Chapter 16

Auditory/Visual Integration Assessment and Treatment in Brain Injury Rehabilitation

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Additional information is available at the end of the chapter

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1. Introduction

Retinal stimulation should be considered as a possible treatment for brain injury. Recent research has demonstrated that activating the retina – in particular, the *peripheral* retina – can influence inputs to the brain in ways that may be useful in rehabilitation. The specific treatment involves designing non-traditional eyeglasses that intentionally alter signaling pathways, rather than simply sharpening central eyesight. These often overlooked peripheral retinal pathways are activated or inhibited by feedback mechanisms linked with internal body systems, such as metabolism and attention. Changes in peripheral retinal stimulation can affect internal perception and can occur at conscious, or beneath conscious, processing levels.

Traumatic brain injury often disrupts retinal circuitry, because the retina is an extension of brain tissue. This disruption can trigger innate protective mechanisms, some of which can include alteration of peripheral retinal sensitivity. Patients' ability to integrate various sensory, motor, cognitive and emotional pathways is often impaired after both focal and diffuse brain injuries, causing a wide range of symptoms. For instance, after a stroke or concussion, patients may have difficulty making accurate judgments in space and time, misjudging object location and/or speed. Current rehabilitative methods could easily be augmented by the use of selective retinal stimulation to take into account the interactions between external sensory inputs and internal processing.

The mechanism underlying this approach lies in the retinal activity that occurs *before* signals are transmitted to the midbrain, brainstem, limbic system and cortex. The eye's linkage with sounds is concurrently involved in feedback and feedforward signaling pathways from both internal and external sources. Studies that demonstrated correlations between retinal function and auditory stimuli [1] paved the way for research on retinal plasticity. Although it was thought that the visual cortex changed in deaf people to meet increased visual demands of watching sign language, recent research discovered changes at the actual peripheral retinal level [2]. The concept of the retinal cells being plastic caters toward unique internal processing in each patient. Interaction between a person and their external environment can become confusing if incoming sensory information is mismatched, e.g., if the ears are receiving a signal that is not properly linked with visual input. Treatment of brain injury can be more individualized by implementing visual/auditory integration activities during visual rehabilitation.

The organization of this chapter is as follows. Relationships between the eye and internal systems are analyzed in Section 2, retinal processing is simplified in Section 3, visual/auditory connections in are discussed in Section 4 and examples of the usage of visual/auditory interactions in diagnosis and treatment are considered in Section 5. Conclusion, Acknowledgements and References follow.

2. The eye as a modulator between micro and macro environments

Visual pathways are important in studying brain function, yet connectivity between retinal signals and other sensory signals remains minimally explored. The mounting scientific evidence regarding retinal circuitry's effect on body functions suggests that retinal stress tolerance might be a clinical indicator of a person's nervous system's resilience to environmental changes. Acceptable ranges of visual stress vary from person to person, so measuring tolerance to retinal load, using optometric techniques, might be a next step in helping stabilize imbalances after brain injury.

After a traumatic brain injury, eye movements and pupil reactions are often used as diagnostic tools to assess brain function. For instance, sudden onset of unequal pupil size is a known symptom of brain injury. A relationship between the eye and internal systems can be further shown by the significantly higher prevalence of depression, anxiety and sleep disturbances in people with visual field deficits than those without field deficits [3]. Research has even shown that retinal imaging of the eyes can show quantifiable differences between intentionally inflicted injury and accidental injury [4], indicating that the limbic system also plays a role during structural injury.

The eye acts as a modulator between external information and internal systems. Just as cellular metabolism is affected by the surrounding *micro*-environment, mood, attention and behavior are affected by the surrounding sensory *macro*-environment. Interferences in the external sensory environment affect internal processing circuitry, as shown in Figure 1.

The study of the connections in neural networks is termed "connectomics". The Human Connectome Project (HCP) was designed with a goal to map structural and functional connections of the human brain [5,6]. Many of those structural and functional connections are involved with visual processing circuitry.

In the most general sense, the relationship between the eye and internal systems can be conceptualized as indicated in Figure 2 – the somatosensory aspect of retinal stimulation. Note that the term "MIND" does not mean "BRAIN".

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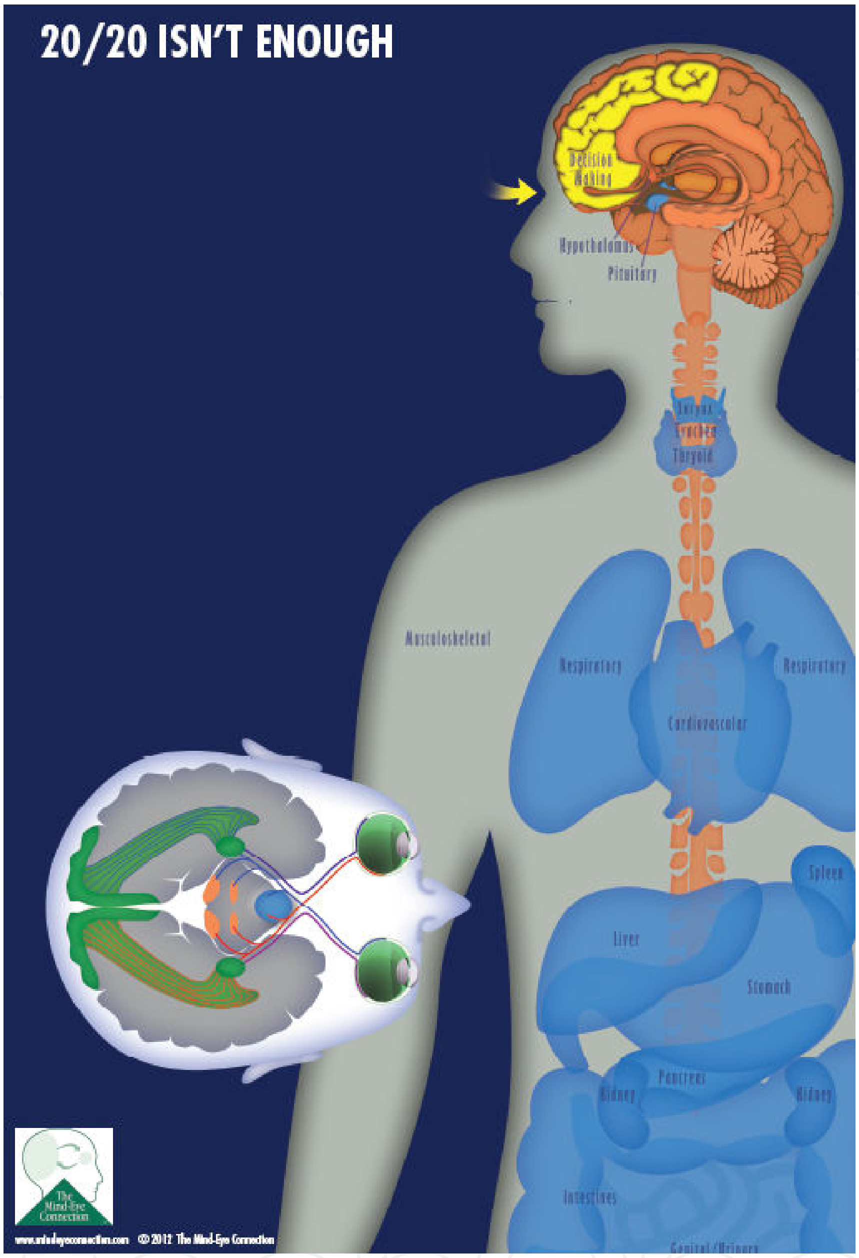

Figure 1. Retinal stimulation affects brain function, which in turn affects body systems. Medical evaluations include review of body systems as a starting point for diagnosis of problems in structural and functional integrity. Internal systems typically run beneath conscious awareness and many have connections with the eye. Multiple neural networks generate feedback and feedforward connections in order to maintain overall homeodynamic balance. When signals shifts out of balance, past habitual comfort ranges, sensory signals eventually seep into the conscious awareness level.

The eye has direct and indirect connections to many structures, allowing internal and external signals to combine and interact. Structures such as the basal ganglia have sensory-motor loops, oculo-motor loops, association loops and limbic loops to assist in sequencing and execution of movements [7]. Structures such as the cerebellum do not have direct connections with the eye, but are indirectly affected by changes in retinal stimulation via such structures as the vestibular nuclei and the inferior olivary nucleus.

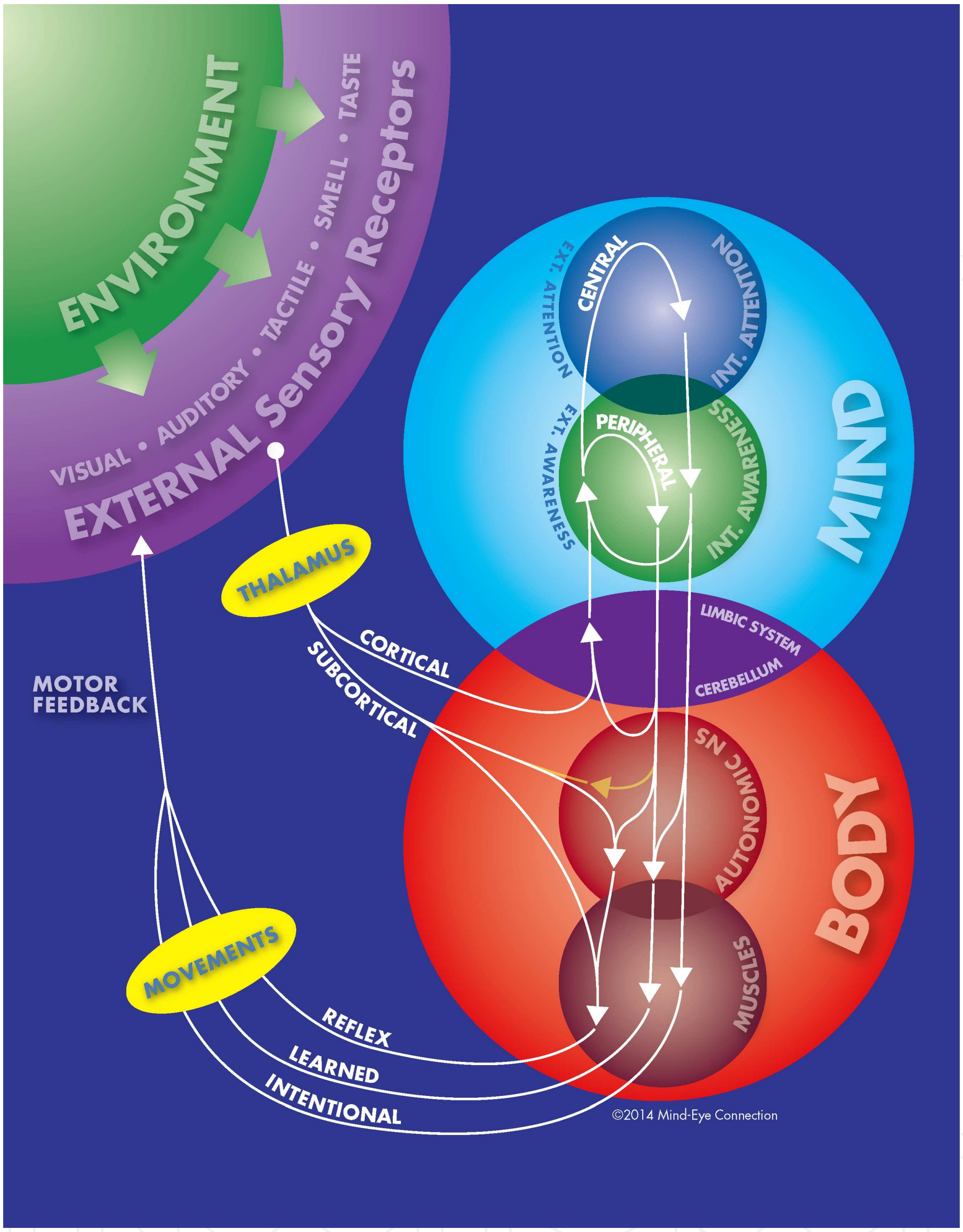

Figure 2. Simplification of Four Main Mechanisms involved in Visual and Auditory Circuitry. Constant signals arise from both internal and external sources. This diagram is a simplification of signaling pathways arising from external sources, showing how eyeglasses can be used in four distinct, yet interconnected, mechanisms. The actual complex bottom-up and top-down processing of simultaneous sensory signals is too extensive for this limited chapter. Many of the pathways have two-way signaling, with fibers returning to the sensory receptors (represented in gold) as well as signals leaving the sensory receptors (shown in white). When external sensory receptors are stimulated by changes in the outside environment, signals are sent to the central nervous system via two main routes, a fast subcortical route and a slower cortical route. The subcortical (reflex) route further separates signals into muscular reflexes and biochemical reactions. The cortical route separates into peripheral and central – Central being a slower route than peripheral. Internal thoughts, cerebellar pathways and the limbic system influence final movements. © 2014 The Mind-Eye Connection. Reprinted with permission.

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Smooth interactions between systems are often disrupted after a brain injury, creating frustration. For instance, the interaction of peripheral backgrounds and central targets aids in quick and accurate depth perception and reaction time. Similarly, the motor system relies on the flawless interaction of direct and indirect excitation and inhibition of movement. The eyes and ears have important roles in those navigation systems which require internal perceptions of external space.

Other examples of how internal and external systems affect eye responses can also be cited. Research studies on patients with amblyopia, diabetes and glaucoma demonstrate how the post illumination pupillary response (PIPR) is an indicator of the integrity of intrinsic photoreceptor cells in the retinal ganglion layer, and how pupil measurements have been found to differ in those patients, as compared to the non-affected population [8,9].

Disrupted sensory circuitry can be a warning sign of early stages of certain disease processes. For instance, disturbances in rapid eye movement during sleep can be a warning sign of dopamine levels changing in Parkinson's disease years before obvious signs are noted [10-12]. New research shows that intelligence is linked with the ability to detect motion, because the ability to ferret out salient details (glimpsed by peripheral eyesight) leads to better and faster decisions [13].

3. Retinal processing

More research is needed to determine the exact role that the peripheral retinal circuitry plays in the body. Consider what happens if a person who is afraid of spiders becomes aware of a large spider. The slow movement glimpsed by peripheral eyesight triggers internal reactions such as changes in adrenaline, heart rate, muscle contraction and a shift in mental attention. The body reaction would be completely different if the person were either unaware of the spider's presence or unafraid of spiders. Another example of how peripheral retinal signals interact with the body is the internal discomfort experienced when a person puts on someone else's eyeglasses.

The above scenarios occur because the retina is an extension of brain tissue and part of the central nervous system [14]. Sensory information enters through over 150,000,000 photosensitive retinal sensors and is funneled into approximately 1,000,000 exiting ganglion axon signals through ten layers of retinal processing. Retinal circuitry is so complex that with or without light stimulation its metabolic activity is continuous – occurring even during sleep, when the layperson assumes the eye isn't functioning. The retina contains many cell types, receptors, and significant feedback and feed-forward loops. Retinal processing involves various types of biochemical reactions that are beyond the scope of this limited chapter. However, the key point is that the eye is affected by both internal chemicals that alter retinal sensitivity to the external environment, and by external stimuli that alter internal retinal chemistry.

3.1. Retinal pathways

Traditionally, the eye is viewed as a structure that sends signals into the brain through two main circuits – central eyesight for paying attention to targets, and peripheral eyesight for maintaining awareness of background. Recently, technology has been able to analyze minute changes in electrical and biochemical activity in retinal receptors, demonstrating that the retina itself is much more than an input channel.

Signals leaving the retina through the optic nerve have eight key (and many smaller) destinations:

Image forming (Eyesight):

1. **Visual cortex via thalamus:** The vast majority of signals leaving the optic nerve travel through the lateral geniculate nucleus (LGN) of the thalamus to the visual cortex, as part of the central and peripheral eyesight pathways. There is also a feedback pathway from the visual cortex back to the LGN [15,16].

Non-image forming:

2. **Thalamus:** The contralateral intergeniculate leaflet (a small section of the lateral geniculate nucleus) contributes feedforward information to the hypothalamus regarding body metabolism and sensory conditions. The intergeniculate leaflet (IGL) is also involved in receiving inputs from the vestibulo-visuomotor system, implying that circadian rhythmicity might be influenced by head motion [17,18].

3. **Hypothalamus:** The pacemaker in the suprachiasmatic nucleus (SCN) of the hypothalamus for circadian rhythms [19].

4. **Habenula** (part of the limbic system) has direct connections from a small percentage of retinal ganglion cells and multiple connections in the brainstem. It registers changes in light and is involved in modulation of both dopamine and serotonin systems, playing a role in sleep, depression and schizophrenia, and also is involved in suppression of motor control [20,21].

5. **Nucleus of the optic tract** for smooth pursuit movement, and other pretectal nuclei for reflexive eye movements and visual stability, such as optokinetic nystagmus reflexes and visual-vestibular interactions.

6. **Olivary pretectal nucleus** for pupil constriction. Recent studies have verified that this structure has greater importance previously assumed, in that it has connections with the SCN and IGL mentioned above. The olivary pretectal nucleus links external information regarding luminance with internal metabolism.

7. **Edinger-westphal nucleus,** accessory nuclei of the oculomotor nerve, for pupillary constriction from external light. These nuclei also receive internal information from the olivary pretectal nuclei [22].

8. **Superior colliculus** for posture reflexes [23] and also rudimentary eyesight beneath conscious awareness [24].

3.2. Chemical circuitry

After brain injury, the integration among the various sensory and motor pathways is often disrupted, and sometimes patients are unable to quickly and comfortably readapt to changes. This signal integration occurs in sensory receptors, subcortical structures and cortical structures. Direct structural damage to the eye, such as optic nerve injury, triggers the production of brain-derived neurotrophic factor (BDNF) to promote ganglion cell survival and help preserve the structural integrity of the surviving neurons. This innate immune network in the retina [25] is set up for survival, as are the separate yet interconnected daily visual cycles to replenish the rods and cones with nourishment [26]. The transduction system from chemical to electrical signals in the retina includes image forming pathways (signals being sorted by speed, size, shape, location, color and detail) and non-image forming pathways (posture, pupil function, circadian rhythms, etc).

3.3. Image forming systems

Eyeglasses can be used to selectively alter central and peripheral eyesight. Those two image forming retinal pathways are very different, as the peripheral retinal tissue develops neurologically from a different pathway than the central retinal tissue [27], and the peripheral retina has sections that arise from several different transcription factors [28]. Classically, the central retina is thought of as seeing colors, however, the peripheral retina is also responsive to chromatic shifts [29]. Structurally, there are differences between the distribution of cones in the nasal and temporal peripheral retina [30]. Those structural differences have a functional effect [31]. Patients who have suffered a brain injury very often do not synchronize the inputs from the central and peripheral eyesight pathways. This imbalance in external eyesight has an effect on internal systems, yet often remains undetected.

3.4. Non-image forming systems

It is well established that light activates the image forming photosensitive cells, (i.e., rods and cones). More recently, a small percentage of retinal ganglion cells (ipRGC) have been documented to be intrinsically photosensitive. They are non-image forming and contain melanopsin [32]. Less than 2% of the retinal ganglion cells are these special melanopsin containing ipRGC types. The remaining ganglion cells don't contain melanopsin. The ipRGC information travels to the hypothalamus and activates chemicals involved in circadian rhythms and general health, and also to many other non-visual structures in the brain for non-image forming purposes [33,34].

At this time, five distinct subtypes of ipRGCs have been identified, labeled M1 to M5. Each type has a high sensitivity to blue light (i.e., short wavelengths). IpRGCs have been shown to affect circadian rhythms and melatonin levels, while contributing to a simple awareness of movement via a separate pathway from the rods and cones [35-37]. A function for subtype M3 has yet to be discovered.

While the ipRGCs in the peripheral retina are important, little is known about how eyeglasses affect their purpose. However, it is known that those cells are affected by both intrinsic and extrinsic signals (from rods and cones as well as from circadian functions) [38]. It has been hypothesized that the ipRGCs may be involved in heart rate regulation [39], and that they support spatial visual perception and luminance [40]. It is also believed that the ipRGCs influence an intrinsic retinal circadian clock to regulate retinal melatonin levels by both exogenous light stimulation and endogenous circadian stimulation) [41]. The effects that the ipRGC have on degenerative processes are studied in diseases such as glaucoma and diabetes [42].

3.5. Beyond the retina

In addition to peripheral and central retinal sensory inputs, proprioceptive input is incorporated into spatial judgments [43]. In fact, ocular proprioception is a major player in spatial localization and maintaining clear central eyesight [44,45], dovetailing with other research demonstrating that problems after brain injury can affect signaling in the peripheral retina. A recent study found evidence that retinal ganglion cells in the peripheral retina showed more activity in people with attention deficit disorder, as compared to a normal control group [46].

Both the visual and circadian systems in the retina have well documented connections between vestibular and proprioceptive systems, with a feedback mechanism in addition to the current feed-forwarded information. The visual cortex, rather than simply receiving sensory information from external eyesight, also receives information from thought processes and transfers some signals back (through retinopetal fibers) to either inhibit or excite retinal photoreceptors. These thought processes, include information on space and time from other sensory inputs as well as anticipatory functions, thus, the eye aiming system is guided by both internal and external information involved in spatial navigation.

It suffices to say that a significant amount of chemical signaling occurs at the retinal level before signals exit the optic nerve to be processed further. That signaling combines inputs from the external environment with signals from internal systems. For instance, if a sudden sound is heard, there are reflexes that rotate the neck and eyes to point at the sound source. However, people can become habituated to a sound so that they inhibit those reflex movements. There are also sounds that conjure up thoughts and images in the mind, allowing for individuals to select whether or not they will point their eyes toward or away from the sound. People differ in how they react to the same incoming stimulus. After brain injury, sensory stimuli can be overwhelming, and patients often suppress awareness of external surroundings by inhibitory processing in the peripheral retina. This suppression occurs beneath the conscious level of awareness.

4. Visual and auditory integration

While the eye interacts with multiple internal systems, one of the best-known relationships between seeing and hearing can be demonstrated by the "ventriloquist effect". When an observer's eyes perceive a dummy's mouth rather than the puppeteer's mouth moving, the observer's brain assumes that the voice heard is actually emanating from the dummy's mouth.

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Many studies have shown how when faced with a sensory mismatch, the visual system dominates [47]. More recent studies demonstrate that the auditory system can be used to modulate visual attention [48, 49].

A person who is able to pass a vision and hearing screening may not necessarily process visual and auditory signals together in order to effortlessly watch and listen. The blending of those two sensory processing systems is advantageous in such life skills as reading and social interactions. Brain injury often disrupts the developed linkage. Diseases also affect sensory linkages. For instance, auditory and visual circuitries are disrupted in early stages of schizophrenia [50, 51]. Functional differences in connectivity between auditory and visual pathways are quantifiable in early Parkinson's disease – first as different patterns of firing within the same circuitry, later with asymmetries present [52].

Integration between auditory and visual systems has been studied for decades. In 1976, the McGurk Phenomenon [53] showed when auditory and visual signals were mismatched, the brain makes a correction so that the sounds/sights make sense. Later, it was found that children with learning problems weren't using those two sensory systems in the same way as children without a learning disability [54]. It was determined that attentional circuitry modulates audiovisual integration of speech, and synchronization of visual and auditory information is combined to assess spatial awareness in babies [55]. Without the synchronization of visual and auditory signals, attention, behavior and concentration suffer, affecting academic, social and athletic achievement. Stability of brain circuitry between auditory and visual systems is important, as is proprioceptive input [56].

Researchers such as Charles Spence [57] in Oxford, England and David Alais [58] in Australia have laboratories investigating visual and auditory perception, including interactions between the two sensory systems during resolution of sensory mismatches. They also work with internal visualization predicted by auditory cues. For instance, if a person has a roommate, and hears a noise in their home, they will visualize the roommate moving around. However, if they live alone and hear the same noise, they might visualize a thief. The former will not elicit the same stress chemicals that the latter scenario will generate. The incoming auditory signal (the noise) is identical, yet body responses and internal visualization are totally different. New research is finding that the visual cortex is involved in a feedback mechanism for higher cortical functions, such as prediction, attention and imagination. This concept of the visual cortex being not only part of a feedforward system of visual signals from the retina, but also being used during feedback circuitry in higher level processes is relatively new [59,60].

Retinal stimulation affects both chemical and neurological signaling pathways, inducing subsequent behavioral responses. In patients with delicately balanced nervous systems, who are genetically predisposed to certain environmental induced diseases, sensory mismatches can create additional stress. Consider the frustration and additional attention required to watch a badly dubbed movie or to speak with someone on a phone or video chat containing a slowed signal. Retinal stimulation to correct these mismatches may lessen overall stress, potentially making the body more resistant to disease. By implication, an integrated measurement of visual and auditory signals is more effective in diagnosis and treatment than isolated testing of visual and auditory ability alone.

5. Using retinal processing in diagnosis and treatment of brain injury

5.1. Diagnosis of dysfunctions after brain injury

The peripheral retina is activated or inhibited by shifts in internal biochemistry. Research has shown linkages between retinal stimulation and such diagnoses as attention deficit disorder, anxiety, depression, obsessive compulsive disorders, sleep disorders and addictions.

Eyeglasses typically are thought of as bending light to strike the macula, producing clear eyesight. But, ambient light may be selectively harnessed to affect chemical signaling pathways in subcortical non-image forming systems, as well as in classic cortical visual processing systems. Tints can affect visual fatigue [61], and eyeglasses can be designed to disperse light differently on individual areas of the retina affecting the central and autonomic nervous systems, because the eye is connected to both. Measurements of retinal stress tolerated before inducing double vision and blurry eyesight is important in the determination of individualized eyeglasses. On the way to the visual cortex, signals from the retinal ganglion cells travel though specific, mapped areas of the brain. Therefore, light can be intentionally directed toward or away from a damaged cortical area. This concept has been successful in helping impaired spatial navigation skills in patients with brain injury and other conditions.

During standard eye testing with the traditional “which is better, one or two?” method, some patients do not consciously perceive differences between visual targets. In those cases, the eye care professional makes a choice, based on many factors. Most patients simply adapt to whichever lens choice is chosen. However, patients with a fragile interaction between sensory systems will demonstrate more visual/auditory stability with one lens choice than the other. In other words, one of the lens choices might distort auditory localization; the other might enhance it. A minor amount of light striking the retina through a closed eyelid is enough to alter auditory localization. Thus, certain lenses provide integrated sensory information and require less overall energy for processing incoming signals. Those hypersensitive patients would benefit from more in depth testing of brain circuitry via retinal sensitivity. Various tests, such as the Yoked Prism Walk Test, Super Fixation Disparity Test©, the Padula Visual Midline Shift Test, the Van Orden Star Test and Z-Bell© Test are simple ways to assess sensory linkages [62]. By using various eyeglasses and contact lenses to effect auditory localization with retinal circuitry as a way to access brain function, even many non-verbal patients can be accurately measured.

Below are a few of the many ways eyeglasses have been used in ways other than for eyesight to provide improved function in traumatic brain injury patients. The retinal interactions with spatial navigation, posture and limbic system activity have sound neuroscience behind them. For instance, substantial research agrees that light striking the retina stimulates dopamine release, and that darkness stimulates melatonin production. Other research shows that too little dopamine in the mesocortical systems is found in patients with schizophrenia, and too much dopamine is found in mesolimbic systems of patients with hallucinations. It isn’t out of the realm of possibility that eyeglasses changing retinal chemistry can alter body chemistry and affect imbalanced systems for the better. Obviously, more research is necessary in order

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to make any conclusive statements. Yet, patients with brain injury who aren't responding to medication might use this non-invasive method of neuromodulation.

- **Post Concussive Syndrome (PSC) vs. Post Traumatic Stress Disorder (PTSD)**

Post Concussive Syndrome (PCS) and Post Traumatic Stress Disorder (PTSD) are two common occurrences after brain injury. Some patients have both. Their symptoms are similar, but treatment differs. Currently they can be differentiated by fMRI techniques.

Anecdotally, when accounting for shifts in proprioceptive inputs, auditory/visual integration testing has shown that spatial perception in patients with PTSD tends to be symmetrically changed. In PSC, spatial perception has been found to be asymmetric. When a patient has both PSC and PTSD, the perception seems to be both constricted and asymmetric, with proprioceptor involvement showing a different effect than in those patients with PSC alone. Quantifying the interaction between external sensory inputs and internal processing has accurately differentiated between conditions such as post concussive syndrome and post traumatic stress disorder in patients.

- **Vertical Heterophoria**

After traumatic brain injury, patients often see double, or have a slight vertical imbalance between their eyes which creates a discomfort, but not a blur or complete doubling. Sometimes a slight angling of light to balance the two eyes has a far-reaching effect. In 2010, a retrospective study showed that of 83 brain injury patients with post concussive symptoms remaining after standard treatment, 77 of them had vertical heterophoria. When treated, there was a 71% decrease in their symptoms [63].

- **Positional Orthostatic Tachycardia Syndrome (POTS)**

Positional Orthostatic Tachycardia Syndrome (POTS) is a condition where the autonomic nervous system's regulation of cerebral blood flow is dysfunctional, and blood vessels constrict rather than expand when more blood plasma volume is required. This deficiency in cerebrovascular autoregulation is often exacerbated when shifting from a seated to a standing position. A person should be able to maintain normal cerebral blood flow in spite of changing blood pressure, but patients with subtypes of POTS can not autoregulate [64].

Patients who had symptoms of syncope due to autonomic dysregulation were treated by the use of therapeutic eyeglasses. One pair of lenses angled light, affecting expended effort on eye muscle control; the other pair was tinted to filter the incoming light's wavelength. When wearing the lenses, both patients reported cessation of fainting and easier adaptation to sudden posture shifts. The proposed mechanism was the intentional change in dispersion of light on the peripheral retina affecting the exiting signals from the optic nerve. The light was designed to balance the imbalances.

Results suggest the possibility that patients with POTS might have narrow ranges of tolerance to environmental changes. Especially in those patients where medication hasn't been successful, using retinal tolerance tests to design eyeglasses might be beneficial. The ability to expand the patient adaptability to shifts in autonomic nervous system responses could affect syncope and quality of life.

- **Seizures and Post-traumatic Epilepsy**

Many patients experience seizures after brain injury, and a small percentage of brain-injured patients develop epilepsy. The proposed mechanism to help those patients is to divert light onto retinal regions where signals travel through undamaged cortical areas.

Some patients who had frequent seizures were able to match auditory and visual perception of space when a tint or a filter was incorporated into eyeglasses. Several patients have been documented to have lessening of frequency and duration of seizures after being prescribed customized eyeglasses designed for the non-image forming retinal pathways. Further studies need to be developed on a broader scale, but this may be a method to employ when seizure medications are not working sufficiently, or if a patient is pregnant and can't tolerate medications.

- **Auditory and Visual Hallucinations**

After trauma or some medications, patients occasionally experience hallucinations. Research shows that those patients have too much dopamine in the meso-limbic systems. Since light stimulation affects retinal dopamine levels and brain signaling, it is possible that signalling can be modified to address the over activity. Patients with schizophrenia have been documented to have disconnects between auditory and visual signalling systems.

A few patients reported the disappearance of voices in their heads after using eyeglasses customized for balancing the auditory/visual spatial judgments. Perhaps the unknown function of the retinal subtype M3 ipRGC will be discovered to be linked with the auditory localization system.

- **Depression**

Brain injury often results in patients with depression who are less aware of their surroundings than non-depressed patients. Deep brain stimulation to the nucleus accumbens has been noted to help symptoms of depression. The nucleus accumbens interacts with auditory cortices [65] and is indirectly connected to retinal processing through the habenula, which modulates dopamine neurons projecting to it [66].

Many patients who have been clinically diagnosed with depression have been helped by the usage of eyeglasses designed to synchronize their visual and auditory perception of space. Anecdotally, there were two whose EEG findings instantly changed when comparing with and without therapeutic eyeglasses.

- **Anxiety**

Anxiety disorders have been shown to have imbalanced chemical production in the cortex and midbrain. Changing retinal stimulation has an effect on dopamine, serotonin and GABA levels [67]. Many patients who exhibit anxiety have been helped by the use of eyeglasses designed for peripheral retinal calming, rather than for eyesight.

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To reiterate, the above usages of eyeglasses appears to have helped many patients in their daily lives after brain injury. The rationale reverts back to the concept of the retina being a modulator between cellular microenvironments and surrounding external sensory environments. Light selectively activates specific retinal regions, sending signals through many feedback and feed-forward circuits in both subcortical and cortical structures. Predictable retinal mapping can shift signaling pathways into an individual's range of tolerance, enabling each patient to have an improved functional outcome. The concept is relatively new, but is non-invasive, and has been successful in many patients with sequellae from brain injuries.

5.2. Treatment – Neuro-optometric rehabilitation

There are several types of eye care providers. Neuro-ophthalmologists identify and treat physical and physiological conditions that manifest in visual impairments, whereas optometrists whose work specifically emphasizes neuro-optometric rehabilitation, use visual pathways to affect changes in physical and physiological functions. Testing can be similar, but the analysis and treatment goals are different. Neuro-optometric rehabilitation uses alterations of light to influence and enhance a person's physical and mental reactions and responses to changes in his environment, enhancing rehabilitative outcomes as an adjunct form of treatment after brain injury. The infinite combinations of internal biochemistry and environmental experiences unique to each person allows for the unconventional usage of eyeglasses on people, even if they have 20/20 eyesight without glasses. Patients with brain injury often fall into a category of not having an eyesight problem, yet still having imbalances in their mind-eye connections.

Neuro-optometric rehabilitation deals with perception and action by measuring a person's awareness of, and responses to, his perceived environment. During an optometric evaluation, this relationship between the "actual" and "perceived" environments is analyzed as well as its effect on the person's internal environment and body posture. By controlling the input of light, and measuring and recording the patient's reaction to new environmental stimuli, optometrists can determine how well the person's visual processing systems are functioning. Measuring the perceived distortion and altering retinal input to change habitual perception, affects comfort, concentration and performance of daily tasks.

Many body functions are directly or indirectly influenced by visual processing at or beneath a conscious level. Signaling is a two-way street – retinal stimulation can influence other systems within the body, and other systems can influence retinal metabolism. Alteration of light on the retina (by varying such factors as the intensity, frequency or direction) changes brain activity. Currently, during standard eye testing, imbalances between right and left and central and peripheral are evaluated, but not necessarily internal vs. external systems or visual vs. auditory systems. Attention can be on internal thoughts or external selected targets. However, if there is a disruption in circuitry, or sensors are stimulated past their range of comfort or tolerance, attention is diverted. People comprehend that glasses might give them a headache or make them nauseous, but the concept of eyeglass prescriptions as a way to alter internal systems beneath conscious awareness has not yet been explored at length. Nevertheless, eye care providers are in a unique position to assess more than simply eyesight and eye health.

SOME COMMON NEURO-OPTOMETRIC INTERVENTIONS

- Angling light toward one edge of the retina. This initially affects the body's positional sense, because reflexive eye movements will point toward the incoming light, triggering internal postural mechanisms in the hips for stability of balance, to counteract the eye movement. Depending on the stability of the person's sense of balance, attention may be shifted off of the body and onto external targets.

- Angling light toward either nasal or temporal retinal sensors. The eyes will also reflexively point toward the light, but this inward and outward movement stimulates different visual and postural mechanisms (shoulders rather than hips), shifting apparent object location.

- Dispersing light toward the edges or the center of the retina tends to make objects appear larger or smaller, by emphasizing or muting the background. This change in light mainly alters the balance between central and peripheral circuitry by having the target and background occupy different percentages of the retinal input.

- Altering either spatial or temporal retinal input with filters affects internal processing and external perception. Tints filter out selected wavelengths of light, stimulating specific retinal cells which alter retinal chemistry (and thus body chemistry), via the autonomic nervous system. Graded occlusion filters alter the spatial components of incoming light.

- Inducing a sensory mismatch between central (target) and peripheral (background) can be accomplished with mirrors. These are used in many aspects of rehabilitation, such as patients with strokes or visual field defects.

Figure 3. Various visual interventions can be used to stimulate the retina through different pathways. ©2010 Mind-Eye Connection Reprinted with permission

6. Conclusion

Traditional eyesight testing is not yet assessing many of the multiple interactions between the peripheral retina and brain function beneath a conscious level of processing. 20/20 eye testing relies on conscious attention to a selected target. As technology advances, by using integrated visual and auditory information, testing eyes and visual pathways might include assessments of such systems as internal visualization, judgments in space and time, balances between dopamine and serotonin pathways, etc. Recent developments supporting this perspective of linking sensory and motor systems as well as internal and external visual systems include three-dimensional movies and Google Glasses, which are designed to verbally access a virtual visual projection. In fact, Google Glasses will soon be in the public domain. Also, the U.S. Food and Drug Administration has recently approved the Vimetrics Central Vision Analyzer (CVA) which tests acuity with contrast and lighting changes rather than the classic black letters on a high contrast white background.

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After brain injury, often a person's external environment might remain the same, but the internal perception and interpretation of it differs. By introducing the possibility that the mind-eye connection – how a person's thoughts, movements and behavior are affected by what is in their mind's eye – is unique to each person's processing system and experiences, rehabilitation can utilize this concept of "mind-eye testing" vs. "eye testing" to prescribe eyeglasses on a more individual basis. Eventually, eye testing will be routinely inclusive of other sensory signals, including the linkage between auditory and visual systems. Perhaps the unknown function of the retinal subtype M3 ipRGC will be discovered to be linked with the auditory localization system. Ground-breaking research strongly suggests that the integration of visual and auditory signals in people with an autistic spectrum disorder appears to originate from a timing deficiency, affecting their language and communication [68]. Auditory processing has been shown to be altered by visual deprivation in adult mice, offering validity to new multi-modal rehabilitation methods such as selective retinal stimulation [69].

As always, new concepts require time to travel from bench to bedside, but research continues to demonstrate that the visual system provides much more than simply sending light into the brain to interpret images from external surroundings. New retinal circuitries and feedback pathways are continually being discovered. Retinal stimulation can have significant impacts on physiological systems; however, future research is needed to design specific protocols for this innovative method before these general concepts become more commonplace. Board certification in neuro-optometric rehabilitation has begun, but it will take another generation for the general population to realize the impact eyeglasses have on internal systems in the body, even in patients who measure 20/20 central eyesight.

The brain injured population is a wonderful start for the beginning of this change in diagnostic procedures. Assessment of patient adaptation to environmental changes via retinal stimulation and integration of visual and non-visual pathways will affect future eyeglass prescriptions. These in turn should allow patients to adapt to environmental changes more easily. Neuro-Optometry is complementary with the new field of neurophotonics bridging neuroscience research with optical physics. The impact on processing pathways can be quantified, and measurements can be used to assess and modify internal tolerance to external changes. Diagnostic methods already in use point to a relationship between the eye and internal systems. It follows that testing the relationship between internal and external systems should gain a pivotal role in rehabilitation.

Visual contributions to a vulnerable nervous system should not be ignored. This paper presented findings derived from the author's experience in using retinal stimulation to alleviate patient symptoms, including those caused by brain injuries. While these methods have not yet been rigorously tested in formal clinical studies, the results have been effective enough to allow the author to build a thriving practice that draws patients from all over the United States and many foreign countries. Given this experience and clinical success, which has been replicated by optometrists Benoit Lombaerts in Belgium, Vasillis Kokotos in Greece, Juergen Eichinger in Germany and Stefan Collier in Switzerland, the author believes that retinal stimulation has great potential for becoming a low-cost, low-risk, and effective therapy for a wide range of neurological and biological disorders. Neuro-optometric treatment can provide substantial benefit to patient rehabilitation after brain injury, with minimal additional time expended by the eye care provider.

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