The effect of head trauma on the visual system: The doctor of optometry as a member of the rehabilitation team

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ABSTRACT: Brain injury results from either head trauma or strokes and causes many visual and visually related disturbances. Rehabilitation is aimed at developing skills that allow the patient to optimally function as a viable and independent member of society. Often the resultant visual deficits remain undiagnosed and untreated, which hinder the patient's total rehabilitation. Optometric evaluation of brain injured patients should routinely be performed as part of the transdisciplinary team approach to rehabilitation. Optometrists are uniquely qualified to diagnose and treat visual and functional deficits of the visual system in the brain injured population. The purpose of this paper is to present a rationale for optometric participation in the rehabilitation of head trauma and stroke patients.

KEY WORDS: Head trauma, visual information processing, functional visual skills, visualization, visual perception, stroke, optometric visual therapy, visual training

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*E*very year approximately 900,000 people are hospitalized for consequences that are secondary to closed head trauma, namely, stroke and accidents involving injury to the skull.[1,2,3] Modern medicine has advanced remarkably in its ability to perform heroic measures that enable the majority of these patients to survive and enter the rehabilitative arena. Recent statistics reveal that approximately 75 percent of patients who survive head trauma and strokes need some form of rehabilitation,[4] with one main goal: to help these patients become more independent and even re-enter their former occupation or be trained for a new one.[5]

The anatomy and physiology of the skull, the vascular network of the brain, as well as the dynamics of head trauma, all contribute significantly to the effects of insult to the visual system. These affect the patient's neurological integrity and his/her ability to process visually related or visually guided information.[6] This is explored in more depth in another article in this *Journal* issue.[a] The symptoms and performance deficits secondary to brain injury are disturbing; they significantly impact the patient's rehabilitative progress.[7,8,9] The most common problems associated with head trauma include: binocular dysfunctions, (convergence insufficiency, acquired strabismus, diplopia), blurred vision, ocular motility deficits, visual field loss and visual perceptual-motor dysfunctions.[9,10,11,16]

A significant amount of our daily functioning requires effective and optimal visual processing and visuo-motor performance. This is especially true for patients with motor handicaps, who are limited in their ability to perform extensive movement. They often enter an occupation or avocation that demands accurate nearpoint visual performance. Occupational therapy and cognitive retraining are extremely dependent on visual recognition and processing. Finally, our society, as well as rehabilitation programs, are using computers extensively; computer usage requires appropriate visual skills for optimal performance.[12,13,b]

Optometrists are uniquely qualified to be members of the rehabilitation team treating patients who have had brain injuries. Optometrists can co-manage the overall rehabilitation of the neurologically compromised patient by minimizing any deficits of the visual system and providing consultation and guidance to the other members of the rehabilitative team.

Overview of the mechanism of head trauma

Open head trauma is defined as a direct invasion through the skull. **Closed head trauma** occurs from a blow to the head that does not cause a direct pathway from outside through the soft tissues to the brain, and also includes cerebral vascular accidents (CVA).[14] For the purpose of this article, our discussion will be limited to the patient who had a closed head trauma accident.

The major forces by which head trauma can cause brain injury include indirect compression of brain tissue, tension on and/or tearing of brain tissues from any movement of the brain within the skull, as well as by shearing or sliding of tissues over tissues and then their subsequent contact with the cranium.[3,10,15]

The type of injury causing the head trauma will generally dictate the nature of the insult to the brain. *Acceleration* injuries occur when the head is relatively motionless and is struck by a more rapidly moving object, usually resulting in a "coup" lesion. The major damage from a coup lesion occurs at the site of the impact. *Deceleration* injuries occur when the head itself is moving rapidly and is slowed down by another force, such as a seat belt, causing the brain to bounce back and forth within the skull, usually resulting in "countre-coup" injury to the brain tissue. A countre-coupe lesion generally causes injury at the impact site as well as directly opposite to the point of impact.[3,10] This information is important for the optometrist to understand; if a patient sustains injury that causes a "countre-coup" effect, then the optometrist must be aware of the fact that visual processing functions associated with brain sites opposite to area impact may be impaired and should be investigated. An example of this is a patient who may have injured his/her left temporal lobe, and experiences deficits associated with the right hemisphere.

Accidents resulting in closed head trauma commonly affect the cranial nerves and can cause visual field defects. The most common visual field defect is a homonymous hemianopia, and the most common cranial nerve insults are to the IIIN, IVN and VIN. Esotropia, hypertropia and exotropia are frequently seen.[9,10,16] Since amblyopia and anomalous retinal correspondence cannot develop in an adult, diplopia and confusion secondary to the binocular breakdown always occur.

Another common but not well documented or understood deficit is the inability of the patient to initiate or sustain an efficient accommodative response.[9] This deficit does not seem to be more common in any specific age group and is most often managed with ophthalmic lenses. It is not uncommon for children or adults under the age of 35–40 to need a nearpoint prescription of plus power, which is normally reserved for patients over 60 years of age.

Any injury to the brain, especially to the right hemisphere, can cause significant deficits in the processing of visual information as well as on performance of tasks requiring the integration of visual information with the other sensory systems.[17,18,19] This will be explained in more depth later in this article.

Optometric participation

Optometrists historically have treated functional and visual perceptual problems in children and adults. Due to their education and background, optometrists also have a significant role to play in the rehabilitation of head trauma patients who exhibit these problems.[7,8,9,11]

An understanding of how the areas of the brain influence function will provide the optometrist with a basis to begin to understand the relationship between how the symptoms and/or performance deficits affect the head injured patient. The processing of visual information is a complex act and is usually categorized by psychologists, neuropsychologists, occupational therapists, optometrists and other behaviorally oriented professionals into functional and behavioral components.[9,20,21]

The functional optometric examination expands upon the primary care exam by focusing in more depth on the areas that can affect performance and especially on one's ability to sustain near centered task demands. The ocular motor system is not only evaluated for comitancy and the extent of range of motion, but also for the quality and accuracy of ocular motor control. The convergence and accommodative systems are evaluated both independently and together for facility of response, as well as the ability for the system to sustain clear, comfortable, single vision for a period of time. Visuo-motor integration is probed in order to determine the ability of the patient to integrate the ocular motor and grapho-motor systems in a coordinated act.[22,c]

The behavioral optometric examination evaluates the full range of visual performance, from the hardware (eye structure and function) to the software, (perception and visual information processing). Visual perceptual processing refers to the entire process by which we receive visual information, integrate it, perform an action and adjust behavior accordingly. A behavioral examination includes tests that probe visual closure, form constancy, spatial relationships, visual memory and visual sequential memory. It is beyond the scope of this article to define each of these perceptual skills. Readers are referred to standard text on this subject. A description of specific tests is discussed in other articles in this *Journal* issue.[c,d]

Brain injury may profoundly affect one's ability to perform everyday functions ranging from simple tasks such as identifying common household objects and responding appropriately, to more complex tasks that require the integration of skills such as vision and motor for walking, writing or reading.

It is well documented that the right and left cerebral hemispheres contribute differently to the total act of perception. The right hemisphere is a global, spatial, simultaneous processor whereas the left hemisphere is a local, successive, temporal processor. The right hemisphere receives sensory input from the left side of the body and subsequently controls the motor movement of the left side of the body while the left hemisphere receives sensory input from and controls motor movement of the right side. In general terms, the left hemisphere is specialized for the understanding and production of language while the right hemisphere is specialized for the analysis of spatial information and the processing of visual information.

Typically, patients who sustain injury to the left hemisphere commonly exhibit aphasia type dysfunctions (speech and language difficulties) and loss of control or weakness to the right side of the body.[23,25,26] Patients with injury to the right hemisphere will exhibit visual attention problems, as well as difficulty with spatial orientation, visual closure (recognizing faces), and with figure-ground analysis. They usually present with motor weakness or loss of function of the left side of the body.[20,23,27,28]

Association areas

Understanding the function of the brain is extremely complex, however, scientists have been able to categorize special areas of the brain that are responsible for both the integration and the association of particular behaviors. The following overviews each area and its specific function:

Frontal lobe

Generally the frontal lobe is involved with motor control, and the execution of complex integrated motor acts (Motor Planning).[23,29] The concept of *Motor Planning* is an important concept needed for an understanding of how we efficiently process visual information. Kornhuber demonstrated in 1976 that prior to executing movement, a considerable degree of brain processing has already taken place. This is a form of "readiness potential". During this time, it is postulated that the brain is formulating and starting to carry out a "motor program."[24] Cool points out that the cells in our sensory cortex are encoded or programmed through early sensory and motor experience.[30] Motor Planning yields a more efficient movement which is then integrated with the environment.

There is evidence that the pre-motor areas of the frontal lobes are concerned with pre-conditioned learned actions.[29] Lesions in the pre-motor area result in an impairment in the learning of conditioned tasks that require the production of different movements in response to visual, tactile or auditory stimuli. However, these lesions do not affect tasks requiring responses to spatial location.[31] In other words, the pre-motor cortex plays an important role in the learning of directing movement which is in response to sensory stimuli from different modalities based on past learned experience.[32] This is most likely a contribution to Motor Planning. The frontal lobes also are important in associating and integrating voluntary movement of the skeletal muscles of the opposite side of the body, voluntary eye movements and for abstract thinking, foresight, mature judgment, and tactfulness.

Temporal lobe

The temporal lobes combine sensory information associated with recognition and identification of objects such as people, places and objects.[33] The posterior parietal cortex and inferior temporal cortex appear to be involved with integrating information about "object identification" and "object localization" and both contribute to the input to the frontal lobe for a "motor planned" response.[33] The temporal lobe also receives auditory stimuli from ears and is the association center for the integration of information for the production of meaningful language response. Areas of the temporal lobe are also important for overall memory function.

Parietal lobe

The parietal lobes are important for the integration, association and analysis of various types of sensory information. The posterior parietal lobe is involved with the integration of information about "object localization" in space and the relationship of objects to each other and contribute input to the frontal lobe for Motor Planning.[33] Damage to the right parietal lobe will affect the analysis of figure/ground and would disturb the motor control needed for drawing or other constructive abilities. An example would be drawings that are distorted and lack spatial organization due to inadequate sensory-spatial representation from the parietal lobe. This deprives the frontal motor system of the necessary information to carry out appropriate movements.[34] Damage to the left parietal lobe will also affect expression of ideas through language.[33]

Occipital lobe

The occipital lobes are the visual sensory and visual association areas of the brain. Lesions in these areas can cause hemianopsias with macular sparing as well as other significant visual field losses. Because of the importance of the occipital lobe as a primary visual association area and its relationship with the temporal and parietal lobes, damage to this area can cause deficits in the formulation of visual stimuli and the comprehension of their meaning.[35]

Other visual changes associated with head trauma

Figure 1[9] lists the common visual changes associated with closed head trauma. The optometrist should relate these to the symptoms presented during the case history with a problem oriented clinical approach in order to make a complete diagnosis and develop an effective management plan.

Overview of the models of information processing

Optometrists who deal with patients who present with dysfunctions of the visual system may use a model to diagnose and manage these problems that is similar to the model used by many occupational therapists and neuro-psychologists. The primary care optometrist should become familiar with these models when examining a head trauma patient. Reitan and Wolfson developed a conceptual framework that was expanded by Bennet, for viewing the behavioral correlates for brain function (Fig. 2).[36] The first level of information processing is the input of information from the external environment to the brain via the sensory system. This input must be recognized and assimilated once the information reaches the brain in order for information processing to occur. Reitan and Wolfson refer to this as the "registration phase". After this initial recognition of incoming information, the brain usually proceeds to process verbal information in the left cerebral hemisphere and visual-spatial information in the right hemisphere. In this model, the highest level of central processing known as "executive functioning," is represented by abstract thought, reasoning, concept formation and logical analysis. Performance, either overt or covert, on the task demand is represented by the output stage.

The similarity of the Wolfson-Reitan model and a model that many behavioral/function oriented optometrists use is represented by Figures 2 and 3. Both models are an attempt to operationalize the processes based on neuro-psychological mechanisms derived from the generally accepted facts concerning lateralization, localization and functional circuits, which were previously described in this article.

Input begins the process of vision. The accuracy and efficiency of this process as it relates to visual processing is affected by the integrity of the optical system (eye health and a clear optical image), efficient functioning of the accommodative and convergence systems, adequate fusional ability as well as accurate and efficient ocular motor functioning.

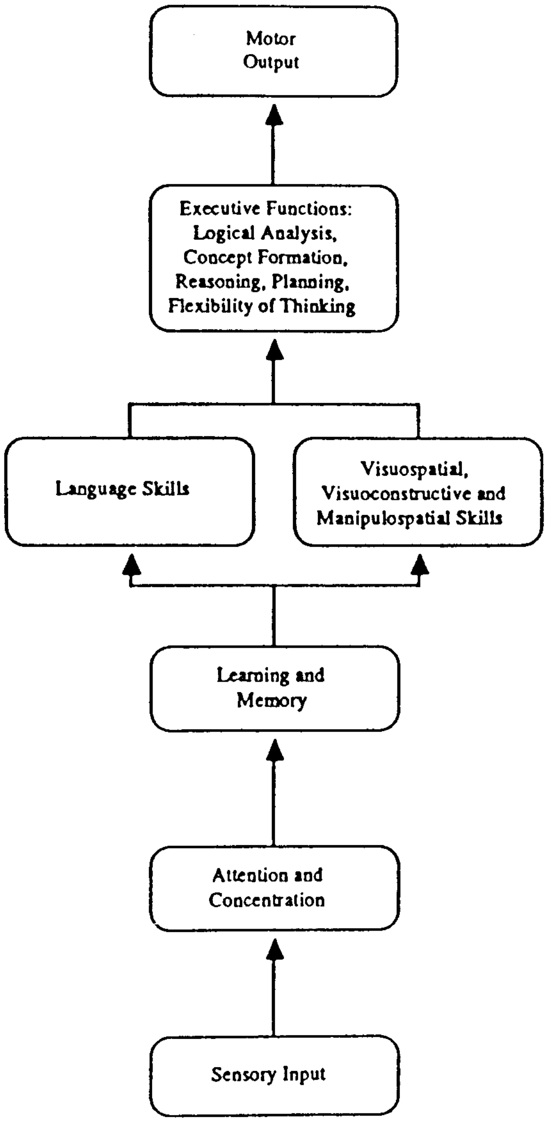
The integrative stage is analogous to the "registration" concept of Wolfson and Reitan and is often defined as visual perception. Visual perception is a complex process, commonly broken down into the following areas: form constancy, visual closure, figure-ground analysis visual sequencing, spatial relationships, visual memory, visual-auditory integration and visual-motor integration.

During this integrative stage, sensory and proprioceptive information are associated and blended. Together this combination produces a concept or plan that will then guide an action to respond. Wolfson and Reitan describe this as an executive function,[36] Barsch defines it as Motor Planning,[37] and Lyons and Lyons define this process as visualization.[38]

Visual Changes Associated with Closed Head Trauma

1. Visual field losses including
   a. total losses
   b. sector losses
   c. central losses
   d. peripheral losses
   e. congruous and incongruous, homonymous defects
   f. altitudinal losses
2. Diplopia due to the non-comitancy of the binocular alignment
3. Nystagmus
4. Lagophthalmus
5. Visual hallucinations
   a. formed variety (trees)
   b. unformed variety (stars, bolts)
6. Anisocoria
7. Frequent headaches
8. Loss of fixation
9. Convergence insufficiency
10. Accommodative problems
11. Reading difficulties (usually the earliest sign)
12. Visual perceptual losses including:
   a. disturbances in body images
   b. disturbances of spatial relationships
   c. Agnosia (difficulty in object recognition)
   d. Apraxia (difficulty in manipulation objects)
   e. Right-left discrimination problems
13. Memory losses

Figure 1: Vascular changes associated with closed head trauma



Reitan-Wolfson: Model of Information Processing

Figure 2: Reitan-Wolfson model of information processing

The output or performance stage is the final result of the integration and association of all input from many areas of the brain combined with the frontal lobe and simultaneously with the motor cortex, which directs the skeletal system. Thus, many visual skills that are categorized as "input affecting" also are involved in final "output" performance. Output performance is affected by the integration of the ocular motor response, the accommodative convergence relationship, fusional and accommodative facility, grapho-motor and eye-hand coordination (visuo-motor integration).

Neuroplasticity and its relationship to the functional visual model

There is significant research to support the effectiveness of optometric vision therapy in enhancing or de-

Model of Visual Processing

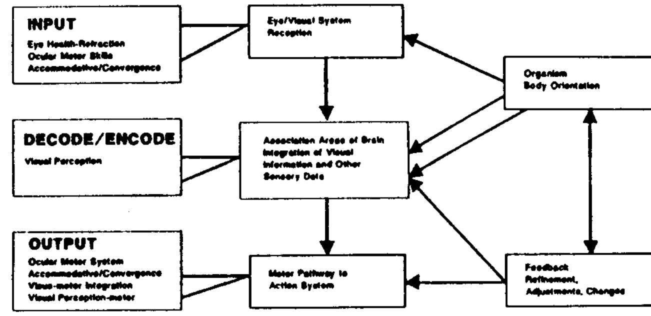


Figure 3: Model of visual information processing

veloping new association pathways for visual performance. In 1949, Hebb proposed a new concept of how the sensory and motor experiences one has early in life help "program" the basic elemental stimulus properties into the circuitry of the brain. He developed the concepts of "cellular programming" of synaptic connections with the brain. This "programming" requires related exposure to various stimulus elements in the environment. Hebb postulated that this "cellular programming" developed "cell assemblies," which represented small groups of cortical cells that become associated with each other through developmental time. Hebb further postulated the idea that the arrangement of the "cell assemblies" into a hierarchical sequence occurs through repeated stimulation and constant reinforcement. The "cell assemblies" begin to function together to form a neural representation of a more global stimulus condition. He called this a "phase sequence."[39,40] In 1981, Hubel and Wiesel won the Nobel Prize in Physiology and Medicine for their research on how the cells of the visual cortex respond to stimulation from the external world. Their hierarchical model of brain architecture points out that in the primary sensory cortex areas, the basic neurons are programmed through an interaction with the environment and that these unitary neurons are then combined in various association areas of the brain to form more meaningful and complex representations of the external world.[41]

Cool suggests that in concept, Hebb's model is exactly the hierarchical model of cortical processing that Hubel and Wiesel proposed and that has been replicated over and over again.[41]

Cool further presents:

> that in the past 8 years, there has been a growing body of literature demonstrating that it is possible to reawaken the suppressed coding possibility of an already programmed cortical cell and to re-program it in a different way. It appears that specific neurotransmitters, norepinepherine, can reawaken cortical cells and new programming can be achieved in the adult cortex. There are behavioral ways of achieving

this goal, through the neural circuits associated with motivation, attention and arousal.[41]

This research in "neuro-plasticity" has helped us to understand why optometric visual therapy has been effective as a treatment modality for visual dysfunctions secondary to brain injury.

The role of the optometrist as a member of the interdisciplinary team

The role of the optometrist as a member of the rehabilitative team is to aid the patient, advise other professionals about the patient's visual status and deficits and the impact that visual disorders may have on the total rehabilitative process. The optometrist will attempt to eliminate or minimize any visual dysfunctions, enhance visual skills, and diagnose and manage ocular disease.

Optometric treatment modalities incorporate the management of ocular disease either directly or by comanaging with other health care professionals, as well as the prescribing of selective occlusion, optometric visual therapy and the integration of optometric visual therapy with physical therapy, occupational therapy, and/or cognitive therapy.

Optometric visual therapy procedures create changes that the patient must respond to. With the appropriate use of lenses, prisms, filters, stereoscopes and other sophisticated equipment, input and output may be modified. The patient must integrate all sensory, proprioceptive and motor responses in order to try to achieve the goal of the visual therapy procedure. "Neurological learning" through "Motor Planning" is enhanced and reinforced through motivation, attention and arousal as the patient interacts with the environment. An example is when a stimulus is displaced with yoked prism (bilateral prism with the basis in the same direction), and the patient learns to respond to the change through a sensory motor interaction. This response has to occur as a result of an integration and association of pathways from the integration of occipital, parietal, temporal, frontal, pre-frontal and motor cortex. If other sensory input is added, such as a metronome, the association of right and left hemispheres become involved. The reader is referred to the article in this *Journal* issue that presents an in depth discussion of the treatment of binocular visual dysfunctions.[e]

Summary

The doctor of optometry can contribute significantly to the overall effectiveness of the rehabilitation process for patients with head trauma and other neurological deficits. He/she can evaluate the level of functioning of a patient's visual skills and assess the effect of these skills to the contribution of the rehabilitative process. In addition, he/she can incorporate effective treatment modalities into the interdisciplinary program.

Primary care optometrists play an important role in the overall management of a patient who has sustained trauma affecting the visual system. Their intervention includes the diagnosis and management of ocular disease, as well as the prescription of ophthalmic lens systems to minimize the effects of optical and binocular vision anomalies.

Optometric Vision Therapy for patients with head trauma is based on an accepted rationale shared by other behaviorally oriented professionals. Lenses, prisms and other treatment sequences are utilized as a therapeutic modality to create changes in the environment that require the integrative response of sensory motor systems. ■

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Footnotes

a. See Vogel article, pps. 537-41, this issue.
b. See Gutting article, pps. 595-8, this issue.
c. See Aksionoff article, pps. 554-8, this issue.
d. See Aksionoff article, pps. 564-8, this issue.
e. See Cohen article, pps. 569-75, this issue.

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