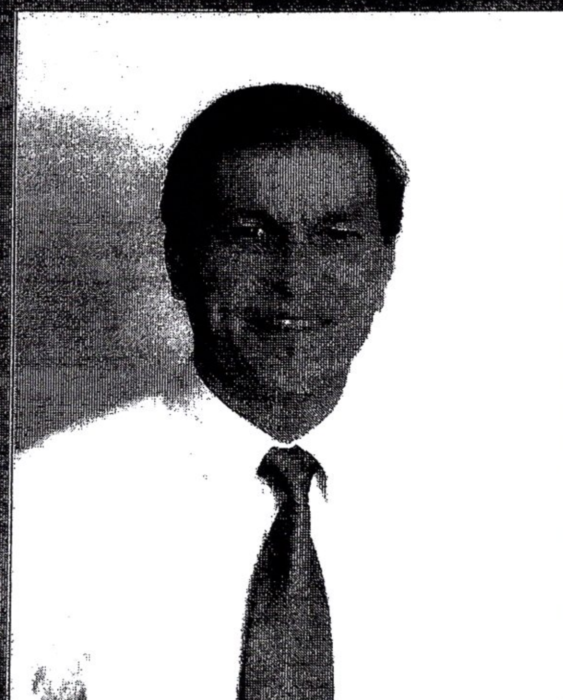

Dr. Steven J. Curtis received his Doctor of Optometry degree from The Ohio State University in 1987.

He is president of Riverview Eye Associates in Columbus Ohio where he provides general, developmental, and neuro-optometric services. He is also on the medical staff at the OhioHealth Rehabilitation Hospital in Columbus.

Dr. Curtis is a fellow of the College of Optometrists in Vision Development and is currently on track to earn fellowship from the Neuro-Optometric Rehabilitation Association. He is frequently asked to lecture on the subject of vision rehabilitation to area physicians and therapists. Most recently he twice provided a 12 hour course titled "Vision Assessment of Acquired Brain Injury Patients for Non-Optometric Rehabilitation Providers". His role is to assist with the collaborative movement that is happening in rehabilitation by making sure non-optometric providers understand the role vision plays so they appropriately know when to request neuro-optometric involvement.

Dr. Curtis is enjoying the tremendous growth in his work with patients who suffer persistent vision disturbances after concussion. This has included athletes from professional teams of the MLS and NHL. Outside of optometry, Dr. Curtis enjoys spending time with his family and performing music.

4. Leddy J, Kozlowski K, Donnelly J, Pendergast D, Epstein L, Willer B. A preliminary study of subsymptom threshold exercise training for refractory post-concussion syndrome. Clin J Sport Med. 2010;20 (1):21-27 [PubMed].
5. Langlois J, Rutland-Brown W, Waldo M. The epidemiology and impact of traumatic brain injury: a brief overview. J Head Trauma Rehabil. 2006;21(5):375–378. [PubMed].
6. Post-Concussion Syndrome. Wikipedia website. https://en.wikipedia.org/wiki/Post-concussion_syndrome.
7. Bigler E. (2008). "Neuropsychology and clinical neuroscience of persistent post-concussive syndrome". Journal of the International Neuropsychological Society 14 (1): 1–22. doi:10.1017/S135561770808017X. PMID 18078527.
8. Post-Concussion Syndrome. Mayo Clinic Website. http://www.mayoclinic.com/health/post-concussion-syndrome/DS01020.
9. Brosseau-Lachaine O, Gagnon I, Forget R, Faubert J. Mild traumatic brain injury induces prolonged visual processing deficits in children. Brain Inj. 2008;22 (9):657–668. [PubMed]
10. Moore R, Broglio S, Hillman, C. Sport-Related Concussion and Sensory Function in Young Adults. J Athl Train. 2014 Jan-Feb; 49(1): 36–41. doi: 10.4085/1062-6050-49.1.02.
11. Brosseau-Lachaine O, Gagnon I, Forget R, Faubert J. Brain Inj. 2008 Aug;22(9):657-68. doi: 10.1080/02699050802203353.
12. Turgeon C, Champoux F, Lepore F, Leclerc S, Ellemberg D. Ear Hear. 2011 Sep-Oct;32(5):667-70. doi: 10.1097/AUD.0b013e31821209d6.
13. Calvert G, Spence C, Stein B. The Handbook of Multisensory Processes. Cambridge, MA: MIT Press; 2004.
14. Perrault T, Rowland B, Stein B. The Organization and Plasticity of Multisensory Integration in the Midbrain, Chapter 15 in The Neural Bases of Multisensory Processes, Murray M, Wallace M, Boca Raton (FL): CRC Press; 2012.
15. Suchoff I, Ciuffreda K, Kapoor N. Visual & Vestibular Consequences of Acquired Brain Injurie. Optometric Extension Program Foundation; 2001.
16. Jiang H, Stein B, McHaffie J. Multisensory training reverses midbrain lesion-induced changes and ameliorates haemianopia JA - Nat Commun PY - 2015/05/29/online VL - 6 SP - PB - Nature Publishing Group, a division of Macmillan Publishers Limited.
17. Steiz A. Study Shows Combination of Sight and Sound Helps Adults Learn Basic Visual Tasks More Rapidly; July 24, 2006 in College and Graduate School of Arts & Sciences, Boston University Public Relations.
18. Neubauer R, Gottlieb S, Kagan R. Enhancing "Idling" Neurons. Lancet. 1990 Mar 3; 335 (8688): 542.PMID: 1968553sdddb 6y.
19. Kandel E, Schwartz J, Jessell T. Cellular Mechanisms of Learning and the Biological Basis of Individuality; Principles of Neural Science (4th ed., pp. 1247-1279). New York, NY: McGraw-Hill.
20. Li R, Zhu X, Yin S, et al. Multimodal intervention in older adults improves resting-state functional connectivity between the medial prefrontal cortex and medial temporal lobe. Frontiers in Aging Neuroscience. 2014;6:39. doi:10.3389/fnagi.2014.00039.
21. Purves D, Augustine G, Fitzpatrick D, et al., editors. Neuroscience. 2nd edition. Sunderland (MA): Sinauer Associates; 2001.
22. Gottlieb R, Wallace L. Syntonic Phototherapy; Photomedicine and Laser Surgery, vol 28 #4, 2010; copyright Mary Ann Liebert, Inc.
23. Wallace L. Syntonics: Optometric Color Therapy for the Treatment of Acquired Brain Injuries; Journal of Optometric Phototherapy, April 2001.
24. Yadav N, Thiagarajan P, Ciuffreda K. Effect of Oculomotor Vision Rehabilitation on Visual Evoked Potential; Brain Inj. 2014;28(7):922-9. doi: 10.3109/02699052.2014.887227. Epub 2014 Feb 24.
25. Prata T, Lima V, De Moraes C, Trubnik V, Derr P, Liebmann J, et al. Short Duration Transient Visual Evoked Potentials in Glaucomatous Eyes. J Glaucoma. 2011 May 10.
26. Simon J, Siegfried J, Mills M, Calhoun J, Gurland J. A New Visual Evoked Potential System for Vision Screening in Infants and Young Children. Journal of AAPOS. 8.6 (2004): 549-554.
27. Garcia-Martin E, Pueyo V, Ara J, Almarcegui C, Martin J, Pablo L, et al. Effect of optic neuritis on progressive axonal damage in multiple sclerosis patients. Mult Scler. 2011 Jul;17(7):830-7. Epub 2011 Feb 7.
28. Parisi V, Uccioli L. Visual electrophysiological responses in persons with type 1 diabetes. Diabetes Metab Res Rev. 2001 Jan-Feb;17(1):12-8.
29. http://www.diopsys.com/products/diopsys-nova-vep.
30. Chugani, Harry T. A Critical Period of Brain Development: Studies of Cerebral Glucose Utilization with PET; Preventive Medicine Vol 27, 184-188 (1998).

PM980274.

31. Wallace M, Carriere B, Perrault T, Vaughan J, Stein B. The Development of Cortical Multisensory Integration. *J Neuroscience* November 15, 2006. 26 (46): 11844–49. doi:10.1523/JNEUROSCI.3295-06.2006. PMID 17108157.

32. Cappe C, Rouiller E, Barone P. Multisensory Anatomical Pathways; Hearing Research 258 (2009) 28–36.

33. Superior Colliculus. Wikipedia website. https://en.wikipedia.org/wiki/Superior_colliculus.

34. Hellerstein L, Winkler P. Vestibular Dysfunction Associated with Traumatic Brain Injury: Collaborative Optometry and Physical Therapy Treatment; In Suchoff I, Ciuffreda K, Kapoor N. Visual & Vestibular Consequences of Acquired Brain Injury; Optometric Extension Program, 2001.

35. Press L. Parallels Between Auditory & Visual Processing; Optometric Extension Program 2002, 23-24.

36. Suter P, Harvey L. Vision Rehabilitation: Multidisciplinary Care of the Patient following Brain Injury. Boca Raton [Florida: CRC, Taylor & Francis Group, 2011.

There are no conflicts of interest, disclosure of funding, nor disclaimers.

Acknowledgements: I acknowledge the College of Optometrists in Vision Development and the Neuro-Optometric Rehabilitation Association for their teachings of neuro-optometric rehabilitation and providing awareness of the valuable role neuro-optometric rehabilitation plays in the healthcare industry. I acknowledge the College of Syntonic Optometry, for their teachings of optometric phototherapy. I acknowledge Mary Bolles of the Sensory Learning Institute for pioneering core integration principals and instruments utilized in this multi-sensory training.