Article ‣ Timing – Rhythmicity – Movement: How We Get from "Hear" to There

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ABSTRACT

Listening to music and its rhythmic patterns may alter the planning and execution of general body movements, create physiological changes in the autonomic nervous system, and has been shown to affect cognitive processing. The goal of this paper is to provide the springboard for incorporating music into the vision therapy arena to enhance visual-motor and visual processing skills. A literature review of internal and external body rhythms is presented to provide a basic introduction to the components of motor planning and execution. The interaction between audition and vision and an introduction of how music is used in the rehabilitation arena is also presented.

Keywords: bio-rhythms, body rhythms, music and the brain, voluntary motor pathways

Introduction

Time-based patterns have been present since the inception of life. Is there a master clock that regulates human behavior? What is the cortical location/time relationship that determines the neurological processes involved in the "simple" act of following a moving target? What are the motor coordination and timing integration (synchronicity) needed to execute the intricate hand and foot movements required in performing a Bach opus on the Mormon Tabernacle's 11,623-pipe organ? Can clapping to the beat of "Dancing Queen" by ABBA assist in the performance of a saccadic activity for children and adults with oculomotor dysfunction or help children with autism spectrum disorder improve attention to tasks? Can listening to music reset the internal timing of persons with acquired brain injury (ABI)/stroke? Can 'bottom-up' processing using musical/rhythmic activities affect 'top-down' processing? To quote Robert Lawrence Friedman in his book, The Healing Power of the Drum, A Psychotherapist Explores the Healing Power of Rhythm:[1] "Through reflection on the rhythms of our universe, the rhythms of our society, and the basic rhythms of our bodily processes, it becomes very clear that there is nothing outside of rhythm." Before these questions can be addressed, a general review of the cerebral cortices' anatomy and corresponding motor functions is presented.

Basic Internal Body Rhythms

Most of us have experienced the disconcerting effects of jet lag, a change in work schedule hours, or how returning to our old routine after a two-week vacation affects our bodies due to a disruption of our normal sleep-wake patterns and daily routines. We have also experienced the hunger pangs when we have skipped one of our meals. The activities of eating and sleeping, common to all mammals, are under the control of circadian rhythms.[2,3] This intrinsic clock, under the control of the many neurotransmitters in the suprachiasmic nuclei (SCN) of the hypothalamus, plays a significant role in the circadian system.[4] The hormone melatonin, found in the pineal gland of the epithalamus, has its greatest effect on the SCN melanin receptors to allow for nighttime sleep. Melanopsin in the retina helps to set the sleep-wake cycle and has profound effects on temperature, mood, energy, mental acuteness, muscular speed, endurance, hunger, thirst, and general well-being via the ventrolateral part of the SCN. The use of prolonged-release melatonin has shown to be relatively effective for the treatment of insomnia in adults 55 years and older.[5]

The SCN of the hypothalamus coordinates behaviors through regulation of hormones to allow for homeostasis of the individual, including the coordination of smooth and striated muscles and secretory epithelial cells, as well as control of our visceral, autonomic, and endocrine functions.[6-9]

Vital brainstem motor activities such as breathing, swallowing, and locomotion are dependent upon metabotropic glutamate receptors in the central nervous system. The interaction between the lower spinal motor neurons and these brainstem activities appears to be coordinated through circuits that are collectively termed central pattern generators (CPG).[10]

The autonomic nervous system (ANS) sympathetic, parasympathetic, and enteric divisions are under the control of the hypothalamus, whose function is to monitor and to control our visceral (organs) system in conjunction the CNS cranial nerves.[11] It is primarily an effector system whose functions include controlling smooth muscle, heart muscle, and exocrine glands, whereas body movements are under the voluntary control of the somatic motor system.[12] The normal resting heart rate for an adult ranges from 50 to 90 beats per minute; systolic blood pressure normal ranges are between 90mmHg to 140mm Hg, with diastolic ranges above 90 mmHg considered suspect.[11] The normal values for respiration are 12 to 14 breaths per minute,[13] resulting in a range of 4 to 5 heart beats per one respiration cycle.

The cerebellum regulates movement directly as it adjusts the outputs of motor cortices and is responsible for automaticity of movement.[12,13] As it is not the intent of this article to provide an in-depth discussion of the cortical/cerebellar planning and execution of movement, I do encourage the reader to review Quick Reference Neuroscience for Rehabilitation Professionals: The Essential Neurologic Principles Underlying Rehabilitation Practice.[14] This text will be beneficial for the optometrist engaged in vision therapy for patients presenting with ABI/stroke. Further information regarding timing of ocular movements can be found in Ciuffreda and Tannen's recent book, Eye Movement Basics for the Clinician,[15] and Wong's Eye Movement Disorders[16] text from Oxford Press.

Brain Motor Circuitry for Voluntary Movement

The brain's central nervous divisions (cerebral hemispheres, brainstem, and cerebellum) all participate in the execution of movement. In the cerebral cortex, the primary motor area located in the precentral gyrus is responsible for the initiation of voluntary and conscious movement; the premotor area, located anterior to the primary motor area, plays a role in motor planning, or praxis. The prefrontal area of the anterior frontal lobe is involved in the cognitive planning of movement, while the supplementary motor area, part of the premotor area, plays a role in the bilateral control of posture.

The frontal eye fields are located in the frontal gyrus and are responsible for visual saccades. The pons and the medulla are located in the brainstem and serve as relay tracts for the motor information between the cerebral cortices and cerebellum at the unconscious level. The cerebellum regulates movement directly as it adjusts the outputs of motor cortices and is responsible for automaticity of movement. While its primary role is the coordination of movement, maintaining posture, and serving as one component of the vestibular system, the cerebellum has also been recognized as a contributor to the cortical activities of memory and spatial organization.[13]

The basal ganglia, the only ganglia located within the CNS, play the major subcortical role in the unconscious or automatic motor patterning of movement. They have also been recognized to have an additional non-motor-related role in cognition and emotional response processes requiring timing[13] and may play a role in the execution of the behavioral responses in ADHD.[17-21]

The cortical areas involved in movement (the planning, initiation, and execution of a voluntary, conscious motor activity) comprise four areas of the cerebrum. The primary motor area, M1, corresponds to Brodmann's area 4 and represents the somatotopic localization of contralateral movements. Lesions in this area will result in weakness of the contralateral body part associated with this area. The premotor cortex, Brodmann's area 6, also produces contralateral movements, which are slower in responding to stimulation than area 4. Area 6 is responsible for programming desired movement, with lesions in this area resulting in apraxia (inability to perform purposeful movement with no paralysis noted). Stimulation of area 8, the frontal eye field, will create deviation of the eyes to the opposite side, while a lesion located in this area causes a deviation of the eyes to the same side and a paralysis of contralateral gaze. In other words, the eyes will deviate to the side of the area 8 lesion, thus giving the practitioner an observational tool as to which side of the cortex (area 8) is affected. The stimulation of the supplementary motor areas (extensions of areas 6 and 8) will result in turning of the head and eyes to the opposite side of the body and also serves to program complex movements when several body parts are used. The prefrontal cortex occupies approximately one quarter of the whole cerebral cortex and is divided into 3 separate areas, with each responsible for a variety of movement activities, which include the following: motivation, problem-solving, judgment, emotions, behavior, and olfactory ability.[13] Lesions in this area can be localized based on the resultant impairment.

Voluntary movement begins with cognitive processing to understand the reason/demands required to perform the task. This is mainly a function of the motor association area. Motor planning requires accessing the reservoir of past motor activities to perform the desired action. These motor "plans" can be found in the pre-motor cerebral area. Implementing the desired motor activity involves the primary motor area, M1.[13]

Rhythms and the Human Brain – Synchronization

Cortical synchronization, or "cross-talk," has been shown to exist throughout the animal kingdom, not only between adjacent sensory areas, but between non-adjacent cortical areas as well.[21] A review of recent research into what cortical/cerebellar areas in the brain are called upon to initiate and to integrate rhythms, whether they are internally or externally driven, follows.

Rammsayer and Brandler[22] investigated whether a universal timing mechanism, referred to as a 'master clock,' exists in humans. Their research concluded that a common pacemaker-based interval timing mechanism existed for task-specific activities, while rhythm perception was unrelated to interval-based timing mechanisms. They hypothesized that the cerebellum is the control center for temporal representation for task-specific activities.

Buhusi and Meck[23] investigated the fundamental concepts of time and space as they interrelate with each other and how they affect the human body. They concluded that the ability to process temporal information is crucial for human functioning (e.g. circadian rhythms) and cited multiple biological mechanisms necessary for internal homeostasis, cognitive time management (interval timing), and the existence of interaction between the timing mechanisms.

Rubia and Smith[24] investigated the neural correlates of cognitive time management and identified brain regions that were thought to be involved in both the areas of motor timing and time perception. They defined motor timing as the physical timing output of motor, speech, or cognitive acts, while time perception referred to the more passive aspects of cognitive time management such as estimating time intervals and timing delays. Their study confirmed that both motor timing and the cognitive act involved in motor planning and its execution are intimately intertwined.

Dotan et al.[25,26] investigated how brain synchronization and cognitive performance were positively affected through Quadrato Motor Training, which involved movement execution to auditory commands, citing the role of dance in improving cognitive flexibility and creativity.

Thaut et al.[27] defined the musical concepts of rhythm (meter, pattern, tempo) and localized through neuroimaging the cortical/neural substrates of music, its rhythmic structure, and its component parts.

Bosman et al.[28] researched the microsaccadic (MS) rhythm, gamma-band synchronization (GBS), and behavior and demonstrated that visual cortical GBS might modulate cortical processing and might, in turn, be modulated by the low-frequency rhythm that controls the MS. They also cited research suggesting that events occurring in one sensory modality can reset the phase of low-frequency rhythm in other sensory modalities and most likely reset the phases across much of the neocortex.

Research by Foley et al.[29] demonstrated how the human cryptochrome protein (CRY), found in the retina, can function as a light-sensitive magnetosensor that might also aid in visual spatial perception for coordinating spatial position (timing in space).

The new science in pharmacology termed chronopharmacology[30] has arisen, which investigates how biorhythms in the elderly may affect the therapeutic responses to medications, especially to reduce adverse drug effects.

The College of Syntonic Optometry[31] uses light of various frequencies (speed of light based on timing) to effect change in the visual system.

Audition and Vision Interaction

Research using cats by Kadunce et al.[32] discovered cross-modal receptive field overlap in the superior colliculus for audition and vision. They found that regardless of which sensory system provided the stimulus, the superior colliculus' resultant response was greater than that produced by either sensory modality alone. Research by Guttman et al.[33] further investigated how conflicting visual and auditory information affects cortical processing and superior colliculus "cross-talk." They determined that the human perceptual system encoded visual rhythm sequences in an apparent auditory manner such that adding irrelevant visual information slightly impaired rhythm discrimination. However, task-irrelevant auditory information affected the visual encoding of time structure, which led them to the conclusion that temporal (time) rhythms are predominantly a function of the auditory processing system.

Hairston et al.[34] examined the relationship between vision and audition and concluded that properties of the visual system play the dominant role in localization of two spatially-separated stimuli, while Repp and Penel[35] found that the auditory system is the more accurate of the two systems for temporal processing of sequentially-presented stimuli.

Music and the Brain – Rhythm and Timing

What are the dynamics of brain activity during music listening? Can music affect the autonomic nervous system, and thus its biorhythms? Can musical structure affect spatial-temporal reasoning?

Press'[36] review of the parallel between visual processing and auditory processing and how these two main sensory systems are integrated will lay a foundation for including music in the vision therapy room to enhance oculomotor, eye-hand, and eye-hand-body abilities. Press includes in his monograph how the auditory processing system can affect attention and learning and concludes with the inter-relationship between audition and vision for cognitive development.

Ellis and Thayer[37] performed a literature review regarding the effect of music on the autonomic nervous system and disease. They used the phrase 'neurovisceral integration' in their paper to describe the relationship between the central and autonomic nervous systems, with the neurovisceral integration model dependent upon inhibition of autonomic activity, thus allowing an increase in physiological activity. Their literature review confirmed that music does indeed have an effect at the behavioral, emotional, and psychological levels – both consciously and unconsciously.

Research done by Phillips-Silver and Trainor[38] demonstrated that movement/sound interaction continued to develop throughout early infancy and adulthood. Their research supported the concept that movement to music influences the auditory perception of rhythm structure (the mathematical timing of the music/the length of time to hold the note and the number of notes per measure). A research project involving 7-month-old infants showed that the infants could differentiate a 2-beat presentation versus a 3-beat presentation produced by a snare drum after they were bounced on their parent's lap during either the 2-beat or 3-beat presentation. The infants would then automatically choose to bounce to the beat on which they were trained when the drum was played in a continuous presentation pattern without beat differentiation. This finding was also found in adults after training in a similar manner using a two-alternative forced-choice task while placed between two loudspeakers. The participants would bounce on every second or third beat while listening to an ambiguous rhythm. They also noted that visual information was not critical in the encoding of the auditory information; however, movement of the body was necessary.

To summarize, their research concluded that body movement is critical to auditory perception of musical rhythm, ergo the title of their article, "Hearing what the body feels: Auditory encoding of rhythmic movement."[39] They also concluded that movement/sound interaction is developed early and is one of the foundations for musical processing. In other words, they found that what we hear is influenced by how we move and is not directly related to what we see.

Kuck et al.[39,40] used electroencephalography on musically trained students to measure the underlying cerebral mechanisms for processing the temporal structures and divided timing into three components: meter, pulse, and rhythm. They defined rhythm as "the serial relation of durations between different acoustical events in a train of sounds" and suggested that pulse or grouping of sounds was based on gestalt principles and was dependent on the relative proximity in time of the sound events. They also suggested that meter involved a time variance of regularly occurring pulses over a longer period of time (a musical measure). Based on their literature review of case studies of patients with either right or left hemispheric brain damage, the following conditions were found: 1) spared judgment of meter with disrupted rhythmic discrimination, 2) that the anterior part of the superior temporal gyrus was critical for meter processing, 3) that processing of rhythm was more associated with the posterior parts of the right posterior temporal gyrus, and 4) that recognition of meter by the right hemisphere is followed by identification of the rhythm by left hemispheric subsystems.

Their results indicated that the processing of both meter and rhythm caused sustained cortical activation over bilateral frontal and temporal brain regions, with a shift to the right hemisphere when the subjects listened to the melody the second time. They also noted that differentiation of rhythm stimuli (such as that produced by a metronome) was processed more in the centroparietal region compared to metric processing (listening to a musical piece). They concluded by suggesting that the right temporofrontal lobe reflects auditory working memory and that a pattern recognition module is used in both rhythm and meter processing. Additionally, they localized activity in the superior anterior temporal gyrus, rhythm processing more localized to the posterior parts of the right superior temporal gyrus, and initial right hemisphere recognition of the pattern followed by identification of rhythm via the left hemisphere subsystems.

Critchley and Henson's book *Music and the Brain*[41] provides insight into the brain areas responsible for the perception, decoding, and synthesis of sound and rhythm. They noted the following:

1. Infants by the age of six months can detect rhythmic variations and by twelve months begin to appreciate the different variations of rhythm based upon their cultural exposure.
2. A stroke affecting the left hemisphere will manifest as rhythm deafness without tone deafness, whereas a right hemispheric stroke will manifest tone deafness without affecting rhythm.
3. The right inferior frontal gyrus is responsible for musical pitch encoding and melodic pitch memory.
4. Congenital amusia (inability to process tones) occurs due to a diminished development of the white matter on the right, inferior frontal gyrus.
5. Amelodia (tone deafness) is a higher order processing function deficit such that the individual is unable to hear the relationship between notes. The amelodic individual may have a good sense of melodic memory, but cannot tell if the note is going up the scale or down the scale; sequencing issues (simultagnosia) may also be present.

Music in Rehabilitation

Antonietti's[42] paper supporting music in rehabilitation suggests that music coordinates the motor system with the visuospatial and verbal mechanisms. She identified three categories in which using music as part of the therapeutic-rehabilitation program for the patient can enhance the total rehabilitative outcome: "to induce a psycho-physiological state" to change/enhance mood; "to activate behaviors and mental operations" to enhance attention, re-train memory functions, and assist in general cognitive recovery; and finally, music can serve as "a tool for action and reflection" to "stimulate the person to relate to other people" whether the patient is alert and functioning or in a coma. She uses the term "multi-register" to indicate that music affects passive cognitive activities via listening, as well as in the production of motor activities such as those needed to speak, to dance, or to play a musical instrument. Antonietti also postulated that music has a visual-spatial component as it has the possibility of making the musical notes initiate visual pictures and has the capability of generating mirror imaging to the therapist's actions for motor/speech activities.

An investigation by Callan et al.[43] of the brain regions involved with the perception of and motor production of spoken word versus singing hints at the rehabilitative use of music for persons with aphasia (Broca's, receptive, and expressive). They found that left planum temporal/superior temporal parietal area, left and right premotor cortex, the lateral aspect of V1 lobule of the posterior cerebellum, the anterior superior central gyrus, and the planum polare were all involved with the production and perception of speech and singing. They confirmed the hypotheses regarding the lateral hemispheric specialization of both listening and speech production to the left temporal lobe while the right temporal lobe was more dominant while listening to someone singing when compared to listening to someone speak (listening only).

Research by Popescu et al.[43] using the magneto-encephalograph demonstrated that listening to the rhythm and tempo changes in music activated the lateral premotor, supplementary motor, and somatomotor areas.

The premise delineated in Gordon Shaw's book entitled *Keeping Mozart in Mind*[45] is the underlying role music plays in establishing spatial-temporal reasoning. He avers that these spatial-temporal abilities are part of the internal neural language, may serve in pre-language abilities, and may play a large role in learning math and science. He introduces symmetry as the common theme in how we think, reason, and create using the trion model of cortical arrangement based on Mountcastles' minicolumnar arrangement of the neurons in the cortex, which involves temporal scales as related to spatial scales (physical receptor area of the neurons). Shaw provides a very interesting table that relates spatial/temporal scale, beginning with the synapse of the cortical neuron to the broader cortex as a whole. Several examples range from the minicolumn which consists of 100 neurons and occupies 0.01 cm cortical area with a time scale lasting 0.02 seconds to the entire cortex occupying 30 cm (if unfolded) with the time scale of 100,000 seconds. Shaw postulates that these spatial-temporal scales are intrinsic, can be affected with music, and have a profound effect on symmetry, which he states is the basis for higher brain functions.

While the "Mozart Effect" has been debunked as a method to improve cognitive ability in children, the use of music's rhythm structure has been demonstrated to enhance movement/coordination in persons affected with motoric disorders such as Parkinson's Disease.[46,47]

It has also been used to facilitate speaking for persons with aphasia.[48,49]

Information Appendices

The following tables are included to enhance the reader's general information:

- Appendix 1: *General Terminology Used in Measuring Time*
- Appendix 2: *Neuronal Role Identified in Time Processing*
- Appendix 3: *Electroencephalography – Measurement of EEG Brain Wave Patterns*
- Appendix 4: *Changes in Brain Rhythms with Pharmacological Agents*
- Appendix 5: *The Motor Functions and Dysfunctions of the Central Nervous System*

Conclusion

Our visual system constitutes the primary sensory apparatus whose input the brain must continually process and coordinate with the other sensory systems to allow for maximum efficiency of the human body. Our role as optometric vision therapists is to maximize the visual process to direct action in a "timely" manner, not only for physical movement, but for information processing/encoding/decoding-action—to achieve purposeful thought-based interaction with our internal and external environments. However, as simple as that may initially appear to be, the speed with which the photic excitation reaches the retina may be compromised by familiar 'filters' such as amblyopia, strabismus, and refractive error. Ocular pathology can affect transduction along the visual pathways for sight and pupil responses. Disruption in the timing of the visual system has a profound effect on integration with other sensory modalities and affects the efficiency of the human body, physically and/or cognitively. Rhythm and timing involve getting the 'right body part to the right place at the right time' for locomotion and cortical processing to enable the human to experience maximum quality of life.

The question thus becomes: Can the timing of a desired body movement be affected by externally driven cues such as rhythmic tempos created by listening to music?

The final article in this series will address the possible advantages of using of music in the rehabilitation arena for persons presenting with the visual sequelae of stroke and traumatic brain injury. It will also emphasize the importance of including music in the vision therapy program to the benefit of development, habilitation and rehabilitation for our patients with oculomotor and visual processing inefficiencies.

As a prelude to the final article in this series, I encourage the reader to review the following articles: "Music and the Brain"[50] written by Weinberger and published in the October 2004 Scientific American and the article by Fujiok et al., "Strike a Chord for Health, Music Matters for Body and Mind,"[51] NIH News in Health, January 2010.

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Appendix 1: General Terminology Used in Measuring Time

Frequency (v) The number of occurrences of a phenomenon within a fixed period of time Electromagnetic frequency extends from 10 to 1 Hz	**Audition** Speed of sound is dependent upon the medium it passes through (slower through air than water or metal); estimate in air is 1,191.6 – 1,193.22 kilometers per hour (740 - 741.5 miles per hour)	
	Vision Speed of light is 3 x 1010 cm/sec (186,000 miles per second)	
Amplitude The amount of displacement from a zero value during one period of an oscillation (strength of signal)	Change from resting state of neuron due to electrochemical stimulation; examples are VEP signal strength and EOG tracking	
Hertz (Hz) Unit of electronic frequency	A unit of measurement wave frequency equal to one cycle per second (cps)	
Rhythm Greek: *rhein* meaning 'to flow' Musically: rhythm is time and space	"the aspect of music comprising all the elements (as accent, meter, and tempo) that relate to forward movement" "the serial relation of durations between different acoustical events in a train of sounds" "a regularly recurrent quantitative change in a variable biological process"	
Synchronicity	"happening, existing, or arising at precisely the same time" "recurring or operating at exactly the same periods"	
Periodicity	The regular, recurrent intervals; may be short, long, lateralized, focal, or diffuse	
Bio-Rhythm	An innately determined rhythmic biological process or function (as sleep behavior), also: the internal mechanism that determines such a process or function	
Wavelength–General Electromagnetic radiation spectrum ranges from 10-14 to 108 nm	**Auditory**: Unit is Hertz (Hz)	The average healthy human can detect 15 – 20,000 Hz
	Visual: Unit is λ and is measured in nanometers	The frequency of visible light ranges from approximately 4.3×10^{14} to 7.5×10^{14} nm
Areal, Intra-areal, Inter-areal	Refers to area of cerebral cortex; intra = within same area of cortical function; Inter = between cortical areas with different areas of function	
Chronobiology	The study of the effects of time and cycles on biological systems	
Phototherapy	The use of light to re-calibrate body's internal clock	
Entropy	The measure of randomness, disorder, or chaos of a system	
Optometric Syntonics	The branch of ocular science dealing with the application of selected light frequencies through the eyes	
Event-Related Potential (ERP)	Signal embedded in the EEG which can be averaged to reflect neural activity related to sensory, motor, or cognitive events, giving a specific temporal record of the neural activity	

Appendix 2: Neuronal Role Identified in Time Processing

Structure Basic neuron: Collect information, process information, transport information, and transmit information using either electrical or chemical signaling	**Role in Time Performance**	**Time Duration**
ANS Axon Conduction Velocities	Intra-neuronal flow primarily electrical due to graded potentials of membranes produced in postsynaptic and receptive membrane areas of receptors	Duration – 1ms to 1 second or more
	Action potentials propagate electrical activity along axons and some dendrites	Duration – 1 millisecond
	Inter-neuronal flow is primarily chemical and relies on neurotransmitters to cause an electrical change on the receptive neuron	
PNS Axon Conduction Velocities	Myelinated: Large muscle afferents and lower motor neurons	Conduction Velocity – 70-120 m/s
	Myelinated: Touch, Position	30-70 m/s
May be Myelinated (Faster) Or Non-Myelinated (Slower)	Myelinated: Efferent to muscle spindles, in general	10-50 m/s
	Myelinated: Preganglionic, some visceral, cold, some pain receptors	5-30 m/s
	Nonmyelinated: Postganglionic autonomic, most pain, warmth and some visceral receptors	0.5-2 m/s
Spike Wave – Change in amplitude	A transient voltage change of short duration Usually lasting < 80msec with an abrupt rise and gradual fall in amplitude	It may originate in the cortex, thalamus, or diencephalon
Sharp Wave – Change in amplitude	May be negative and/or positive phase lasting 80-200 msec	

Appendix 3: Electroencephalography – Measurement of EEG Brain Wave Patterns

Brain EEG Waves	**Frequency**	**Location**	**Associated Activity**
Alpha Rhythms α	8-13 Hz	Occipital/Parietal region	Quiet & waking states; present at rest w/ eyes closed; attenuates on opening eyes or with sensory or mental stimulation; central alpha rhythm is associated with development of motor and locomotor skills in infants
Beta Rhythms β	14-30 Hz—fastest of brain rhythms	Frontal regions; may be posterior dominant	Signal an activated cortex; can be increased or decreased with barbituates
Delta Rhythms Δ	1-4 Hz	Varies depending upon age: frontal for adults and posteriorly in children	Occur during some sleep states and is hallmark of deep sleep; can be seen diffusely or localized depending on pathology or trauma
Gamma Rhythms γ (combine with Fast Activity waves)	25-100 Hz Fast activity waves Are 100-400 Hz and Ultrafast are 400-800 Hz	Found in all sensory modalities, especially in the visual cortex; observed after sensory stimulation	Translates communication from external world to the brain for: cognition, perception, consciousness, cognitive tasks, long-term memory. Synchrony of the gamma rhythms allow for rapid communication across the various cortical areas
Mu Rhythms μ	8-13 Hz limited to 0.5-2 sec. duration	Sensorimotor cortex	Translates "seeing" and "hearing" into "doing"; volitional control in brain computer interface; may be directly linked to mirror neuron activity
Sigma Rhythms Σ Sleep "Spindles"	10-14 Hz with some ranging from 8-15 Hz	Sensorimotor cortex changes with maturation from neonate throughout adult life	Hallmark of sleep in stage 2 non-REM sleep
Theta Rhythms θ	4-7 Hz Occurs with low amplitude	Variable; found in locations not related to task	Inhibition of elicited responses; may be degree of alertness and arousal; occurs during some sleep states

Appendix 4: Changes in Brain Rhythms with Pharmacological Agents

Pharmacological Agent Used	Effects on Brain Rhythms	Side Effects
Anticonvulsants	Most increase range of 15-35 Hz	May make children hyperactive
Tranquilizers/Psychotropic	Most decrease general EEG function	Sedation; antidepressant; decrease anxiety
Narcotics	May increase or decrease EEG activity as function of drug used	Analgesics
Steroids	Decreases alpha activity to as low as 1-0.5 Hz	Long term use may decrease alpha permanently
Alcohol	No appreciable effect	May be used as anticonvulsant in infantile spasms
Sedatives and Hypnotics	Generalized diffused reduction in EEG	Generalized sedation
	Increases 15-30 Hz frequencies frontal dominant with some diffuse activity	Sedation; occasionally anesthesia (Pentothal)
Psychotomimetics	Marijuana – Slight change in Alpha	Mood alteration, intoxication
	L.S.D. – Slight increase in Alpha	Hallucinogenic
	Methamphetamine – Slight increase in fast EEG's	Hallucinogenic
	In general, may affect both slow and fast EEG dysrhythmias	
ADHD Medications: generally CNS Stimulants	Paradoxical effect on children	Decreases activity, solemnescence, for children
CNS Stimulants	Can increase rate of neuronal discharge or block inhibitory neurotransmitters	Used to treat narcolepsy and obesity; restore mental alertness; as respiratory agent

Appendix 5: Motor Functions and Dysfunctions of the Central Nervous System

Brain Region		Function	Lesion-Created Dysfunction
Cerebral Cortex	Primary Motor Area (M1) Pre-Central Gyrus	Site for initiation of voluntary and unconscious movement Site of the motor homunculus (body parts' motor map) which may change if damage occurs to corresponding body part represented Right side controls left side of body and vice versa	Loss of voluntary movement to contralateral body part Loss of ability to carry out specific motor plan
	Premotor Area Located anterior to M1	Motor planning (involves cognition)	Causes apraxia (inability to access or inability to understand the appropriate motor plan)
	Motor Association Area (prefrontal area located in frontal lobe)	Cognitive planning of movement	Cognitive loss of previously learned motor plans Cannot understand how to carry out specific motor functions
	Supplementary Motor Area Located inside MLF of the premotor area	Plays a role in the bilateral control of posture	May contribute to loss of posture
	Frontal Eye Field Located anterior to the premotor area in the middle frontal gyrus	Responsible for visual saccades	Causes deviation of the eyes to the same side as the lesion
Brainstem	Pons	Motor information mediated at sensory unconscious level Relay system between cerebral cortices, cerebellum, and spinal cord	Loss of information for action
	Medulla	Relays descending motor messages from cerebral cortices to spinal cord	Loss of information for action
Basal Ganglia are masses of gray matter located directly inside the CNS. Modulates cortical output through multiple parallel loops via thalamus—may be inhibitory or excitatory Unconscious motor system: Operates subcortical level and is involved in the higher-order aspect of movement Main function is to modify the output from the cerebral cortex Positive = increase in number of muscle contractions Negative = decrease in number of muscle contractions Involuntary movements and may demonstrate decreased velocity and amplitude Eye Movement: Smaller and slower saccades	Striatum (caudate nucleus, nucleus accumbens, & putamen)	Putamen: receives info from motor and somatosensory cortex and projects to motor, premotor, and supplementary motor areas via thalamus Caudate: receives info from assoc. areas of cortex and is more involved with cognitive function Acts in the inhibitory control of movement in conjunction with the striatum Striatum: receives input from the cerebral cortex, substantia nigra, and thalamus	Disorders cause involuntary movement abnormalities such tremors, disturbances of muscle tone, or dystonia Dyskinesias: Tardive dyskinesia, Tremors, Dysdiadokokinesia, Bradykinesia, Hypokinesia, Akinesia
	Globus pallidus (Along with Putamen are considered the Lenticular Nucleus)	Striatum: projects to globus pallidus and substantia nigra Excitatory in function and works with caudate for balance in motor behavior	
	Substantia Nigra	Projects to all areas of the caudate nucleus Reticular portion provides input to the superior colliculus and thus serves as a route for the basal ganglia to participate in eye movement	Destruction of striatum is major factor causing Parkinson's disease
	Subthalamic Nucleus	Provides strong excitatory input to globus pallidus and substantia nigra	Hemiballismus: flailing of contralateral arm and leg usually as a result of stroke in one branch of the posterior cerebral artery
Cerebellum Coordination of movement, maintenenace of posture, maintenance of equilibrium Secondary: attention shifting, practice-related learning, spatial organization, memory	Flocculonodular Lobe	Uncoordinated trunk movements (ataxia) Balance deficits due to connection with vestibular nuclei Nystagmus due to connection with oculomotor system	
	Neocerebellar Lobe (posterior lobe of cerebellum)	Ipsilateral ataxia Dysmetria (inability to judge distances) Adiadochokinesia (inability to perform rapid alternating movements) Dyssynergia (decomposition of movement) Asthenia (muscle weakness) Intention tremors Inability to regulate reciprocal movements Ataxic gait Staccato voice	
	Paleocerebellar Lobe (anterior lobe of cerebellum)	Severe disruption of extensor tone	