

Beethoven in the Vision Therapy Room

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Abstract

This paper provides a brief review of the anatomical and functional correlates of the brain. This review will prepare the reader for the rationale for including rhythm, timing, and music in the vision therapy room and to incorporate the multi-sensory model to enhance and accelerate the patient's outcome.

Key Words

acquired brain injury, brain anatomy, brain function, optometric vision therapy

It has been said that if you teach the brain to see, the eye will see. In my experience, I have found that if you teach the eye to see the brain will see. The area of evaluation and management of patients with acquired brain injury (ABI) has and will continue to grow in the future, yet there are so many unanswered questions. Do the primary senses of vision and audition interact or “cross-talk” in the human cerebral cortex? Can incorporation of optometric vision therapy (OVT) into the rehabilitation program enhance the outcome for patients with ABI or stroke? Can the addition of music during OVT enhance the patient's ability to control and integrate eye movements, eye-hand movements, and eye-hand-body movements?

This three-part series will provide the reader with a literature review and personal clinical perspectives on why the inclusion of music in the vision therapy program will assist the habilitation/rehabilitation for patients presenting with diagnoses ranging from traditional ocular-motor dysfunction to ABI. The first paper in this series will provide the reader with the anatomical correlates of the brain and how they interact with each other to provide actions and responses of the individual. The second paper will provide insight for the reader on the neurological processes of rhythm and timing and their effect on the ocular-motor system. The third paper will provide the reader with the rationale of including rhythm, timing, and music in the OVT program.

The Brain-Anatomy and Function Considerations

The human brain is divided into the central nervous system (CNS) and the peripheral nervous system (PNS). For this paper, we will concentrate only on the CNS (cerebral cortices, brain stem, and cerebellum). (Figure 1) A discussion of the spinal cord will be reserved for future papers. The brain can be divided further into six component parts. The cerebral lobes (right and left) (Figure 2), the diencephalon, the basal ganglia, the cerebellum, the brainstem, and the limbic system allow for the division of labor and parallel processing. This provides increased efficiency in performance, regardless of

sensory input and expected output. Each, without the other components, would be of little consequence.¹

Figures 2-6 will provide the functional correlates of the major structures of the cerebral cortex, brainstem and cerebellum.

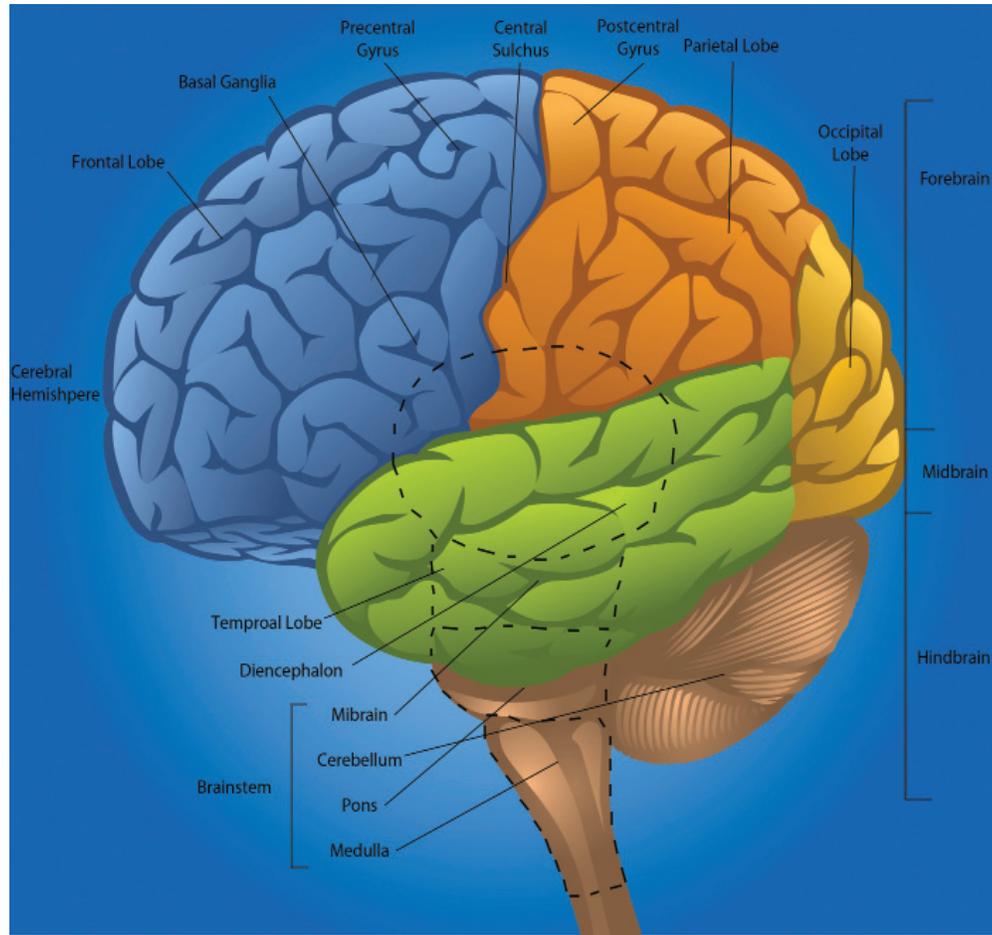
Hemispheric Specialization Right Cerebral Hemisphere-Sensory

Of specific interest are the cerebral lobes, the cerebellum, and the brain stem. The cerebral lobes of the right and left hemispheres have different areas of specialization. The right hemisphere is largely responsible for attentional awareness and the integration of spatial awareness and perceptual processing (received via the auditory and visual senses) to direct the human to act.¹⁻⁴ This action may involve attending to a new situation or to an unexpected or threatening stimulus such as a car approaching rapidly. It allows the individual to react immediately. The right hemisphere is more global in nature as it sees the entire “forest” rather than the individual “trees.” The right hemisphere then communicates with the left hemisphere to engage the individual to either “fight, fly, or freeze!” This phylogenetically older brain function may be a preserved function for survival.⁴ The right occipital cortex is responsible for the left visual field. The right hemisphere also processes information coming from the right and left visual hemispaces.^{2,5,6} This may be one reason why trauma to the right hemisphere may disrupt awareness of objects located on the left while damage to the left hemisphere does not seem to produce as much difficulty in the awareness of objects located on the right side of the individual.

Right Cerebral Hemisphere-Motor

The primary motor component of the right hemisphere is to control the skeletal muscles of the left side of the body (excluding the ocular muscles). Its primary auditory function is to interpret the nuances of language, also termed the prosody of language, while the primary visual function is to represent the left visual field. If the right hemisphere undergoes disruption due to cerebro-vascular accident (CVA) or ABI, the individual may display the phenomenon of “visual neglect”

Figure 1. Basic Anatomical Structures of the Brain



or visual inattention, to objects on the left side, making that individual less aware of the total visual environment.^{2,5,6}

Left Cerebral Hemisphere

The left hemispheric specialization for language is well-established as associated with the motor production of speech in the left pre-motor area of the frontal lobe (Broca's area) and the interpretation and expression of speech in Wernicke's area of the temporal lobe.^{2,5,6} The left hemisphere is also recognized as the "what" hemisphere and is vitally important for the individual to be able to maintain attention on task. The left hemisphere is responsible for motor movement of the right skeletal muscles and the right visual field.^{2,5}

Prefrontal Cortex

The prefrontal cortex (PFC), or 'lobe' called the Genius Engine⁷ by author Kathleen Stein, is the site where all memory and sensory impulses and planning are intertwined. It is where memory, action, planning, and reasoning are integrated. The PFC is the summit of the perception-action cycle as it integrates the input and output from the many brain levels, thereby producing responses to the environment. It receives, analyzes, and sends information back to the posterior cortices for action. It is not restricted to any sensory modality, such as vision, but serves to integrate the senses for outcomes of behaviors. (Figure 2)

The frontal eye field within the PFC and the V4 region of the visual cortex operate in synchrony via oscillations which

operate up to 60 Hz. These oscillations are associated with attention, learning, and consciousness. This neural synchrony, termed gamma oscillation, is not selective for the visual system alone, but serves as the mediator of distant brain regions and the PFC as it serves to provide top-down influences on other brain areas. Research has supported the concept that gamma oscillation of the neurons in the PFC fire in unison and send signals to not only to the visual cortex, but allow all the brain regions to communicate rapidly with each other.⁸⁻¹⁰ Additional studies corroborated these earlier research findings of multi-sensory integration for spatial attention between audition and vision as well as vision and touch.

To facilitate the understanding of integration between the cerebral cortices and the remaining brain structures, I would encourage the reader to refer to *NEUROSCIENCE for Rehabilitation Professionals: The Essential Neurologic Principles Underlying Rehabilitation Practice*.⁵

Geniculate Nuclei

Anatomical proximity of the visual and auditory pathways in the thalamus (lateral geniculate nucleus for visual processing and medial geniculate nucleus for auditory processing) and the midbrain relay centers (superior colliculus for vision and inferior colliculus for audition) may lead the observant reader to postulate that vision and audition may be inherently intertwined. Therefore, multisensory integration occurs throughout the brain to allow the organism to function in the

Figure 2. Cerebral lobes: The division of the cerebral lobes with their functional correlates.

Frontal Lobe

- Motor planning
- Control, execution, integration of complex motor acts
- Frontal Eye Fields
- Voluntary eye movement (along with areas in Parietal Lobe)
- Abstract thinking, judgment, foresight

Temporal Lobe

- Associated primarily with audition/auditory processing
- Inferior temporal cortex plays large role in global visual processing
- Combines sensory information associated with recognition and identification

Prefrontal Lobe

- Pre-conditioned "Learned" actions, regardless of sensory input modality
- Organizing and sequencing complex motor activity
- Seat of attention

Occipital Lobe

- Visual sensory and visual association areas
- Visual input- decode-code-output
- Areas V1 & V2 -Form and Patterns
- Area V2- Parastriate Area
- Participates in sensorimotor eye movement
- Possible origin of smooth pursuit of targets
- Areas V1, V2, and Middle Temporal Lobe (V5)
- Depth and Movement
- Area V3 – Peristriate area- Accounts for lateral expanse of occipital lobe
- Extends into the posterior and temporal lobes
- Area V4 – Color, depth perception, detection of movement

Parietal Lobe

- Superior portion is the orientation/association area
- Processes information about space, time, and the orientation of the body in space
- It determines where the body ends and the rest of the world begins
- Left parietal lobe – sensation of the physically limited body
- Right parietal lobe – sense of physical space in which body exists
- Assists in tactile recognition of objects
- Integration, association, and analysis of information regardless of input system
- Contributes to frontal lobe for motor planning
- Involved primarily in matching sensory input and motor output

most efficient manner possible. This may specifically be noted in the integration of vision, audition, and somatosensory system in the superior colliculus. The actions of the superior colliculi are not necessarily restricted just to the specific sensory input alone, but may also have varied responses as a result of the combination of senses providing the input (ie, vision and audition, vision and somatosensory system, audition and somatosensory system, or combination of all three).^{1,2,5,11,12}

Limbic System

The limbic system, oft forgotten in discussion of the cerebral cortex, is located deep within the cerebral lobes and is one of the phylogenically older structures, as is the cerebellum. It is responsible for our emotions and behaviors.^{2,3,5} The

Figure 3. Brainstem: Functional Correlates of the Brainstem.

Midbrain

- Midbrain—Automatic reflexive behaviors concerning vision and audition
- Superior Colliculus—relay centers for vision, communication with LGN
- Inferior Colliculus—relay center for audition, communication with MGN
- Allows information to be processed at UNCONSCIOUS LEVEL
- Together they are called the Tectum

Pons

- Relay system among cerebrum, cerebellum, and spinal cord
- Mediates motor information at UNCONSCIOUS level
- Cerebellar Peduncles
- Middle and Superior
- 4th Ventricle
- Corticospinal Tracts

Medulla

- Carries descending motor information from cerebrum to spinal cord
- Carries ascending sensory information from spinal cord to cerebrum
- Area where the motor fibers cross over to the contralateral cerebral side
- Contains the Basal Ganglia

cingulated and parahippocampal gyri, the amygdala, and the hippocampus comprise the limbic system. The hypothalamus of the autonomic nervous system along with the limbic structures and neocortex provides the emotional content of our existence. Without an emotional tag, memories often quickly fade and the motivation to perform a specific task may be absent.^{2,3,6}

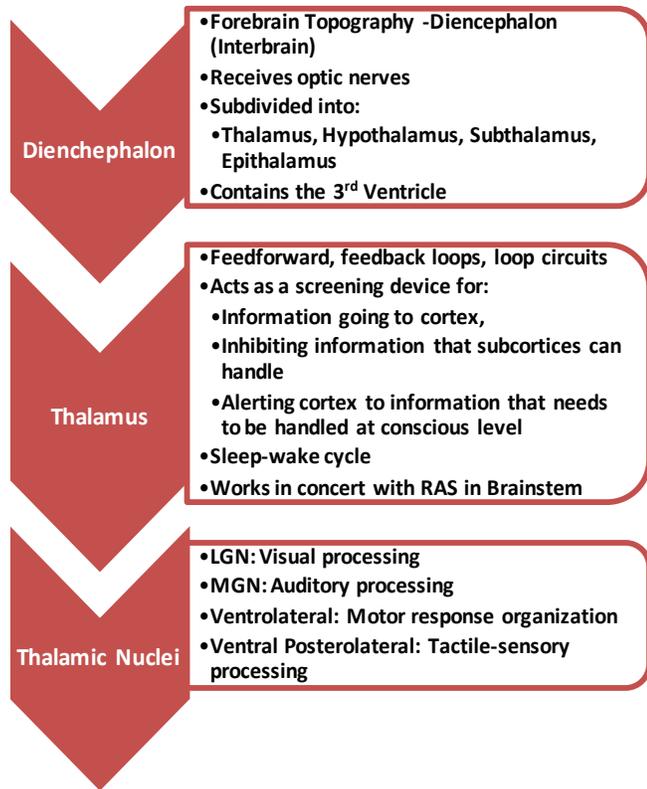
Brainstem

The brainstem is composed of the midbrain, pons, and the medulla. (Figure 3) Its primary functions include respiration, the cough, gag, and swallow reflexes, and the pupillary reflexes.^{1,2} The midbrain contains the superior and inferior colliculi controlling the automatic reflexive behaviors of vision and audition. The superior colliculus serves as the relay center for vision and communicates with the lateral geniculate nucleus (LGN). The inferior colliculus is the relay center for audition and communicates with the medial geniculate nucleus (MGN). The superior and inferior colliculi together are called the tectum, and allows information to be processed at the unconscious level.

Pons

The pons is the relay system among cerebrum, cerebellum, and spinal cord as it mediates the motor information at the UNCONSCIOUS level.^{1,2} It is composed of the cerebellar peduncles (superior, middle and inferior), the 4th ventricle, and the corticospinal tracts. The function of the middle cerebellar peduncle is to send sensory information about body position in space to the cerebellum while the inferior peduncle carries sensory information from the pons/medulla to the cerebellum. The superior peduncle also carries sensory information from the pons to the cerebellum, and acts as a conveyor of sen-

Figure 4. Diencephalon: Functional Correlates of the Diencephalon with Emphasis on the Thalamus.



sorimotor information from cerebellum to thalamus. The 4th ventricle conveys the descending motor tracts from the primary motor area (M1), the precentral gyrus. (Figure 3)

Medulla

The final component of the brainstem is the medulla.^{1,2} Its primary function is to carry descending motor information from cerebrum to spinal cord and ascending sensory information from spinal cord to cerebrum. It is the area where the motor fibers cross over to the contralateral cerebral side. The medulla also contains the reticular formation containing the reticular activating system (RAS) and the reticular inhibiting system (RIS). The RAS is responsible for states of wakefulness and alerting the cerebral cortex to important sensory stimuli. The RIS is responsible for states of unconsciousness including sleep, stupor, and coma. (Figure 4)

The last but not least important components of the medulla are the basal ganglia. They serve as the unconscious motor system operating on a subcortical level which specifically mediates automatic motor patterns such as walking, typing, and driving that are learned by the cortex. Once learned, these motor activities are stored subcortically and integrated by the basal ganglia. The basal ganglia work collaboratively with certain cognitive and affective processes that require **TIMING**. For this reason they may be involved in Attention Deficit Hyperactivity Disorder and are implicated in the movement disorders found in Parkinson's disease.^{2,5,6} Interestingly, it is the motor system that receives input from virtually all areas of the cerebral cortex, sending information to the pre-motor area and subsequently motor cortex. It also has a strong influence on the thalamus via its interconnections with the pallidum (the primary output nucleus of the basal ganglia).

Figure 5. Cerebellum: Functional Correlates of Cerebellum and Integration with Cerebral Hemispheres.

Cerebellum-General Function

- Regulates movement directly by adjusting outputs of motor systems of brain
- Posture adjustments to gravity, vestibular system-balance
- Serves as the somatosensory control (input from skin, muscles and joints) regarding body position and movement
- Monitors this information and establishes a way of formatting the information to the other sensory cortices for action
- Motoric Memory – Automaticity of Movement

Cerebellum-Interaction with Cortex

- Specifically this feed forward loop to the visual cortex provides stabilization of the peripheral retina for control of spatial environment and for fusion of the images from each eye
- Without this loop in the cortical system, detail would be seen without spatial representation, body awareness

Figure 6. Parietal lobe: Integration of Parietal Lobe with Other Cerebral Lobes.

Parietal Lobe-Visual Interaction

- Fibers from V1 , V2 fibers
- Information to the middle temporal lobe to the medial superior temporal lobe to the posterior parietal lobe.
- Interacts with the language centers in the left hemisphere, with spatial relationships, and other language skills from the right hemisphere
- Critical for interpretation of objects perceived – where visual perception and differences of shape, color, size take place
- Object, Color, and Depth Agnosias
- Posterior Parietal Lobe contributes to Egocentric Location

Cerebellum

The cerebellum, often called the “Little Brain,” has as its major function being proprioception (the unconscious awareness of the body's position in space).^{2,5} It analyzes and adjusts the body for precise movement and balance. It also sends information to the thalamus via the superior peduncles, which, in turn, send the motor information back down through the brainstem to spinal cord. The cerebellum regulates movement directly by adjusting outputs of motor systems of the brain, provides posture adjustments to gravity, and plays a role in the vestibular system for balance. It also serves as the somatosensory control (input from skin, joints, and muscles) regarding body position and movement, monitors this information and establishes a way of formatting the information to the other sensory cortices for action. It is responsible for the automaticity of movement via motoric memory, and is involved in attention shifting, spatial organization, and memory. The feed forward loop from the cerebellum to the visual cortex provides stabilization of the peripheral retina for control of spatial environment and for fusion of the images from each eye. Without this loop in the cortical system, detail would be seen without spatial representation and/or body

awareness. Ergo, the cerebellum rightfully should be called the “Little Brain.” Without it, ideation will occur without action! (Figure 5)

Discussion

Where does all of this lead us, the providers of vision care? Does our vision system act alone via the eye, optic nerve, optic tracts, and occipital lobe to allow us to “see?”¹³ Under what definitions of sight do we operate? Are you aware that “Once the retina is stimulated, activity occurs in over 30 brain regions outside the primary visual cortex to allow the person to respond to that stimulation...and that... the functional systems for perception, motor coordination, and movement interact during a simple behavioral act.”² I would like to offer one definition of the meaning of sight and encourage the reader to ponder a second definition. Sight, as defined in the *Dictionary of Visual Science*¹⁴ is “The special sense by which objects, their form, color, position, etc, in the external environment are perceived, the exciting stimulus being light from the objects striking the retina of the eye; the act, function, process, or power of seeing...” Whereas vision, as defined by the author is “the mental image produced via the primary sensory modality of sight which is then integrated with all other sensory processes--touch, audition, smell, taste; including both the emotional (limbic) and motor systems, to derive meaning and initiate action.”¹⁵ Integration IS the Big Picture! Not only can we modify the person’s response to that stimulus with lenses, prisms, and vision therapy, but through understanding the wonderful complexity of the brain, we can summon all the senses to maximize rehabilitative care. Music, rhythm, timing, and memory activities are incorporated in the OVT program to enhance the final integration of the senses for the patients we see.

Returning to the question posed at the beginning of this article: Do the primary senses of vision and audition interact or “cross-talk” in the human cerebral cortex? I believe the answer to this question regarding integration between vision and audition is a resounding YES! The next article in this series will be a brief literature review of rhythm and timing in the brain with emphasis on motor movement.

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