INTERACTIVE METRONOME – UNDERLYING NEUROCOGNITVE CORRELATES OF EFFECTIVENESS

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Many clinical disorders, whether acquired or developmental, have as characteristics impairment in attention, motor planning, coordination, mental organization, and sequencing. The Diagnostic and Statistic Manual – Fourth Edition (DSM – IV) includes these characteristics, among others, as criteria for disorders such as Attention-Deficit/Hyperactivity Disorder, Mental Retardation, Pervasive Developmental Disorders (including Autism and Asperger's Disorder), Developmental Coordination Disorder, specific learning disorders, and cognitive disorders. This section will explain how through improving these basic cognitive functions that the Interactive Metronome can improve functioning in many higher-order skills. The IM program targets the participants timing, rhythmicity, attention and concentration, and motor planning, focusing on the brains neuroplasticity to enhance cognitive functioning (Shaffer et al, 2001; Libkeman, Otani & Steger, 2002). This section will review recent research in the areas of plasticity, rhythmicity, timing/synchronicity, and motor planning as the underlying neurocognitive correlates that are affected by training with the Interactive Metronome.

Background

Theories regarding the brain-behavior relationship have evolved over time from the early 19th century with the work of Franz Gall (1758-1828) and his localization theory. Gall postulated that the brain consisted of separate organs, each of which was responsible for specific psychological traits. The criticisms of this theory resulted in a theory of equipotentiality. According to this theory, it is speculated that even though basic sensiormotor functions may be localized in the brain, some processes were too complex to be confined to any one area of the brain. Hughlings Jackson (1835-1911), in the second half of the 19th century, postulated that neither the theory of localization nor the theory of equipotentiality fully explained the brain-behavior relationship. He proposed that more complex mental functions were a compilation of several more basic skills. It is the combination of these skills that result in the exhibited behavior. Based on this theory, a person can experience an injury or loss in a particular area of the brain that will affect numerous higher-level behaviors. It is the interactions among many areas of the brain that produces behavior.

Alexander Luria (1902-1977) proposed adaptations to this theory, resulting in significant changes in the approach of understanding the brain and its functions. In his functional model, Luria defined each area of the central nervous system involved in the brain-behavior relationship as being a part of one of three basic functions, which he labeled units. The first, which consisted of the brain stem and associated areas, controls basic arousal and muscle tone. The second unit,

which includes posterior areas of the cortex, is integral in the reception, integration, and analysis of sensory information, receiving input from both internal and external stimuli. Executive functions such as planning, executing, and verifying behavior and motor output are regulated by the third unit, the frontal and prefrontal areas of the brain. According to Luria's theory, all behavior is the result of the interactions of these three units. Each unit is structured hierarchically, with primary, secondary, and tertiary zones. Processing follows a strict hierarchy in this model from primary sensory where identification of movement and objects occurs, to secondary sensory where this movement is a person walking toward to greet you, to tertiary processing where the sensory information would be integrated to allow the realization of this person's intentions. This information is then led through memory and emotional systems where the interaction would be recorded and an emotional value placed, then on to the tertiary motor system where your plans and intentions are developed, to secondary motor where the decision to execute these plans are developed, and then finally to primary motor cortex where you stick out your hand and smile as you great the person. Kolb and Wishaw (1996) highlight that Luria's theory assumes that the brain processes information serially, in a specific order, and that this serial processing is hierarchial. However the brain is not a "feed-forward" only system. In fact all cortical areas have reciprocal connections with area to which they are connected.

Modern research has continued to advance Luria's ideas of functional units through theories of parallel distributed processing and neural networks. Felleman and van Essen's (1991) model of parallel-hierarchical processing assumes that cortical functions are organized hierarchically as Luria postulated, but with more than one area allowed to occupy a given level, with both forward and backward connections. These neural network models use computer modeling to simulate actions of brain processes. Common characteristics of connectivist networks include units which receive input from other units and are connected in layers. Three basic layers are described including input, where information is received, output where a response is generated, and a hidden layer where processing occurs. The connective weight of a unit indicates it degree of influence it has on other units and layers. These computer models develop learning algorithms where an input is allowed to compute through to an output. This output is then compared to the desired output. If incorrect, then small adjustments backward in the connective weights are made from output to hidden layer and then to input layer. If these adjustments move toward the correct output then these connections are increased, otherwise the connections are decreased in weight. These neural network models have been used to successfully explain much of human cognitive processes and behavior. Servan-Schreiber and his colleagues (1998) used a neural network model to predicted dopamine effects on selective attention. Additionally, such models have been used to explain learning pronunciation rules and reading skills (Seidenberg & McClelland, 1989), and recognition of objects (Reisenhuber & Poggio, 2000). It is this functional connectivity, the impact of one neuron onto another that describes a process called neuroplasticity (Banich, 2004).

Neuroplasticity

Neuroplasticity implies that the brain is capable of long-term changes in function, neural assemblies or regions in response to physiological or pathological stimuli (Gynther, Calford & Sah, 1998). The brain's ability to reorganize and repair itself has been established in numerous studies. This plasticity is more profound during a critical period following birth when the most activity-dependent changes can occur. Animal studies have provided the most evidence for reorganization. For an example, Izareli, Koay, Iamish, Heickle-Klein, Heffner, Heffner, and Wollberg (2002) found that auditory stimuli elicited activation of the visual cortex in hamsters whose eyes had been surgically removed prior to birth, but not to those whose eyes were intact. This indicated that the visual cortex as well as the auditory pathway was activated by sounds, evidencing a reorganization of the brain functions. In higher sensory cortical areas, Gynther, Calford & Sah (1998) reported that binocular deprivation from birth in cats reduced the number of visually responsive cells and increased the number of cells that respond to auditory or somatosnesory stimuli.

While plasticity is more limited in the adult brain, significant changes have been demonstrated. Gynther, Calford & Sah (1998) reported that 12 years after severing the spinal nerves of adult monkeys that conduct sensation to the hand, wrist, forearm, and upper arm, the deprived sensory cortex became responsive to stimulation of the face. Other evidence of this plasticity has been found in studies that involved the denervation of large areas of skin resulting in areas of the somatosensory cortex to become unresponsive to stimuli. Gradually, this cortical region may become sensitive to stimulus to adjacent areas of skin. Similar results have been found in humans, especially in the realm of language and speech. As early as the 1800s, it was established that language centers were normally located in the left hemisphere. However, it was soon discovered that patients, especially children, who suffered damage to the left hemisphere did not necessarily exhibit permanent deficits in language. Later studies have shown that depending on the age at injury, the language centers could move either to the right hemisphere or to undamaged areas of the left (Kolb, 1999). It should be noted that the mature brain is not as capable of reorganization, but is capable of strengthening and reparation.

Neurobiologists have found that manipulation of the immune system, extracellular matrix, or growth-associated genes can facilitate neural regeneration in the mature brain (Homer & Gage, 2002). Additional research has provided evidence that certain neurotransmitters such as dopamine, particularly through D_1 receptor activation (Nicola, Surmeier, & Malenka, 2000), and a decrease in GABA-related inhibition facilities (Ziemann, Muellbacher, Hallett & Cohen, 2001; Gynther, Calford & Sah, 1998, Sanes, 2003), for example, can promote neuronal plasticity. Numerous studies have provided support for the notion that physical activity as well can not only attenuate the decline of cognitive functioning (McDowell, Kerick & Santa Maria, 2003), but is instrumental in

neuronal growth (Homer & Gage, 2002; Trachtenberg, Chen, Knott, Feng, Sanes, Welder & Svoboda, 2002).

Donald O. Hebb, in his neuropsychological theory of learning, proposed that neuronal plasticity underlies behavioral and cognitive learning and change (Hergenhan & Olson, 1997). He theorized that neural pathways that are intensively used may become strengthened, on the other hand, pathways that are infrequently used may become weaker (Gynther, Calford & Sah, 198; Hergenhan & Olson, 1997; Kolb, 1999). Sanes (2003) reports that many neocortical regions, including the motor related areas incontrovertibly exhibit plasticity and are believed to contribute to motor learning. On a cellular level, Kolb (1999) explains that synaptic plasticity is the base of observed changes. In studies of rats and monkeys whose brains had been damaged, treatment lead to growth of existing dendrites and spine density and the growth of new dendrites, creating more synapses in the damaged areas. He linked this anatomical change with behavioral observations, stating that behavioral recovery and cellular changes are correlated. These changes are linked to several agents including trophic factors, which serve to keep the neurons alive, to direct or enhance neuron growth, or to make possible specific protein production; cell-adhesion molecules; the extracellular matrix, which provides the environment for cell migration; and an enriched environment. Kolb sites an earlier experiment in which he found that simply stroking rat pups with a paint brush for 15 minutes three times a day stimulated changes in the brain and promoted skilled motor learning when these rats became adults.

Synchronization and Timing

The simplest form of motor learning is a repeating a single movement. Sanes (2003) found that the primary motor cortex of subjects repeating a particular finger movement was altered for ten minutes or more. More complex movements require a synchronization of cognitive functions and coordinated neural processing and result in longer-term changes (Sanes, Donoghue, Thangaraj, Vankatesan & Edelman, 1995). Sanes (2003) points out that whether a motor skill involves the adaptation of previously learned skills, or the formation of new sensory – motor relations, new patterns of neural activity are found. Learning a motor sequence yields convergent processing in the neo cortex from the frontal to the parietal regions as the skill becomes better learned. This indicates that the frontal cortex is involved in the acquisition of the motor skill whereas the knowledge about the sequence is primarily located in the parietal cortex (see also Marois, 2002; Karni, Meyer, Jezzard, Adams, et al, 1995).

Synchronization involves different areas of the brain, as has been found in many studies. In a study of coordinated motor skill acquisition involving both the wrist and foot, Debaere, Swinnen, Beaste & Sunaert (2001) found that a distributed network was responsible. Using functional magnetic resonance imaging (fMRI) procedures, they detected activations in the supplementary motor area,

cingulated motor cortex, primary sensorimotor cortex, premoter cortex, and cerebellum. A study by Cassidy, Mazzone, Oliviero, Insola, Tonali, Lazzar & Brown (2002) indicates that the basal ganglia is also involved in voluntary movements, being primarily concerned with the control of ongoing movement including feedback processing. The activations in these different areas of the brain exceed the sum of independent actions. Debaere, et al (2004) suggested that the supplementary motor area is more integral for less stable, parallel movements and its role may be for higher-order, online planning of movement sequences as well as their execution.

Motor Planning

Motor planning or praxis is expressed in the integration of selecting the best course of movement to reach the goals necessary. For example, taking a drink of water integrates the visual perception of the glass of water, the proprioceptive knowledge of where the glass is and the specific motor actions needed to activate the muscles to engage in the act of drinking (Wolbert, 2000). Developmentally, motor planning has been found to take place as early as 10 months old (Claxton, 2003). It requires a combination of attention, sensory integration and synchronization, and timing (Bhat & Sanes, 1998). Sanes (2003) cites studies of Ramnani and Passingham who found that progressive acquisition of temporal sequences are necessary in accurate performance. Integrating and synchronizing the different senses revealed overlapping activation of separate areas of the brain, predominantly the premotor area and prefrontal cortex, which indicated that these areas participate in the coordination of choosing the movement and determining when to start a sequence. These aspects, or sensorimotor synchronizations, are targeted in the IM exercises, affecting stimulation of these networks.

Rhythmicity

Information from the different sensory modalities is processed in separate cortical regions, and our perception of the environment relies on the integration of this input (Figelkurts, Figelkurts, Krause, Moettoenen & Sams, 2003). It has been found that in some circumstances, the balance of neural resources allocated to different aspects of senses may shift according to situational demands (Dromey & Benson, 2003). In a study utilizing fMRI technology, Galati, Commiteri, Sanes, and Pizzamiglio (2001) found that the posterior parietal and frontal regions of the brain appear to provide multimodal spatial representations in sensory coordination. Sensorimotor synchronization or rhythmicity is subject to tempo changes, and the adaptation to these changes is proposed to be based on two processes. Phase correction, which is largely automatic, and period correction, which requires conscious awareness and attention (Repp, Keller, Repp, 2004). In this study, subject performed a finger-tapping task in synchrony with auditory sequences. The sequences contained a tempo change. Following that change, the participants were to continue tapping after the sequences ended. Whether to

adapt to the tempo change was manipulated through verbal instruction. Distractions were provided in the form of mental arithmetic problems, and the changes in tempo were assessed through perceptual judgments. The findings indicated that period corrections were indeed related to distraction, awareness, and instruction whereas phase correction depended only on intention. Therefore, attention and awareness play integral roles in directed behaviors. In other studies of sensory integration, auditory stimuli were found to be dominant over visual (Aschersleben & Bertleson, 2003; Hickok, Buchsbaum, Humphries & Muftuler, 2003; Repp, 2003). The exercises performed during training of the IM incorporate auditory and motoric stimulation as well as a significant amount of attention; exciting multiple sensory modalities.

Summary

The Interactive Metronome ® incorporates motor planning, rhythmicity, and sensory integration over the exercises presented. These elements have been shown through research, some of which is reviewed here, to facilitate neuronal stimulation. Consistent with theories of neuropsychological functioning and cortical organization, this treatment can facilitate greater attention, mental processing, and cognitive abilities. The advantages that this treatment facilitates can be applied to many diagnostic populations as well as to individuals who wish to improve their concentration and performance. Finally, the impact that training with this system can have on other disorders that involve mental processing and attention is meaningful.

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