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Effects of motor sequence training on attentional performance in ADHD children

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Abstract

This study examines whether the nervous system can be made more efficient as a cognitive processing instrument and how signal detection theory may be used as an instrument for examining human performance and the effectiveness of clinical treatment. In this paper we will examine how IM affects human cognitive and neuromotor capacities and functioning and how signal detection methods may be used to functionally evaluate treatment efficacy as well as identifying clinical populations and characteristics for rhythmic training is likely to have a positive effect. Rhythm feedback training appears to have a significant effect on clinically observed changes in behavior in attention-deficit/hyperactivity disorder (ADHD) elementary school-age children. Signal detection studies are ongoing to examine the nature of the observed relationships.

Keywords: ADHD; fixed action patterns; motor sequencing; signal detection theory.

Introduction

The capacity for timing and rhythmicity plays an important role in a variety of behaviors including motor planning, sequencing, and cognitive functions, such as attention and academic achievement. The core process is compromised in a variety of challenges involving attention, language, motor planning, motor coordination, social interactions, and learning disabilities, including non-verbal learning disabilities, as well as during the aging process. In just about all advanced thinking and problem solving, the ability to plan and sequence thoughts with behaviors occurs at a basic, foundational level. While there exist interventions that exercise and improve the middle to higher levels of cognitive and social skills, there are none that directly address and improve basic, foundational level skills of timing and rhythmicity.

Attention-deficit/hyperactivity disorder

Attention-deficit/hyperactivity disorder (ADHD) is the most common neurobehavioral disorder of childhood (1). ADHD is also among the most prevalent chronic health conditions affecting school-aged children. The core symptoms of ADHD include inattention, hyperactivity, and impulsivity (1). Children with ADHD may experience significant functional problems, such as school difficulties, academic underachievement (1, 2), troublesome interpersonal relationships with family members (3) and peers, and low self-esteem. Individuals with ADHD present in childhood and may continue to show symptoms as they enter adolescence (4) and adult life (5). Pediatricians and other primary care clinicians frequently are asked by parents and teachers to evaluate a child for ADHD. Early recognition, assessment, and management of this condition can redirect the educational and psychosocial development of most children with ADHD (2).

It is known that children with hyperactive behavior are impaired in the temporal organization of their motor output. Rubia et al. (6) tested that notion by examining the performance of 11 boys, scoring above a cut-off on standard scales of over activity and inattention. These boys were compared to controls in progressively more complex motor-timing tasks. The tasks administered required self-paced and externally paced sensorimotor synchronization and sensorimotor anticipation. Deficits at a perceptual level were investigated with a time-discrimination task. As they had hypothesized, these investigators found that hyperactive children had no deficits in their perception of time but were impaired in timing their motor output. Hyperactive children were more inconsistent than controls in maintaining a freely chosen tapping rhythm, in synchronizing, and in anticipating their motor response to external visual stimulation.

Motor sequencing training

Neural substrates, which may be especially important in executive function, working memory and ADD, are those of the nigrostriatal structures. Crinella and associates (7) reported findings suggesting that these structures contribute to the control of functions such as shifting mental set, planning action, and sequencing (i.e., executive functions). As Pennington and colleagues (8) indicated, many developmental disorders may result from a general change in some aspect of brain development such as neuronal number, structure, connectivity, neurochemistry, or metabolism. Such a general change could have

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a differential impact across different domains of cognition, with more complex aspects of cognition, such as executive functions being most vulnerable and other aspects being less vulnerable.

In the past, motor areas of the brain were thought to be distinct from areas that control cognitive functions. However, over the last few years, those lines have blurred significantly and it is now recognized that areas such as the cerebellum and the basal ganglia influence both motor function and non-motor function. It is thought that cognitive function, or what we call thinking, is the internalization of movement and that cognition and movement are really the same (1). The function of the motor planning and sequencing system is outlined in Figure 1.

The lateral parts of the cerebellar hemispheres are largely associated with achieving precision in the control of rapid limb movements and in tasks requiring fine dexterity, for initiating and terminating movements. Symptoms of dysfunction include disorders of the temporal coordination of complex movements involving multiple joints, and disorders of spatial coordination of hand and finger muscles.

The cerebrocerebellum contributes to the mechanisms for the preparation for movement (feed forward and expectancy) activities. In contrast, the spinocerebellum is more concerned with movement execution or (feedback) adjustments. The intermediate zone is fed a copy of the motor program that is being sent by the motor cortex to the muscles, this is known as the efferent copy. The cerebellum, especially the lateral cerebellum is the initiator of all motor learning. In regard to motor learning, the cerebellum responds primarily to novel activities, It also appears to play a role in the stimulation and memory storage of learned behavior.

The way the cerebellum responds to novel situations to produce motor learning has been recently shown to be involved in higher cognitive and behavior learning in much the same way (9–13). All human learning of behavior and movement

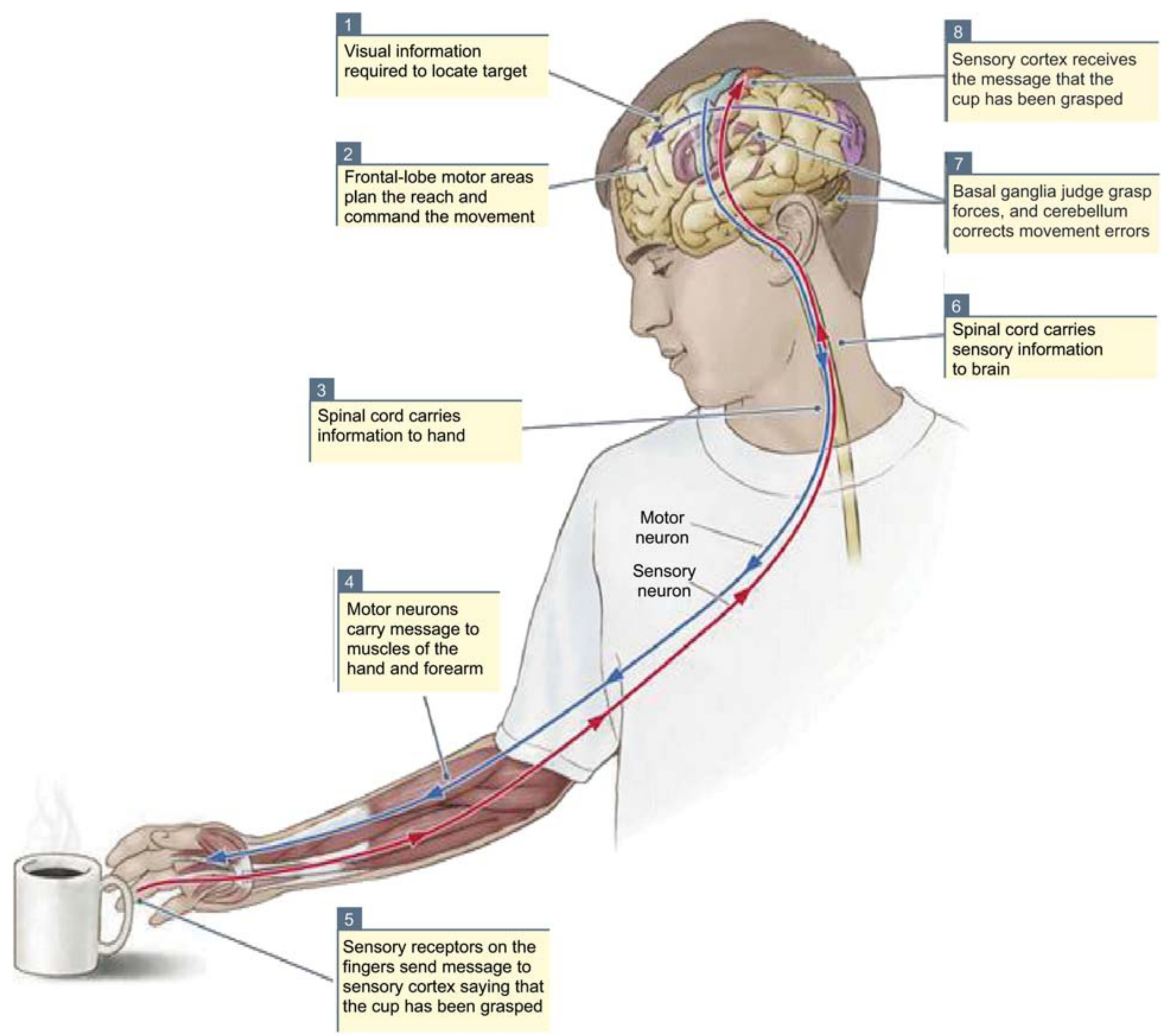

Figure 1 The system of motor planning with feedback.

seems to involve the cerebellum. The cerebellum responds to novel movements that are complex rather than simple in a continuous single plane (14, 15). If an individual muscle is stretched or contracted causing stimulation or stretch of the muscle spindle receptors, these receptors send fibers that fire back to a specific area of the cerebellum, which has a somatotopic representation of body schema. Therefore, specific body areas and specific muscles will fire to specific discrete areas of the cerebellum. Therefore, if an arm movement is produced in a unitary and linear plane, specific granule cells will fire to Purkinje cells and nuclei in a specific area associated with that arm (16). This inhibition of Purkinje cells outside of the area responsible for prime movement produces disinhibition of the nuclei that are involved with the initiation of movement of other muscles not associated with the exemplified arm motion (16). This has the potential to bring contiguous areas of the cerebellum not directly responsible for the specific arm motion described, closer to the threshold making them better able to react to a lesser stimulus (16). Such a situation would allow the creation of a smoother coordinated movement that is characteristic of normal cerebellar function.

This process may be one way that the cerebellum promotes motor-cognitive as well as emotional learning. Because similar pathways and areas are involved in cognitive and behavior learning the same principles may apply using the cerebellum as a way to promote novel learning of all types. Therefore, any dysfunction or lesion within the cerebellum that disrupts or affects the function of Purkinje inhibition may affect smooth coordinated movements and the ability to learn new activities. Likewise, anything that affects projections to the cerebellum or areas of the brain with projections from the cerebellum such as the thalamus, motor cortex, premotor cortex, or basal ganglia may result in a learning disability or ADHD. There are specific types of symptoms that are associated with cerebellar dysfunction outlined in Table 1.

The frontal lobe plays a major role in motor activities such as planning and in the execution of movements. The primary motor area proximal to the precentral gyrus is the motor strip. This is located just anterior to the central sulcus. The most anterior region of the frontal lobe, the prefrontal cortex, is responsible for higher aspects of motor control and planning and in the execution of behavior; these tasks require integration of information over time. The frontal lobe is the largest lobe in humans and the prefrontal cortex constitutes approximately 50% of the size of the frontal lobes. The system described herein is summarized in Figure 2.

Rhythmic rehabilitation programs 'train the brain' to plan, sequence, and process information more effectively through repetition of interactive exercises. During these types of clinical intervention strategies, a trainee wears stereo headphones and listens to special sounds that software programs generate to guide the training process. Motion sensing triggers, connected to the computer via cables, relay information about the trainees' performance to a computer during training. One trigger is worn like glove on either hand. It senses exactly when the hand makes contact when tapped during training. The other trigger is placed on the floor, and senses exactly when the trainee taps either a toe or heel upon it. Different hand and foot exercises are performed while auditory guide tones direct the individual to match the beat. Programs analyze the accuracy of each tap as it happens and instantaneously creates a sound that the trainee hears in the headphones.

Signal detection theory

The theory of signal detection was developed by mathematicians and engineers in the 1950s working in the fields of mathematical statistics and electronic communications. Signal detection deals with the detectability of signals and controlling the criteria that are used for the human response to stimuli. Early on, it became apparent that this theory has application to psychophysics because the observer's criterion affects the judgments they make. The theory of signal

Table 1 Common symptoms of cerebellar dysfunction.

Excessive rebound	Inability to stop the limb rapidly
Delayed motor response	Delay in initiating responses with an affected limb
Dysmetria	Judgment errors in the range and force of movement
Dysdiadchokinesia	Clumsiness in performing rapidly alternating movements
Dysnergia	Errors in timing complex multi-joint movement
Intention tremor	Tremor with fine motor precision
Titubation	Tremor of head and neck muscles
Dysarthria	Disorder of muscles of speech
Hypotonia	Decrease in muscle tone
Ataxia	Gait with wide stance and unsteady balance

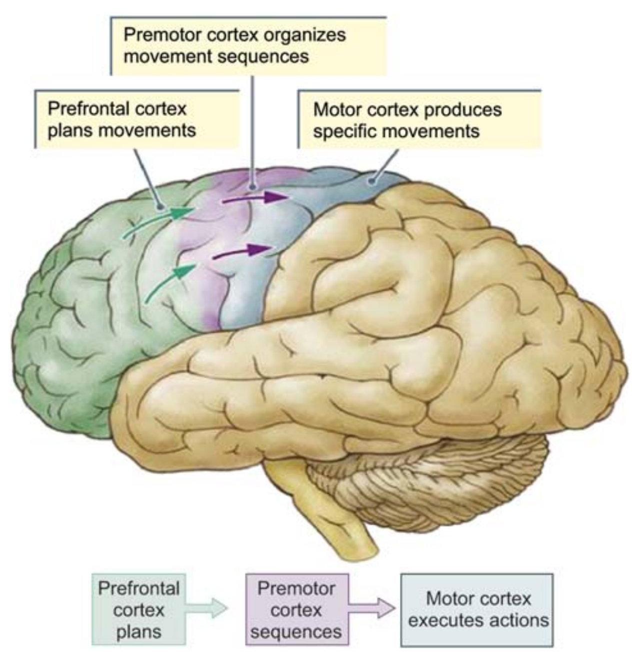

Figure 2 Cortical basis for motor sequences and planning.

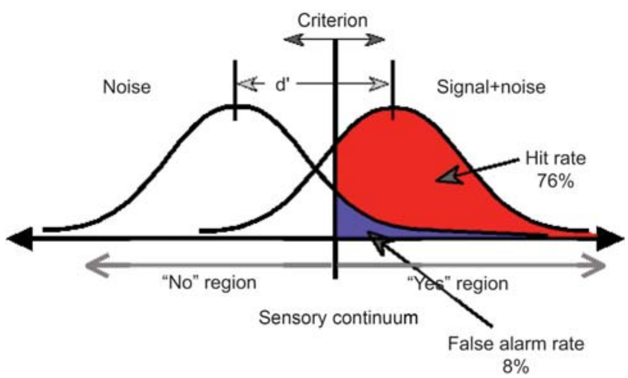

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Figure 3 Signal detection theory.

detection allows for the ability to separate the effects of the stimulus detectability from the observer's criterion in sensory experiments. Figure 3 explains the key concepts needed to understand signal detection theory.

The subject's task is to detect a signal which is presented along some sensory continuum. For example, the sensory continuum in the case of the experiment of Hecht et al. (17), was a visual continuum of flash intensity. Present in the observers' nervous system is noise that may arise from a variety of sources such as spontaneous neural discharge. When a signal, a flash in this case, was presented to the subject, in order to detect the flash, the subject had to discriminate the signal which was added to the inherent noise, from the noise alone. We think of the noise as having a distribution; at any point in time the noise has a value that varies from a mean level. We assume that the noise distribution is normal. When a signal is added to the noise, the distribution is shifted to the right along the sensory continuum. Again we assume that the signal+noise distribution is normally distributed and that it has the same standard deviation as the noise distribution alone. We can normalize these distributions (to simplify and standardize the math involved) so that the mean of the noise distribution is zero and the standard deviations of both distributions are 1.

When a signal+noise distribution (SN) is detectably different (let us assume we know the detectible difference, for now) from the noise distribution (N) the two distributions are separated by a distance called d′ (d-prime). d′ is a sensitivity index which is the distance of the mean of the SN distribution from the N distribution when the N distribution has a mean equal to zero and both distributions have a standard deviation of 1.

When a subject is presented with the signal at any particular time, the signal will fall along the sensory continuum according to the SN distribution. The subject will base his judgment of detection of the signal according to some criterion along the sensory continuum. If no signal is presented during a trial, the subject is still subject to an event at that time along the sensory continuum which has a probability associated with the N distribution. For any particular trial, the sensory event (which may be the result of a signal presentation or no signal presentation) is above the criterion level the subject will report seeing the flash. If the sensory event is below the criterion, he will report not seeing the flash.

Let us assume the subject's criterion is located at the point shown in Figure 1. If the subject is presented with multiple trials in which the signal is presented or not presented, there will be a probability associated with the subject's response due to the distributions of the N and SN. These probabilities can be summarized in a conditional probability matrix. The rows of the matrix represent the presence or absence of a signal and the columns represent the subject's response. This matrix is exemplified in Table 2A.

If the subject says he saw the signal ("yes") when it was present, this is called a hit. If the subject says he did not see the signal ("no") when it was present, this is called a miss. If the subject says he saw the signal ("yes") when it was absent, this is called a false alarm. If the subject says he did not see the signal ("no") when it was absent, this is called a correct rejection. The notation P(Y|SN) means the probability of a yes response given the presentation of the signal and P(N|N) means the probability of a no response given that the signal was absent.

Therefore in the example presented here the table would look like that represented in Table 2B. For example, when the signal is not present, there will be a false alarm rate of 8%. Notice that the probability sums to 1.0 reading across the table.

Childhood ADHD is primarily characterized by an unusual level of motor activity, impulsivity, and attention-related deficits. Among the issues reportedly deficient in these children include changes in perceptual and response strategy (e.g., the decrease of signal-detection measures of d′/d′ (less sensitive detection threshold) and β-criterion (more liberals response-bias) (18, 19).

The research question being investigated here is what is the effect of rhythmic intervention strategies using a motor sequencing training program on ADHD children during the first and second grade years, on detection thresholds and the ability to maintain signal detection performance over short periods, and the influence of feedback on performance in these children rhythmic, psychomotor, and attentional performance? Signal detection methods will be examined to reflect the ability of children to remain on task in terms of stimulus detection (d′) and decide cautiously or liberally (β-criterion)

Table 2A Four possible outcomes of signal detection.

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	Response	
	"Yes"	"No"
Stimulus		
Present SN	P(Y|SN) Hit	P(N|SN) Miss
Absent N	P(Y|N) False Alarm	P(N|N) Correct Rejection

2B

	"Yes"	"No"
SN	0.76	0.24
	0.08	0.92

to minimize target omissions or false alarms. We were most interested in examining whether an intervention program of interactive rhythmic training would have any significant effect on signal detection performance in the children being examined.

Methods

Subject distributions are shown in Table 3. A group of 36 male children aged 6–11 years, diagnosed with ADHD was selected. They presented with inattention, hyperactivity, impulsivity, academic underachievement, or behavior problems, and all met the criteria of the Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition and clearly demonstrated the absence of coexisting conditions, including learning disabilities. The children were patients at clinics in New York, San Francisco, South Carolina, Massachusetts, and Australia. The children had homogeneous WISC IQ Scores of 90 or better. The children were treated with a 3-month course of motor sequencing training. A second group of 42 male children aged 6–11 years, with ADHD were selected as above, but were not treated with a 3-month course of motor sequencing training. Children in each of the groups were randomly assigned. A third group of 16 normal male children aged 6–11 years were the matched control group and receives a 3-month course of exposure to the sequencing training. A fourth group of normal children received no motor sequencing training. A Hotellings t-test was used for statistical comparisons of subjects for matching normal subjects to the other groups. In all cases, pre- and post-treatment objective academic performance measures and neuropsychological tests were analyzed. These data are available as part of the developmental and educational experiences of each subject, and are consistent across subjects.

Procedure

Because perceptual motor skills enable children to process concrete information, they are the foundation upon which one develops the capacity to manipulate abstracts. In addition, there is some degree of continuity between early and late dimensions of perceptual development. Therefore, a signal detection task was used (20).

Each child pressed a key on a keyboard in response to a number of letters presented on a computer monitor. Most of the letters were "V" (Noise). On some of the trials a "U" also appeared on the screen (Signal). The child's task was to detect the letter "U" and to indicate this by pressing the appropriate keys whether there was a "U" present (Signal+Noise) or not (Noise only).

Each child performed two blocks of 150 trials each with the order of the blocks randomized. The child won points for correct responses and lost points for errors. The child tried to accumulate as many points as he or she could. The two trials differ in the "payoffs", or the number of points won and lost for various conditions. The signal occurred on half the trials in random order. Practice trials were provided. Each display was presented for 500 ms. If the child produced 70% correct or less, the display duration was increased by 100 ms. If the child had 90% or more correct, the display duration was decreased by 100 ms. Sensitivity and bias was measured separately, using signal detection theory producing a receiver operating curve (ROC). There were one of four outcomes per trial: reporting a signal when it was present (a hit), failing to report a signal when it was present (a miss), reporting a signal when it was not present (a false alarm), or correctly reporting that no signal was present (a correct rejection).

Sensitivity (d′) and bias (b) was measured from a table of values of z for each subject individually and then averaged for each group. The probabilities of hits and false alarms were plotted for each of the two blocks of trials. Bias and sensitivity were examined between the two conditions. d′ was calculated as: d′=[z for p (false alarm)]–[z for p (hit)]. The calculation of b (the measure of bias) was calculated as follows: b=[ordinate for p (hit)]/[ordinate for p (false alarm)].

Table 3 Motor sequencing training signal detection study participants.

Group	n	Treatment
ADHD	36	Training
ADHD	42	Control
Normal	16	Control
Normal	15	Training

Results

Reports on signal detection measures are largely consistent on the issue of poorer detection performance in ADHD. Considering that d′ is likely to vary with the task requirement, few have reported on different tests in the same subjects (18). Reports have often given conflicting results on the β-criterion (18, 19, 21). This lack of consensus here is problematic considering the clear interaction between impulsivity, a feature of ADHD children, and a cautious/liberal response bias. Previous studies on signal detection ability had either worked with a non-homogenous group of schizophrenic patients or applied signal detection theory to Continuous Performance tests.

In this study we examined signal detection performance pre- and post-motor sequencing training in groups of ADHD children with and without training and a group of normal children with motor sequencing training. Table 4 presents the probability of hits and false alarms for pre- and post-treated groups and Figure 4 represents the ROC curves for these same subjects.

Discussion

It has been shown that the inferior olive plays such an important role in timing that organisms with damage to these nuclei have problems learning new motor behaviors (22, 23). Intracellular recordings from cells in the inferior olive have shown that these cells oscillate spontaneously at 8–13 Hz. The inferior olive cells fire their action potential in a rhythmic fashion and it is thought that through its connection to the cerebellum the inferior olive is responsible for the timing signal that helps

Table 4 Probability of hits and false alarms for pre- and post-treated groups.

Group	Pre-treatment	Post-treatment	Pre-treatment	Post-treatment
Normal	0.74	0.28	0.76	0.28
ADHD	0.36	0.68	0.49	0.38

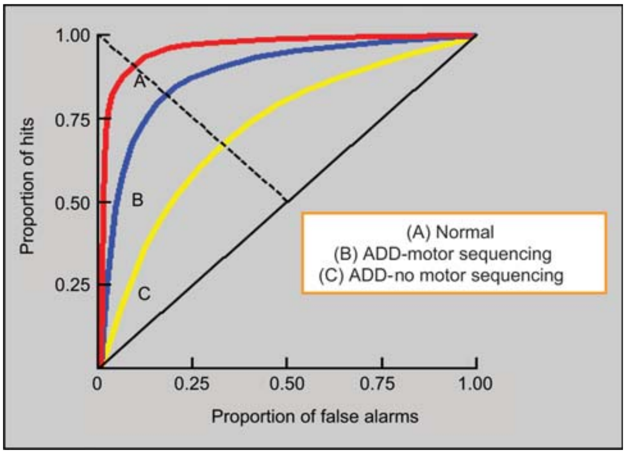

Figure 4 ROC analysis of motor sequencing feedback program subjects.

to control all movements. It is thought that the oscillation of the inferior olive results in a slight tremor of 10 Hz and occurs even when one is not moving (24). This movement, as previously described, is known as physiological tremor, allowing us to time movements as a metronome, when we learn to play the piano. It also has been demonstrated that with the experimental destruction of the inferior olive, behavioral tremor is abolished (24).

A similar type of timing mechanism is found in the cerebral cortex to help generate conscious thought. We require a mechanism with which we will be able to bind information from different sensory sources, so that the essential result will be an internal representation or sensory motor image that can associate memories or thoughts with this internal construct such as imagining or remembering. As Llinas (25) states, the task of cognition is to create an experience, which brings together elements that are truly ours with elements that are truly foreign. This same oscillatory function occurs in the brain and produces temporal coherence (26, 27). Temporal coherence according to Llinas is thought to be the neurological mechanism that underlies perceptual unity, the binding together of independently derived sensory information, or cognitive binding. This is a mechanism similar to that produced in motor binding where through the inferior olive motricity precise temporal activation of muscles is required in order to implement even the simplest movement correctly. Synchronous activation of neurons that are spatially distant is most likely to be the mechanism that improves the efficiency of the brain. Fixed action patterns set well-defined motor patterns. This has been described as motor tapes or engrams that produce well-defined and coordinated movements such as walking. These patterns are called fixed because they are stereotyped and relatively unchanged not only from individual to individual, but within the species. These patterns, however, can be seen as simple or complex motor patterns.

The fixed action patterns are seen as more elaborate reflexes that seem to group lower reflexes together to achieve a more complex goal-oriented behavior (28). This allows the brain freedom efficiency and diminishes processing capacity as the brain does not need to focus time and attention on each aspect of the specific movement, only when it needs to modulate that movement due to a change in repetition. In other words, fixed action patterns allow the brain time to do and "think" about other things rather than concentrate on a specific stereotyped movement. Fixed action pattern are more sophisticated than simply the control mechanisms for walking, which can be controlled by the brainstem and the spinal cord. Therefore, fixed action patterns are thought to reside in the higher centers of the brain.

In the case of more complex fixed action patterns such as playing an instrument, throwing a ball or swinging a bat, it is thought that these are generated centrally by the basal ganglia (29, 30). It is thought that the basal ganglia act as a storehouse of motor programs, but how this actually works is not understood. As within the cerebellum, the majority of connections within the basal ganglia are inhibitory and have many reciprocal contacts. Neural pathology of these nuclei may be due to either producing an excess of fixed action patterns thought to be seen in Tourette's syndrome or defects associated with their loss as in Parkinson's syndrome. Very importantly, fixed action patterns have evolved to improve the survivability of organisms. A correct choice needs to be made quickly and repetitively for an organism to move through the world successfully. The underlying basis of movement is built around conflicting alternatives such as approach-avoidance or approach-approach behaviors and signal detection methods is the measurement vehicle of these behaviors.

Fixed action patterns require synchronous and coordinated activations of a number of different and very specific muscle synergies, driving this motor event in a synchronous and coordinative firing of very specific motor neurons with functionally specific firing patterns, frequencies, and durations. However, the cerebral cortex has the ability to override a fixed action pattern at any given time, which still allows us an enormous number of possibilities. Even language as well as emotions is considered a fixed action pattern. Activities may not start out as fixed action patterns such as learning how to play an instrument, but through repetition they can become fixed action patterns and thereby free up the cortex from the responsibility of control and it can focus on other things. These differences are most clearly seen in the difference between letter and word-habits in learning out to type or, in fact, the learning curve associated with any sensory motor skill (14–16, 31, 32). Therefore, fixed action patterns are subject to modification, they can be learned, remembered, and perfected as we have exemplified here.

In summary, movement needs to be accomplished in an intelligent and coordinated fashion to not overload the brain and nervous system as an information processor. The brain seems to have evolved two main strategies. The first was to develop an internal clock or timing mechanism that would turn all of the muscles on and off thereby reducing demand. The perceived temporal continuity of both sensory and motor behavior, exemplified by the apparent smooth and coordinated fashion in which muscles move, belies the fact that neither sensory nor motor function continuous in actuality. This perceived continuity allows all muscles, which are not directly connected to one another to be connected in time. Therefore, functionally connected but spatially distant muscle groups could be coordinated into a purposeful movement. This is thought to be the beginning of abstract thought. An abstraction is something that does not occur in reality. Organisms coordinate their motor systems as one when they are, in fact, made up of separate independent muscles that are not directly connected and are by definition, an abstraction. We have also shown (1) how the external properties of muscles eventually become imbedded in internal areas of the nervous system and eventually the brain. This is integrated with other sensory inputs to obtain a larger picture of the organism (or self) and the surrounding world. This is then used to form a sensory motor image of that world which is critical for the nervous system to predict the most important function to be performed.

We can see that cognitive functions developed as ways to improve purposeful movement for either approach or withdrawal behaviors. The properties of muscles were imbedded deeper and deeper into the nervous system so that the nervous system would be able to compare movement to other properties of the world and generate the most accurate prediction of proper response. These control mechanisms involved in sensory-motor interaction are the largest and unique in humans and reside in the frontal and prefrontal areas of the cerebral cortex. These areas perform executive functions and it is this region of the brain that is primary affected in function and efficiency in neurobehavioral disorders of childhood. The timing mechanism strategies that developed to make motor activity more efficient were used to eventually allow us to make cognitive sense of the world. The pacemaker for muscles resides in the inferior olive and cerebellum. The oscillator or pacemaker in the cognitive realm is the thalamus. Just as muscles have no direct connection to one another, sensory information is never fused together in the cortex (28). There is no one area in the brain to which all sensory input converges that allows for thinking and emotional responsivity. However, to make sense of the world we need to combine sensations and body movement to provide a temporally and spatially resolved reality.

This study addresses the apparent lack of motor coordinative abilities of ADHD children and provides a means of demonstrating the likelihood that a large scale clinical trial of motor-sequence training would have a significant effect on improving signal detection ability and therefore attentional focus in ADHD children.

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