IM Research Packet

interactive metronome

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IMPROVEMENTS IN INTERVAL TIME TRACKING AND EFFECTS ON READING ACHIEVEMENT

GORDON E. TAUB

University of Central Florida

KEVIN S. MCGREW

Institute for Applied Psychometrics

TIMOTHY Z. KEITH

University of Texas

This study examined the effect of improvements in timing/rhythmicity on students' reading achievement. 86 participants completed pre- and post-test measures of reading achievement (i.e., Woodcock-Johnson III, Comprehensive Test of Phonological Processing, Test of Word Reading Efficiency, and Test of Silent Word Reading Fluency). Students in the experimental group completed a 4-week intervention designed to improve their timing/rhythmicity by reducing the latency in their response to a synchronized metronome beat, referred to as a synchronized metronome tapping (SMT) intervention. The results from this *non-academic* intervention indicate the experimental group's post-test scores on select measures of reading were significantly higher than the non-treatment control group's scores at the end of 4 weeks. This paper provides a brief overview of domain-general cognitive abilities believed effected by SMT interventions and provides a preliminary hypothesis to explain how this *non-academic* intervention can demonstrate a statistically significant effect on students' reading achievement scores. © 2007 Wiley Periodicals, Inc.

In recent years the role of the school psychologist has expanded to include greater involvement in students' reading acquisition, performance, and curriculum-based evaluation. This increased participation may be attributed to several national initiatives including Reading First under No Child Left Behind (U.S. Department of Education, 2002), the National Reading Panel's (2000) report, the Individuals with Disabilities Education Improvement Act (2004), and the impact of empirical research in reading on district- and state-level policies and procedures (e.g., Daly & McCurdy, 2002; Sheridan, 2004). Recent technological advancements also provided school psychologists with a broader understanding of the process of reading at a physiological level. Results from neuroscience studies (e.g., functional magnetic resonance imaging investigations involving individuals experiencing reading difficulties or diagnosed with dyslexia) have provided new insights into the process of reading at the neural level (e.g., see Katzir & Paré-Blagoev, 2006). This groundbreaking research has demonstrated individual differences in the functions of anatomically similar brain regions of impaired readers and nonimpaired readers (Katzir & Paré-Blagoev, 2006; Shaywitz & Shaywitz, 2005; Shaywitz et al., 1999, 2003).

The integration of our understanding of the process of reading at a physiological level with reading at a behavioral level (i.e., neuroscience-based interventions) may be the next frontier for school psychologists and reading research. One intervention that has received considerable empirical attention, both pro and con, is the FastForWard method (Tallal, Miller, Jenkins, & Merzenich, 1997). A lesser known neuroscience-based intervention is the use of synchronized metronome tapping, which links research on mental interval timekeeping (e.g., see Buhusi & Meck, 2005) and academic achievement. Preliminary results from this research indicate that children diagnosed

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Correspondence to: Gordon E. Taub, University of Central Florida, ED 123K, Orlando, FL 32816. E-mail: gtaub@mail.ucf.edu

with dyslexia may have deficiencies in their timing and rhythm abilities, as evidenced by their responding within a wider range of times on either side of a metronome beat, when compared to nonimpaired readers (Wolff, 2002). Similarly, McGee, Brodeur, Symons, Andrade, and Fahie (2004) reported children diagnosed with a reading disability differed from children diagnosed with attention-deficit/hyperactivity disorder (ADHD) on retrospective time perception, a finding interpreted as consistent with Barkley's (1997) behavioral inhibition theories. Research also implicated mental or interval timekeeping (time perception) in a number of academic and behavioral disorders (see McGee et al., 2004). Some researchers believe the connection between timing/rhythm and reading may be so robust that a student's mean latency response to a metronome beat may predict performance on standardized reading tests (Waber et al., 2003; Wolff, 2002). Furthermore, a recent study has suggested that elementary timing tasks may represent a form of *temporal g* that is more strongly correlated ($r = .56$) with psychometric *g* than the standard *reaction time g* ($r = -.34$) approach to measuring the *essence* of general intelligence (Rammsayer & Brandler, in press). Given the growing evidence suggesting a potentially important link between mental interval timekeeping and cognition and learning (Buhusi & Meck, 2005; Rammsayer & Brandler, in press), the connection between timing-based neuroscience interventions (e.g., synchronoized metronome tapping) and academic achievement warrants investigation.

To investigate the relationship between improvements in timing and rhythm (due to synchronized metronome tapping-based intervention) on reading achievement, Taub, McGrew, & Lazarus (2007) administered subtests from the Woodcock-Johnson Tests of Achievement III (WJ-III ACH; Woodcock, Mather, & McGrew, 2001) as pre- and posttest measures of reading. In this study, over 250 high-school-aged participants were randomly assigned to either a control or experimental group. The experimental group participated in a rhythmic synchronization metronome-based assessment and intervention technique (herein after referred to as the Interactive Metronome [IM] method), a *nonacademic* intervention. The IM treatment sessions lasted for approximately 45 minutes each day for total of about 15 hours. (The IM intervention method will be discussed in detail below.) The results from this study indicated, when compared to the control group, the experimental group demonstrated statistically significant improvements on the WJ-III ACH posttest measures of broad reading and reading fluency. Participants who received IM-based interventions also demonstrated statistically significant improvements in domains other than reading.

IM training was also reported to produce positive effects in a number of nonacademic domains. For example, after receiving IM training, participants demonstrated statistically significant improvements in golf performance (Libkuman & Otani, 2002). Shaffer et al. (2001) reported that boys prediagnosed with ADHD demonstrated improved performance, when compared to two ADHD control groups, in the domains of attention, language processing, motor control, reading, and parent report of regulation of aggressive behavior after their participation in an IM-based intervention.

Mental Interval Timing Research and Models

Cognitive psychology's interest in mental timekeeping has spanned decades. For example, cognitive differential psychologists first reported the identification of a *temporal tracking* capability in 1980 (Stankov, Horn, & Roy, 1980). Temporal tracking was identified as being found in various auditorily presented tasks that involved the mental counting or rearrangement of temporal sequential events (e.g., reorder a set of musical tones; Carroll, 1993).

Researchers in cognitive psychology have studied the phenomenon of *interval timing* through a number of research paradigms, one which requires individuals to maintain synchrony (via a bimanual motor response) with auditory tones (e.g., from a metronome), also known as synchronized metronome tapping (SMT). Tapping in synchrony with a metronome requires an individual to correct for asynchronies in their response to a reoccurring beat. The most viable theoretical explanation for SMT behavior can be derived from the pacemaker-accumulator model, which is based on scalar timing/expectancy theory (see Buhusi & Meck, 2005). Briefly, SMT asynchrony corrections are thought to be accomplished through an internal adjustment to the phase of one's underlying master mental time clock (Buhusi & Meck, 2005; Vorberg & Fuchs, 2004). This error correction is triggered when observed temporal deviations (as determined via the accumulation, in a short-term storage *accumulator*, of neural pulses or tics from a cognitive *pacemaker*) are determined to differ from a reference *standard* (which is maintained in a *reference memory*), via performance feedback. This process is referred to as an *automatic phase adjustment*. The allocation of *attentional resources* and the minimization of stimuli that may divert cognitive processing resources away from timing have been hypothesized to play a significant role in mental interval timekeeping and metronome-based synchronization of rhythmic movements (Brown & Bennett, 2006; Buhusi & Meck, 2005). In addition, the quickness and efficiency of the phase adjustment mechanism is believed to eliminate the necessity for, or excessive reliance on, long-term memory (e.g., accessing the reference memory) or learning (Vorberg & Fuchs, 2004).

How SMT-Based IM Training Works

During IM training participants wear a headphone and listen to a reoccurring metronome beat. As they listen to the beat, they engage in physical movements such as clapping hand-to-hand with a sensor on one palm as they match their physical movement to the presentation of the beat (e.g., clap at the beat). The goal of IM training is to reduce the mean negative synchronization error during normal tracking of the regularly occurring metronome beat (clapping prior to or past the beat).

During training, participants receive feedback through an auditory guidance system as they progress through the simple, interactive physical movements. Although feedback is also provided through visual stimuli, the auditory feedback guidance system is the primary feedback method. The auditory feedback system provides tonal stimuli that indicate whether the participant responded *prior to*, *at*, *or past* the regularly occurring auditory metronome beat. The accuracy of participants' expectancy response to the metronome beat is provided in milliseconds (ms), with different tones indicating *far from*, *close to*, or *at* the metronome beat. A visual reading of millisecond latency is also presented on a computer screen.[1] The purpose of IM training is to improve participants' timing/rhythmicity by reducing the latency between the onset of the metronome beat and participant's expectancy response to the beat. After about 3–4 weeks of training, or 15–18 hours, participants are typically able to respond to within approximately 15 ms on either side of the beat. This compares to the average 80–100 ms latency response prior to training. At the completion of training, participants typically have engaged in approximately 25,000 motoric repetitions. These movements are the physical indication of one's expectancy of the onset of the metronome beat. Collectively, results from initial studies suggest that statistically significant improvements in a *domain-specific* SMT-based intervention are associated with statistically significant *domain general* improvements in the areas of academics, ADHD, and sports. How can rhythmic SMT-based interventions result in improved performance across such diverse domains of human performance as academics, ADHD, golf, and tennis?

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[1] Readers are referred to the Interactive Metronome, Inc.'s Web site to view a corporate-sponsored video showing IM training or to obtain additional information: http://www.interactivemetronome.com.

Purpose

Although hypothesized domain-specific cognitive mechanisms are possible, the domain-general or cross-domain SMT training effect is intriguing and argues first for replication of prior studies and second for investigation of potential domain *general* cognitive mechanisms to account for observed cross-domain improvements. Given this assumption, the purpose of this study was twofold.

The first purpose was to replicate an earlier study by examining the impact of improvements in timing/rhythmicity on students' reading achievement. The second purpose was to offer preliminary hypotheses that will contribute to a better understanding of the across-domain general cognitive mechanisms that may explain SMT treatment effects across such diverse human performance domains as academics, ADHD, and sports.

METHOD

Participants

Study participants included 86 students attending a public charter school receiving Title 1 funding located in Central Florida. As a public charter school, the school is a part of the public school system; the key difference between the public charter school and a public school is that the charter school receives funding directly from the State of Florida. The school currently has 133 students and provides education from kindergarten through fifth grade. All students attending the school are African-American, and 83% of the students receive free lunch. The study participants ranged in grade from first to fourth grade. There were 16 first-, 36 second-, 23 third-, and 11 fourth-grade students in the study. A total of 37 participants were male and 48 were female. Participants' ages ranged from 7 years old to 10 years old with a mean of 8.15 years (*SD* = 1.0).

Instruments

The instruments administered to evaluate the effects of IM training on participants' academic achievement and attention/concentration include selected subtests of the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999), Test of Silent Word Reading Fluency (TOSWRF; Mather, Hammill, Allen, & Roberts, 2004), Test of Word Reading Efficiency (TOWRE; Torgesen, Wagner, & Rashotte, 1999), and the WJ-III ACH (Woodcock et al., 2001). Table 1 provides a brief description of each test and identifies the specific subtests administered from each instrument.

Reliability

Most of the reported average internal consistency and alternate form reliability coefficients of the CTOPP exceed .80 and the test–retest coefficients range from .70 to .92 (Wagner, Torgesen, & Rashotte, 1999). The reported average alternate forms' reliability coefficients of the TOWRE all exceed .90 and the test–retest coefficients range from .83 to .96 (Torgesen, Wagner, & Rashotte, 1999). The median reliability coefficients of the tests selected from the WJ-III ACH are all at or above .87 (McGrew & Woodcock, 2001).

A lesser know test was the Test of Silent Word Reading Fluency. This instrument was standardized on 3592 individuals representing demographic characteristics that were similar to the 2001 U.S. Census data in terms of geographic region, gender, race, ethnicity, and parents' educational background. The instrument's normative tables are grouped in 3-month intervals for students ages 6-6 through 7-11, 6-month intervals for students 8-0 through 10-11, and at 1-year intervals for students ranging from 11-0 through 17-11 years of age. Reported test–retest reliabilities

Table 1
Names and Description of the Pretest and Posttests

Test	Description of tests and combinations of tests
Test of Oral Word Reading Efficiency	*Sight Word Efficiency*: A timed test of word recognition and decoding fluency, measures the ability to accurately and quickly recognize familiar words *Phonemic Decoding Efficiency*: A timed test measuring the ability to accurately and quickly read phonetically regular nonsense words. *Total Word Reading Efficiency*: Combines Sight Word Efficiency and Phonemic Decoding Efficiency.
Test of Silent Word Reading Fluency	Students are presented with several rows of words, which increase in difficulty. There are no spaces between the words (e.g., didhimgot). Students are required to draw a line between the boundaries of as many words as possible (e.g., did/him/got) within a 3-min time limit.
The Comprehensive Test of Phonological Processing	*Blending Nonwords*: Phonetic coding synthesis task of nonwords—an auditory processing task that is independent of acquired knowledge (less dependent on students' existing knowledge). *Segmenting Nonwords*: Phonetic coding analysis task of nonwords—an auditory processing task that is independent of acquired knowledge. *Rapid Digit Naming*: Rapid automatized naming test of digits. *Rapid Letter Naming*: Rapid automatized naming test of letters. *Rapid Naming Composite*: Combines Rapid Digit Naming and Rapid Letter Naming. *Alternate Phonological Awareness Composite*: Combines Blending Nonwords and Segmenting Nonwords.
Woodcock-Johnson III Tests of Achievement	*Letter-Word Identification*: Untimed measure of sight-word recognition. *Passage Comprehension*: Measure of reading comprehension and word knowledge. *Reading Fluency*: A timed test measuring reading speed, automaticity and rate of test taking. *Word Attack*: Untimed test requiring pronouncing nonwords that conform to English spelling rules.

for students ranging in age from 7 to 10 years of age, the age range of the present study, were all above .80, and the alternate form reliability coefficients exceeded .85 (Mather et al., 2004).

Procedure

All students completed a pretest battery of psychoeducational instruments (see Table 1). After completing the pretests, students were randomly assigned to either an experimental or control group. The experimental group participated in the IM intervention, at their school, during regular school hours. While the experimental group was participating in the IM intervention, the control group and nonparticipating classmates engaged in recess activities. Students in the experimental group were divided into four groups, one for each grade level. Two certified master trainers worked separately with each of the four grade-level groups. The groups ranged in size from 7 to 12 participants. The students in the experimental group participated in an average of 18 sessions, each lasting approximately 50 minutes. There was one treatment session each day per group. Upon completion of the IM intervention, posttests were administered to all participants. The same tests were used during the pre- and posttest administrations.

Participants completed both individually and group administered tests; however, the TSWRF and WJ-III ACH's Reading Fluency were the only group-administered tests. During the individual assessment each evaluator worked with a student one on one. The individual assessment took approximately 35 minutes to complete. Group administrations were conducted in the students' own classrooms and participants from the experimental and control group completed all group tests together as classmates. Students who were unable to participate and/or who were absent on the day of the group assessments completed the group tests either individually or with other nonclassmate students. During all test administrations the test proctors and administrators were unaware of each student's group assignment. A lead test administrator directed all group assessments. The administrator followed the standardized instructions included in each test's manual. For one test, WJ-III ACH Reading Fluency, minor modifications were made in standardized administration procedures to facilitate group administration of the test. Several steps were followed to ensure that standardized test administration procedures were followed as closely as possible. These steps included (a) a doctoral-level proctor was present during all group administrations, (b) a minimum of one proctor to every four students was maintained during all group administrations, (c) all test proctors were graduate-level school psychology students who either completed or were near completion of their second psychoeducational assessment course, and (d) if a student did not accurately complete a sample item, the group administration was stopped and the proctor followed standardized administration procedures to ensure adequate completion of the sample item. All students progressed through the group test administration at the same time.

Results

Unless otherwise noted, all analyses controlled for pretest scores using the same measure as the posttest (through analysis of covariance). For analyses that did not use developmentally based scores, such as raw or growth scores, age was also controlled in the analyses by entering age as a covariate in the ANCOVA. Given the prediction that statistically significant differences would favor the experimental group, one-tailed tests ($\alpha = .05$) were used to evaluate statistical significance.

Effects on Timing/Rhythm

The initial analysis examined the effect of IM training on timing and rhythm as measured by the IM assessment system. The IM treatment had a statistically significant effect on posttest timing and rhythm scores, with pretest score controlled, $F(1,76) = 107.376$, $p < .001$. Furthermore, the treatment had a large effect (Thompson, 1999) on the posttest outcome ($\eta^2 = .586$, $g = 1.974$). IM training accounted for more than 50% of the variance in IM posttest scores and resulted in close to a two standard deviation increase in those scores (with IM pretest scores controlled).

It seems likely that IM training should be more effective for children who initially showed poor performance (high scores) on the measure of timing and rhythm. Sequential multiple regression was used to evaluate the possibility of a statistically significant interaction between the pretest and treatment. The IM posttest was regressed on the centered IM pretest and group membership in one block, with the centered pretest by group cross-product entered in a second block. As summarized in Table 2, the addition of the cross-product to the regression resulted in a statistically significant increase in R^2, indicating that the Pretest × Treatment Group interaction was statistically significant. The nature of the interaction is demonstrated in Figure 1, which shows separate regression lines for the posttest on the pretest, by treatment group. The lines show that the experimental group performed better on the posttest than did the control group, but that training was indeed most effective for participants with poor initial timing/rhythmicity.

Reading

Multivariate analysis of covariance (MANCOVA) was used to test the effect of IM training on the four measures of reading skill from the WJ-III ACH (Letter-Word Identification (LW-ID),

Table 2
Sequential Multiple Regression to Test Whether IM Training Was More Effective for Those with Initially High (Poor) Scores on Timing/Rhythmicity

Variables entered	ΔR^2	*p*
IM Pretest (centered), Treatment Group	.707	$<.001$
Pretest by group cross-product	.082	$<.001$

Reading Fluency, Passage Comprehension, and Word Attack). Pretest scores on these measures were used as covariates. As recommended by the test authors, *W* scores (a continuous, equal interval growth scale scores) were used for these analyses. The results of this analysis (and subsequent MANCOVA results) are summarized in Table 3. As shown in the table, the IM training did not demonstrate a statistically significant effect on reading achievement as measured by the WJ-III achievement tests.

Table 3 also shows the effects of IM training on measures of reading efficiency, TOWRE (Sight Word, Phonemic Decoding), and fluency, TSWRF. For this set of analyses, standard scores ($M = 100$, $SD = 15$) were used as both pre- and posttest scores; pretest scores and age were the

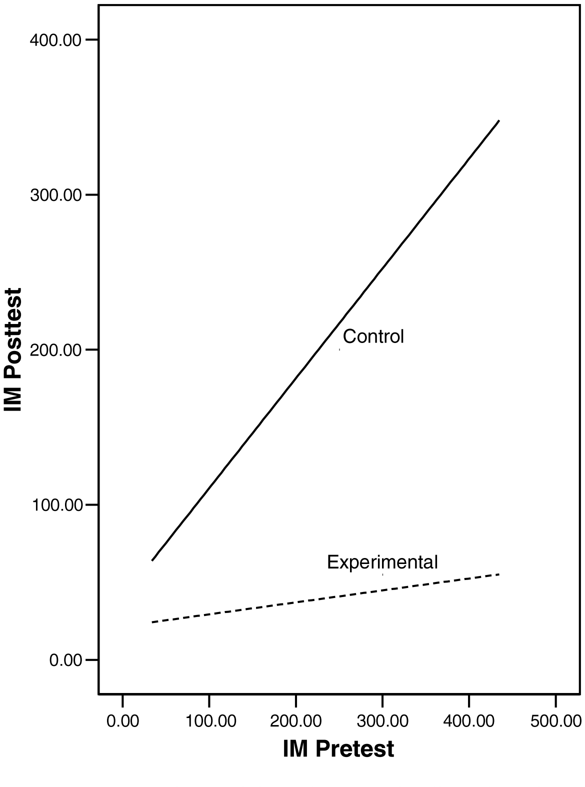

FIGURE 1. Interaction between IM pretest and IM training. The regression lines show that IM training was most effective in improving the timing and rhymicity of children with initial poor performance (low scores represent better performance).

Table 3
MANCOVA Results: Effect of IM Training on Reading

Measures	Hotelling's trace	$F(df)$	p	η^2
WJ Achievement Reading	.045	.842 (4, 75)	$>.05$	.043
Reading Efficiency & Fluency	.098	2.414 (3, 75)	.037	.089
CTOPP Phonological Processing	.205	3.899 (4, 76)	.003	.170

controlled variables. As shown in the table, the IM training produced a statistically significant effect on measures of reading efficiency and fluency. Participants who received IM training scored at a higher level on the multivariate dependent variable. The IM treatment accounted for 8.9% of the variance in reading efficiency and fluency, a small effect size (Keith, 2006, p. 508). Follow-up tests (univariate ANCOVAs) revealed a statistically significant effect for the TOWRE Sight Word Efficiency measure, $F(1,76) = 5.881$, $p = .009$, $\eta^2 = .072$, $g = .481$,[2] but not for the other measures.

Table 3 also shows the results of analyses of the IM effects on phonological processing skills as measured by the CTOPP (digit naming, letter naming, segmenting, and blending). Participants who received IM training demonstrated statistically significantly higher CTOPP scores, and the IM treatment accounted for 17% of the variance in CTOPP scores, a moderate effect. Univariate follow-up statistical analyses revealed statistically significant effects on the letter naming subtest, $F(1,79) = 8.680$, $p = .002$, $\eta^2 = .099$, $g = .536$, but not for the other components of the CTOPP.

Discussion

The current study employed a pre-/posttest evaluation design to investigate the effect of a specific SMT intervention (viz., Interactive Metronome) on reading performance in a sample of 86 first-, second-, third-, and fourth-grade students in a public charter school receiving Title 1 funding. Participants were randomly assigned to either an experimental (IM) or control group. The experimental group participated in a 3–4-week IM intervention designed to improve their timing/rhythmicity. The control group engaged in recess activities with nonparticipating classmates during each of the approximately 50 minute daily intervention sessions. All participants completed the same reading pre- and posttest measures, which were then analyzed via statistical methods that controlled for initial pretest performance levels and age (ANOCOVA, MANOVA).

Timing and Rhythmicity Treatment Findings

The results indicated that the IM treatment produced significant improvements in the timing and rhythmicity of elementary school students (as measured by the IM measurement system). The students in the IM treatment group, when compared to the control group, demonstrated statistically significant improvements, close to a two standard deviation increase in measured timing and rhythmicity scores.

IM treatment transfer effects were evaluated vis-à-vis pre-/posttest changes on standardized measures of reading achievement. The reading-dependent variables sampled four of the five reading skills identified as critical for early reading success by the National Reading Panel (2000). The

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[2] We know of no formula for calculating Hedges' g for overall MANOVA results. Therefore, partial η^2 is reported for MANOVA results and both η^2 and g are reported for the univariate follow-up tests.

reading-dependent variables included standardized measures of phonics, phonological awareness, reading fluency, and comprehension. The fifth key reading skill, vocabulary, was not measured.

Before discussing the IM academic transfer effect findings, it is important to note this intervention did *not* include instruction or training of any kind in phonics, phonological awareness, and/or reading—this was *not* an *academic* intervention. The IM intervention is designed to improve participants' timing and rhythmicity through beeps, tones, tapping, and clapping. In other words, it would not be expected that participants in an intervention designed to improve timing and rhythmicity would demonstrate changes in reading achievement. Furthermore, the experimental IM treatment lasted approximately 3–4 weeks. Developmental *growth* curves based on nationally standardized reading tests (McGrew & Woodcock, 2001) suggest that similarly aged students (8.2 years) typically demonstrate little academic growth (as reflected by norm-referenced tests) over a 3–4-week period.

Reading Achievement Findings

Analysis of the individual reading tests indicated that the IM intervention produced significant transfer effects in phonics, phonological awareness, and reading fluency. Students in the IM experimental group demonstrated statistically significant improvement in their ability to *fluently* recognize familiar words within a *limited timeframe* (TOWRE test). In contrast, no significant treatment effect was demonstrated on an *untimed* word recognition measure (WJ-III LW-ID test). It is important to note that the primary difference between the TOWRE and WJ-III LW-ID tests is that of a *rate fluency* (TOWRE) versus *level* (WJ-III LW-ID) distinction. *Rate fluency* refers to the time taken to work from the beginning of a test to the end of a test. *Level* refers to the difficulty of an item or task (see Carroll, 1993).

Within the context of a rate-fluency/level-ability distinction, the current results suggest the hypothesis that although students did not *learn* to recognize more familiar words in isolation (i.e., their absolute word recognition *level* did not increase), they were able to recognize the words they previously *knew* faster (i.e., the fluency of their level of word recognition skills was improved). It appears that SMT-based IM treatments may demonstrate transfer effects on reading fluency/efficiency of existing word recognition skills, but not increase the overall level of word recognition skills in a student's repertoire.

The IM treatment group also demonstrated statistically significant pre- to posttest improvement accounting for 8.9% of the variance on an equally weighted multivariate reading composite measure (TOWRE and TSWRF). More impressive, however, was the posttest improvement accounting for 17% of the variance on a multivariate composite score that included the CTOPP tests Digit Naming, Letter Naming, Segmenting Nonwords, and Blending Nonwords and accounted for 9.9% of the variance on the CTOPP rapid automatized naming (RAN) test Letter Naming.

An alternative way to examine effect size is Hedges *g* (Howell, 2002). This statistic may be used to explain effect size as a percentage of growth, using a normal curve. Applying Hedge's *g* to the current results, the experimental group experienced a 20% growth on the CTOPP's RAN Letter Naming test and an 18% growth on the TOWER's Sight Word Efficiency. These growth rates compare favorably to the 15% growth identified in a meta-analysis of phonics instruction verses whole-word instruction conducted by the National Reading Panel's Committee on the Prevention of Reading Difficulties in Young Children (National Reading Panel, 2000).

The pre- to posttest reading achievement results suggest that improvements in timing and rhythmicity were associated with statistically significant improvements in three of the five major areas of measured reading: phonics, phonological awareness, and fluency. Yet, the results are not conclusive and must be moderated with a number of cautions. First, the experimental group did not demonstrate statistically significant increases on all the TOWRE's subtests. Second, although a significant improvement was observed on the CTOPP Letter Naming test, participants' performance on a similar test (Digit Naming) was not statistically significant. The key difference between the two tests is that the Letter Naming Test uses 26 letter stimuli, whereas the Digit Naming test's stimuli consist of 9 single-digit numbers. Third, on another measure of fluency (viz., WJ-III Reading Fluency) there was no statistically significant treatment effect. The lack of a significant effect for WJ-III Reading Fluency is at variance from a previous study involving high school students, wherein the experimental group demonstrated a statistically significant, 1-year grade level, improvement on the WJ-III Reading Fluency test (Taub, McGrew, & Lazarus, 2007).

Collectively, the current reading results suggest that students in the experimental IM treatment group demonstrated statistically significant improvements on more *fundamental* early reading skills (i.e., phonics and phonological awareness) and in their speed of processing basic lexical information (e.g., RAN for letters). However, with the exception of fluency of word recognition (i.e., Sight Word Efficiency test), students in the experimental group did not demonstrate statistically significant improvements at the single-word level.

Possible Causal Explanations: A Proposed Explanatory Framework and Preliminary Hypotheses

Previous IM intervention research reported statistically significant improvements in high schools students' performance on measures of reading recognition and reading fluency compared to a nontreatment control group (Taub, McGrew, & Lazarus, 2007). Similarly, IM-treated students with ADHD were reported to demonstrate statistically significant improvements in attention, reading, and language processing (Shaffer et al., 2001). This small collection of academically related studies, investigating direct reading achievement indicators and behaviors that exert an indirect causal influence on achievement (i.e., attention and concentration), are intriguing and suggest the need to focus efforts on understanding *why* improvements in timing and rhythmicity (via SMT interventions) display such far-point transfer effects.

In an effort to jump start efforts directed at understanding the underlying SMT–academic causal mechanisms, it is proposed that SMT-based research needs to be placed in a theoretically sound and empirically based research/conceptual framework. Furthermore, it is argued that the observed positive cross-domain or domain-general effect of SMT-based interventions result from improvements/changes within a domain-general cognitive mechanism (or a small number of domain-general mechanisms). Based on a review of relevant mental interval timekeeping literature, the following preliminary hypotheses are offered.

Master Internal Clock Based on Scalar Timing Theory

To deal with time, organisms (animal and human) have developed multiple timing systems that are active in more than 10 orders of magnitude with various degrees of precision (Buhusi & Meck, 2005). According to Buhusi and Meck, humans have developed three general classes of timing systems (circadian, interval, and millisecond timing), each associated with different behaviors and brain structures/mechanisms. The millisecond timing system, which is involved in a number of classes of human behavior (e.g., speech, music, motor control) and that primarily involves the brain structures of the cerebellum, basal ganglia, and the dorsolateral prefrontal cortex (Buhusi & Meck, 2005; Lewis & Miall, 2006), is most relevant for understanding SMT-based interventions.

Pacemaker-accumulator model. Human behavior based on the perception and timing in the range of seconds to minutes has traditionally been explained by the predominant model of interval timekeeping, namely, the *pacemaker–accumulator model* (PAM). The PAM, which is based on the *scalar expectancy or timing theory* (Church, 1984; Gibbon, Church, & Meck, 1984; Meck, 1983), "is relatively straightforward, and provides powerful explanations of both behavioral and physiological data" (Buhusi & Meck, 2005, p. 755).

Briefly, the PAM model implicates the processing of temporal information via three synchronized *modular information processing systems* (see Buhusi & Meck, 2005). The *clock* system consists of a dopaminergic *pacemaker* that regularly generates or emits neural ticks or pulses that are transferred (via a *gaiting* switch) to the *accumulator*, which accumulates ticks/pulses (neural counting) that correspond to a specific time interval. The raw representation of the stimulus duration in the accumulator is then transferred to working memory, a component of the PAM *memory* system. The contents of working memory are then compared against a *reference standard* in the long-term (reference) memory, the second component of the PAM memory system. Finally, the *decision* level of the PAM is conceptualized to consist of a *comparator* that determines an appropriate response based on a decision rule that involves a comparison between the interval duration value present in working memory and the corresponding duration value in reference memory. In other words, a comparison is made between the contents of reference memory (the standard) and working memory (viz., are they "close?").

Given evidence that supports a domain-general master internal clock central to many complex human behaviors (see Buhusi & Meck, 2005; Lewis & Miall, 2006), it is suggested that the *master internal clock* may be the mechanism that mediates SMT performance and intervention effects. It is hypothesized that SMT training improves human performance across a number of domains (e.g., reading and ADHD) via an increase in the *clock speed* of the master internal clock.

It is beyond the scope of the current study to describe the specific hypothesized brain mechanisms that produce a higher *clock speed* for the internal master clock. What is important to note in the current context is that mental interval timekeeping and temporal processing research has suggested that a *higher mental clock rate* enables individuals to perform specific sequences of mental operations faster and reduces the probability of interfering incidents (i.e., less disinhibition). These two conditions produce superior performance on cognitive tasks as well as more efficient basic information processing skills (Rammsayer & Brandler, in press).

The Master Mental Clock and Cognitive/Neuropsychological Constructs

The major components of PAM-based mental interval timekeeping have strong similarities to a number of domain-general cognitive mechanisms featured in contemporary cognitive information processing and/or neuropsychological research. Working memory, which is pivitol to PAM, is a central concept in major models of information processing. In addition, the PAM long-term (Buhusi & Meck, 2005) memory likely invokes early stages of memory consolidation in long-term memory or storage, another major component of information processing models of cognition. Furthermore, the *if-then* decision-making function of the PAM *comparator* is a function typically associated with skills involved with executive functioning (e.g., monitor, evaluate, change). Finally, research has implicated the important role of *attention* during the cognitively controlled portions of interval timing (Buhusi & Meck, 2005). Therefore, it is hypothesized that a conceptual cross-walk between the major components of the PAM master internal clock and contemporary cognitive information processing theories suggests that SMT performance and SMT transfer effects result in an increased efficiency in the functioning of the domain-general cognitive information processing mechanisms of (a) working memory, (b) executive functioning, and/or (c) controlled or executive attention.

Working Memory, Executive Functioning, and Executive Controlled Attention

Executive functioning (EF), which is also frequently called the *central executive system*, is a term used for a broad construct that represents a cluster of skills necessary for efficient and successful goal-directed behavior (Welsh, 2001). The EF constructs of planning, monitoring, inhibituation, and attention/concentration, elicit a range of basic cognitive processes (e.g., attention, perception, language, and memory) that are coordinated for a very specific purpose: subserving goal-directed behavior.

EF processes are believed to work in symphony to facilitate goal-directed task completion. Timing and processes related to mental timing are believed to be a component of executive function (Welsh, 2001), as is the utilization of executive functions during reading performance (Bull & Scerif, 2001). Because EF is an integration of a constellation of abilities necessary for the planning, self-monitoring/regulating, and evaluation of successful task completion, the area of self-regulated learning has received considerable attention with regard to a variety of cognitive activities (e.g., meta-cognition, pre-attentive processes, sluggish attentional shifting, specific strategy selection and implementation, inhibition, multitasking activities, task switching, maintenance of information under conditions of interference, and resistance to interference; Bull & Scerif, 2001; Borkowski, Carr, & Pressley, 1987; Kane, Bleckley, & Conway, 2001). The central role of EF in the enhancement of selective or controlled attention, the ability to switch between plans and strategies, and the inhibition of task-irrelevant information (intrusions) in working memory (Engle, Tuholski, Laughlin, & Conway, 1999; Passolunghi & Siegel, 2004) is consistent with theoretical and descriptive interpretations of SMT and interval time tracking models.

It is proposed that the *executive controlled attention model* of working memory (Engle, Kane, & Tuholski, 1999; Kane, Bleckley, Conway & Engle, 2001), which invokes the EF system, should be entertained as a potentially useful initial model to explain the domain-general effects of SMT-based interventions. Briefly, the executive controlled attention working memory model hypothesizes that individual differences in task performance are related to EF *controlled attention*. This means that individuals with higher working memory demonstrate better (or more efficient) use of attentional resources and are more able to resist interference during the encoding and retrieval processes than individuals with lower working memory. It is our hypothesis that SMT training does not improve working memory by increasing capacity, rather that SMT training may result in more *efficient* use of an individual's working memory system. The central role that the *general* capability to *efficiently process* information plays in task performance is consistent with a general mechanism explanation for the diversity of across-domain effects of SMT training. Central to the controlled attention working memory model is the role of EF. The alternative working memory view, which argues more for emphasis on underlying *modality-specific* working memory subprocesses (Palladino, Mammarella, & Vecchi, 2003), in contrast to resource-sharing models, presents a much more complex alternative model by which to explain positive SMT training effects across such diverse performance tasks (although it would be inappropriate to completely discard it as a possible explanation at this time). The search for a domain-general mechanism to explain SMT generalized training effects, such as the controlled attention working memory model, represents a more parsimonious approach that is believed to be preferred as formative attempts are made to describe and explain SMT training effects.

Finally, the recent suggestion that *g* or general intelligence (the most enduring and robust domain-general cognitive mechanism in the history of the psychometric study of intelligence) may be more a function of *temporal processing* and not necessarily reaction time (as measured by the traditional Hick paradigm; Rammsayer & Brandler, in press) suggests that mental interval timekeeping models (e.g, PAM) may describe and explain a primary elementary cognitive mechanism involved in most all complex human behavior. If *temporal g* exists, then the across-domain positive treatment effects of SMT training might be explained as the improvement of general neural efficiency via greater resolution of the temporal *g* internal clock.

Summary

This study investigated the effect of a SMT training intervention on elementary-school-age students' reading achievement. The observance of statistically significant improvements in the experimental group's performance on posttest measures of reading, when compared to the control group, is impressive given the nature of the *nonacademic* intervention. Yet, the results are not conclusive and are inconsistent in some cases. For example, the elementary school students scored significantly better on a timed single word recognition test, yet, there was no significant between-group difference on a measure that required reading short simple sentences (WJ-III Reading Fluency). Also, previous research with high school students reported a statistically significant relationship between SMT improvements and reading fluency. One possible explanation for the divergent developmental intervention effect findings is that elementary school students are *learning how to read*, whereas high school students are *reading to learn*. In other words, high school students have mastered or automatized their reading skills, whereas the elementary school students are learning how to read.

Nevertheless, the automatization of critical early reading skills (viz., phonics, phonological awareness skills, and RAN performance), which emerge primarily during the early school grades, are the specific areas where the elementary-aged experimental participants demonstrated the most significant improvements in the current study. It is also possible that studies (the current study, inclusive) that have reported improvements in timing and rhythmicity over short periods (3–4 weeks) may only demonstrate significant effects on the processing of overlearned (automatized) information, in contrast to the more deliberate or controlled learning of new information. This may also explain why golfers, who presumably have overlearned their golf swing, become more accurate with improvements in timing/rhythmicity.

It is believed that subcomponents of the constellation of executive functioning are effected by SMT interventions. Because of the cross-domain influence of working memory on task completion, the executive controlled attention model of working memory, which is heavily dependent on the executive functioning system, was hypothesized as a potentially useful model for conceptualizing SMT research and for interpreting research findings. The executive controlled aspect of working memory was suggested as a possible general cognitive mechanism responsible for the observed positive influence of SMT training across such diverse domains as academics, athletics, and attention/concentration.

Limitations and Future Research

This study may be limited by participants' parents self-selection to have their child attend a public charter school receiving Title 1 funding. Participants may also have been more similar on several demographic variables (e.g., ethnicity, socioeconomic status) than would be found in public school settings.

Because of the relatively small sample size it was not possible to make a distinction between students receiving special education services and those who were not. It is recommended that future studies examine this difference as well as investigate differential SMT training effects with regular education students experiencing academic difficulties. It is also recommended that future studies investigate SMT training effects with students who were unable to graduate or progress to the next grade level because they did not reach a threshold score on high-stakes tests of academic achievement.

Finally, in the present study posttests were administered immediately after SMT training; therefore the stability of the observed positive effects of SMT training on the academic achievement dependent variables is not known. It is recommended that future studies investigate the consistency of the observed positive effects of SMT training on academic achievement over an extended period.

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Dr. Neal Alpiner: MD
William Beaumont Hospital
White paper and results to be presented at national PM&R conference 2004

Results Summary

The Role of Functional MRI in Defining Auditory-Motor Processing Networks

OBJECTIVE: To determine if existing auditory-motor processing networks can be augmented through specific auditory-motor sequencing tasks, effectively training the brain through synaptic modulation.

METHODS: Seven normal adults (age 26-64; 4M, 3F) were selected because of their extensive training in Interactive Metronome* (brain-based computer driven auditory-motor sequencing program). One subject without IM training was used for control. fMRI was selected because of its ability to correlate cerebral blood flow with neuronal activity via changes in deoxyhemoglobin. The subjects were placed in the scanner, instructed to use the scanner's internal cycling noise ("chirping") to simulate IM auditory cues. These guide sound cues allowed for the subject to recreate learned auditory-motor behaviors. All subjects used right hand-leg neuropatterns. 512 images were acquired during the subject's 30 second on/off performance. Images were acquired using T1 weighted echo, TE 60 ms, TR 3 sec, flip angle 90 degrees, 1.5 MRI system.

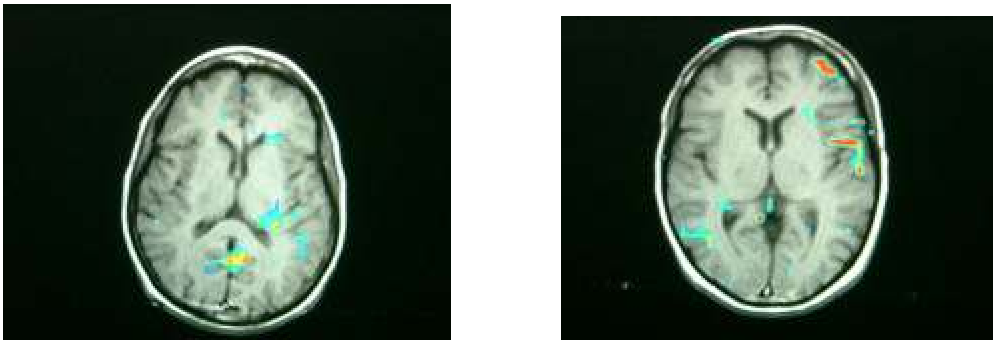
RESULTS: 5/7 subjects revealed increased activity at right Calcrine Sulcus, 3/7 showed bilateral increased activity at Cingulate Gyrus. 5/7 subjects showed increased activity at left posterior Temporal Gyrus, 2 patients show bilateral increased temporal activity. 3/7 patients show increased activation at right superior Frontal Gyrus, 4/7 patients showed increase at left Superior Frontal Gyrus with 1 patient revealing bilateral activation. 3/7 patients showed activation at left Posterior Central Gyrus. The 1 patient without IM training had absent activity.

CONCLUSION: Auditory-motor processing is complex, working through multipal neuronetworks. This present study provides a preliminary analysis of possible structures involved, specifically: Cingulate Gyrus, Temporal Gyrus, Superior Frontal Gyrus. Of note is the significance of bilateral activation for these tasks. Repetitive auditory-motor training, specifically IM holds promise for neuroplasticity of higher and lower brain centers.

fMRI Study Summary

"We know there are certain key regions of the brain acting simultaneously to control multi-system neural networks- cognition, emotional, sensory and motor function - much like Grand Central Station controlling subway traffic. This initial study allows us to correlate theory with reality; proposed mechanism of action with actual mechanism of action. That is what makes this work exciting,"
Neil Alpiner, MD.

Results from Early Clinical Trials



Results from a Pilot fMRI (Brain Scan) study show IM Directly Activates Multiple Parts of the "Neuronetwork"

Cingulate Gyrus

- Allows Shifting of Attention & Focus
- Cognitive Flexibility

Basal Ganglia

- Integrates Thought and Movement

Medial Brainstem

- Neuro-Motor Pipeline

Key Findings

- These parts of the brain (Cingulate Gyrus, Basal Ganglia, & Medial Brainstem) provide input/output connections to frontal lobes, where cognitive and motor processing occurs.
- IM exercises strengthen the "neuronetworks" to make the transmission of information between areas faster and with greater accuracy.

IM Training is Based on Several Medical Theories:

- Motor planning processes of organizing and sequencing are based on an internal sense of rhythm.
- Prefrontal and striatal regions of the brain are responsible for high-order motor control.
- Timing training can improve neuromuscular connections.

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I. “Improving Motor Planning and Sequencing to Improve Outcomes in Speech and Language Therapy”

article by LorRainne Jones, M.A.,CCC-SLP, Ph.D.

Upon learning about the Interactive Metronome® (IM) technology in the fall of 1999, I became extremely excited about trying this recently available intervention with my clients. At our Tampa, Florida based pediatric therapy practice, Kid Pro Therapy Services; we provide speech, occupational and physical therapy to children with a variety of disabilities including ASD, Down syndrome, language delay, dyspraxia, motor coordination disorders, ADD, ADHD, cerebral palsy, and other neurological disorders. Intuition had me interested in the IM as a way of improving motor planning and sequencing in clients with a wide range of problems.

At Kid Pro Therapy we routinely address the sensorimotor processing and motor planning deficits of children referred to the practice. Taking it a step further, seven years ago we joined with the owner of a local gym to offer a language and sensorimotor based therapeutic gymnastics program for children with more severe challenges, particularly focusing on children with autism. Through the therapeutic gymnastics program we saw gains in a matter of weeks that months or years of more traditional treatment could not achieve.

It has always been clear to me that motor planning and sequencing play a significant role in the acquisition of speech, language, and communication skills. In my book *For Parents and Professionals: Expressive Language Delay*, published by Linguisystems, I encourage clinicians to look at a child’s motor planning and sequencing development when doing an overall assessment. I thought that the IM might be a useful tool to add to the therapeutic “tool chest” by offering an objective means to identify and measure, as well as, serving as a systematic training environment for motor planning and sequencing difficulties.

The IM is an innovative technology that creates an opportunity to directly exercise rhythmicity and sequencing of motor patterns and actions. The IM employs a special sound guidance system to systematically guide the user through the learning process during a variety of types of planning and sequencing actions. The IM training format provides a structured, graduated and goal oriented training process, which typically can be completed over a three to five week period.

In a clinical study published in the March volume of the *American Journal of Occupational Therapy*, the IM trained group was compared with a control group receiving no intervention, and a second control group receiving a placebo computer based intervention. The IM trained group showed statistically significant improvements over both control groups in areas of attention, motor control, language processing, reading and the ability to regulate their aggression.

Temporal processing and its relationship to language skills is an area that neuroscientists have researched for some time. In studies of children with and without language disabilities, researchers found that both groups were able to discriminate and sequence tones (Merzennich et al., 1996; Tallal & Piercy, 1973). The disabled group required hundreds of milliseconds, while the non-disabled group only required tens of milliseconds. From these findings the researchers postulated the difference in sound processing rates affected the brain’s ability to organize and categorize the building blocks of language.

The field of speech pathology recognizes the role of motor planning and sequencing in speech production and intelligibility. Children with apraxia of speech often have difficulty sequencing and coordinating movement to produce intelligible speech. Greenspan (1993) and Greenspan and Weider (1998), suggest that motor planning and sequencing play a significant role in more than speech production. Greenspan contends that motor planning and sequencing play a role in language, social, and emotional development as well. Language flows from the actions and movements of play. Interaction and engagement for infants and young children are filled with gesture, movement and facial expression, all of which require motor planning and sequencing. Emotional development and attachment evolve from the interactions between infants and their caregivers - interactions that consist of movement and gestures in addition to vocalizations and speech. At higher levels, Greenspan asserts planning and sequencing capacities may influence the development of verbal reasoning and problem solving. Children problem solve by developing a plan and implement it by piecing together steps and motions. Difficulties in planning and sequencing may lead to deficits in reasoning and problems solving skills.

An illustration of the IM's clinical application can be viewed by the case study of a 12-year-old girl with a diagnosis of CAPD and ASD. This patient presented with sensory defensiveness, poor attention span, high distractibility, abnormal prosody, and poor sequential thinking. Following IM training, a decrease in sensory defensiveness was noted. Attention span increased and prosody of speech improved resulting in a more natural sounding voice. Post IM training, standardized assessment of language and motor skills showed as much as a two-year gain in some areas.

Other case reports include results such as improved conversation skills, improved intelligibility, and improved fluency for stuttering clients as well as more "thoughtful and introspective" conversation in some adolescents with attentional problems. Improvements in motor coordination is leading to improved performance in a variety of skill areas which in turn leads to reports of improvements in self esteem.

The research findings and anecdotal reports from children, their parents, and other IM practitioners from around the country, now over 500, provide direction for the comprehensive, systematic study of the relationship between motor planning and a variety of language and social capacities in children. I encourage researchers to systematically study how and why IM might impact motor speech disorders, apraxia, stuttering, auditory and linguistic processing, social skills, conversation skills, narrative skills and verbal reasoning and problem solving.

As for the clinical usefulness of the IM, as my intuition originally suggested, I have found the IM to be an extremely helpful intervention for motor planning and sequencing problems. It is helpful in the motor and sequencing aspects of language as well as attention and motor coordination. The IM is a true complement to the traditional therapy and innovation programs, like gymnastics therapy, we offer to clients. I strongly recommend that speech language pathologists take a closer look at motor planning and sequencing when assessing and treating communication disorders in children.

II. IM Case Reports

by Debbie Brassell, JD, MS, CCC-SLP and Deborah Friedman, OTR/L

Kathy's mother is thrilled with the excellent progress in developing self-help skills that her daughter has achieved. She is participating in community activities that previously she never was able to join. Kathy's mother credits her daughter's new abilities to her Interactive Metronome (IM) therapy at the Center for Rehabilitation and Development (CRD).

CRD has helped children and parents like these for more than 15 years. It operates rehab clinics in Roanoke, Blacksburg, Bedford and Lynchburg, VA. CRD's clinics are the first therapy centers in Southwest Virginia to offer IM.

CRD's sensitive therapists understand the importance of integrated sensory systems for normal development. Other sensory-based treatment modalities already were being offered at CRD's clinics when Aditi Silverstein, MA, CCC-SLP, Speech/Language Pathologist and President of CRD learned about IM. "I was particularly interested in IM because, like some of the other intensive modalities with which I work, such as Fast ForWord, IM can help to drive changes in the brain. The result is that clients can make excellent progress in short periods of time."

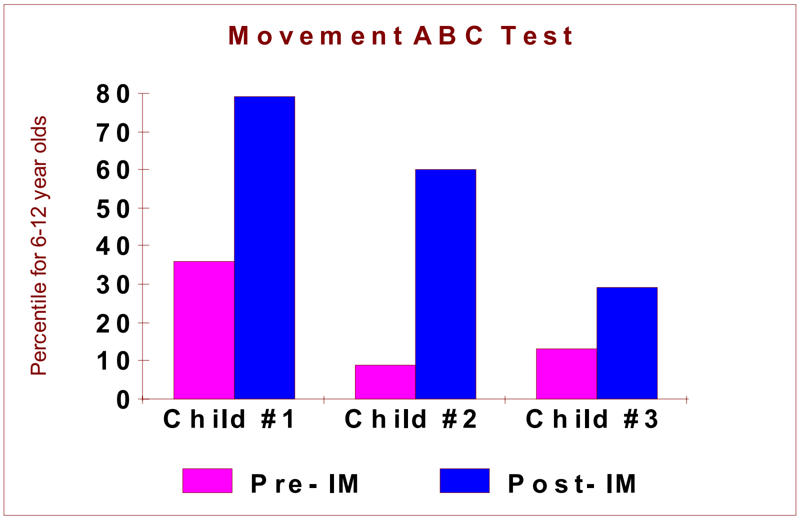
Interactive Metronome combines the principles of a traditional, musical metronome with the precision of a personal computer to create engaging interactive training exercises. Its patented auditory guidance system progressively challenges participants, to improve their motor planning, sequencing and timing, while providing support-like training wheels on a bicycle.

"IM Training can help children to improve their concentration and coordination as well as language skills and academic achievements," says Silverstein. A recent study showed that, following IM training, children with ADHD had better attention, motor planning, language processing, reading comprehension and control of aggression. These findings are consistent with recent research on the brain that indicates that environmental influences, not just genetics, contribute to a child's development. The results of this study about the efficacy of IM will be published in an upcoming edition of the American Occupational Therapy Journal.

At CRD, IM has been shown to be effective not only with clients who have ADHD, but also with children and adults with autism, cerebral palsy and problems involving motor control, coordination and learning and those with speech and language deficits.

IM has been fun and easy to incorporate into the clinical setting at CRD. Therapists complete 15 hours of IM training before beginning to use this modality with clients. "It has been really helpful to experience the training first hand. It gives me empathy for the challenges and successes my clients have as they do the IM exercises," says Deborah Friedman, OTR/L and IM therapist. During IM training, stereo headphones are worn to listen to special sounds that the IM computer software program generates. Motion-sensing triggers, connected to the computer via cables, relay information to the computer. One trigger is worn like a glove. The other trigger is placed on the floor. These triggers sense exactly when the hand or toe or heel taps the sensor. The IM program analyzes the accuracy of each tap as it happens and instantaneously creates a sound that is heard in the headphones. CRD's clients learn to focus all their attention on the steady metronome beat heard in their headphones, without being distracted by thoughts or stimuli around them.

Improvement after IM training can be seen in better standardized test scores. At CRD, most children are tested before and after IM treatment with the Movement ABC Test. Typical results are shown on the graph below.



Parent and client reports following IM training are another rewarding aspect of the treatment. "The changes sometimes appear subtle until we get the parents' feedback. They often notice significant differences in behavior and performance," notes Silverstein. One parent noticed that her child had improved after IM training when she saw that he could sit and listen to a story without fidgeting and flipping through all the pages of the book. Another mother gratefully reported that she and her son had stopped arguing. Someone else told us, "I was so surprised when I heard J. carrying on a conversation on the telephone. He never said more than 'hello' before IM". One young man diagnosed with Asperger's Syndrome said that he was able to look people in the eye after IM treatment. A client with spastic diplegia was delighted that her balance was better and she could stand still in line without fearing that she would fall on the person behind her. The Speech/Language Pathologists who work with children who have had IM training report increased sentence length and improved vocabulary usage, problem solving and abstract thinking skills for their clients.

For more information about Interactive Metronome, including background, reprints, training opportunities, and research, you may visit their web site at www.interactivemetronome.com. To learn more about The Center for Rehabilitation and Development, you may visit its web site at www.crdus.com or to find the clinic nearest you, contact our main offices at 2727 Electric Road, Suite 104, Roanoke, VA 24018, 540-989-3550. Article written by Debbie Brassell, JD, MS, CCC-SLP and Deborah Friedman, OTR/L.

III. Applications of Technology to Solutions for Communicative Disorders

by Lisa L. Nelson, M.A., CCC/SLP

The American Heritage Dictionary of the English Language (Houghton Mifflin Co. 1978) defines "technology" as "1.a. The application of science, especially to industrial or commercial objectives. b. The entire body of methods and materials used to achieve such objectives."

The word "technology" is derived from the Greek *tekhne,* which means "craft" or "art", and *logia,* which means "the study of". Thus, one interpretation of technology is the study of crafting, meaning the shaping of resources for a practical purpose. Technology encompasses not only material resources but nonmaterial resources, such as information, as well. One of the primary applications of technology is communication, and language provides the foundation for our species communication. Technology seems to provide ever-improving means for recording and distributing human language. Art, language and machines are all forms of technology, and all are a means for the continuation of evolution. Like most other evolutionary trends, the pace of technology has greatly accelerated over time.

Speech-language pathologists use a variety of methods and materials to achieve objectives in service delivery. Scientific method drives decision making involving assessment and intervention techniques. Many practitioners report feeling "lost in the knowledge explosion", particularly where "high technology" is involved. More experienced practioners may have started professional training at a time when "low technology" was standard practice. Some practitioners even had professors who insisted that one needed as tools only one's mind, a pencil and a pad of paper to achieve any therapy goal. How difficult it was to do many therapy tasks armed with only these instruments!

As the body of knowledge from science grows, and as technological options for diagnosis and treatment expand at an alarming rate, "keeping up" with innovations seems almost a full time job in itself. Do you recall having to use a computer in your work as an initially frightening, frustrating and rather humbling experience? Can you now imagine doing your work without one? Even if you are still somewhat in awe of the constant innovations and the need to keep informed, we now have many more tools and resources to help - in the form of the world wide web and other information/resource sharing endeavors.

While the old "medical model" is slowly being replaced with more educational and habilitative models of practice, we have also recognized that "symptom management" must be replaced by treatment of underlying causes. When we work with children who have developmental dyspraxias, articulation problems, fluency disorders, we often get the notion that there is *something* which we are missing. When we work with adults who have apraxia, TBI, autistic spectrum disorders, we may get an inkling that there is *something below the level of the cerebral cortex* that we should be addressing. That *something* often involves looking at the neurobiological substrates of the behaviors we are attempting to modify or improve. We need to be able successfully evaluate and treat the substrates of some of the "higher order" communicative behaviors we are working with. There are cases in which those substrates involve the planning, sequencing and execution of motor activity. The timing, rhythmicity and motor skills that are underlying processes vital to cognitive, communicative and learning skills have often seemed "elusive" to precisely evaluate and treat.

IM provides a unique application of technology to evaluate and enhance services to those who have motor planning and sequencing difficulties.

IV. Motor Speech Disorders

by Lisa L. Nelson, M.A., CCC/SLP

The connection between mind-body is becoming clearer as research reveals more subtleties about the human central nervous system. We know that the brain is actually a system of systems. Neurons organize into networks, networks are integrated into structures and functional areas in the brain, and different regions and structures are able to work together as systems. The story of how these systems develop is vital for understanding how we learn and communicate. Our sensory-motor systems are central to the story. All that we know, learn, think and feel is mediated through the sensory-motor systems. The integrity of these systems shapes our experience, and our experiences, in turn, shape the sensory-motor systems.

Development of the brain is interdependent with development of the rest of the body. As we experience our external and internal worlds, that information gets built into neural networks. Sensory input from the environment (seeing, hearing, tasting, touching, smelling, moving) is a major component of our experiences. Neural networks grow out of our unique sensory experiences, and the richer our sensory environments, the greater our freedom to explore, the more intricate the networks become. Learning , thought, emotional well-being, creativity and communication arise from the sensory-motor bases we establish through experience.

As we encounter sensory experiences, sensations travel through the brain stem and the reticular activating system and pass through the thalamus of the limbic system. The sense of smell is the only sense that doesn't pass through the thalamus. The thalamus sends and receives information from the neocortex of the brain, which takes up only about a fourth of the total volume of the brain, but has about 85% of the total neurons in the brain. The neocortex is a central area for making connections. The thalamocortical system is a key to allowing us to create meaning from our experience.

Language and communication arise from integrating sensory-motor information, processing through neural networks that engage mind, body and emotions. The developmental process that supports language begins in utero, as the child moves from a sense of rhythm and vibration. Development of the motor cortex, responsible for muscular movement of the eyes and facial muscles, jaw, mouth, tongue and larynx, begins with these movements in utero. The motor cortex also connects with the thinking, reasoning areas of the frontal lobe of the brain. Development of speech and language skills is a highly complex process, and is subject to disruption at numerous levels.

Oral communication requires:
1. Organization of concepts and their symbolic formulation for expression.

2. Coordination of concurrent motor functions of respiration, phonation, resonance, articulation and prosody in speech.
3. Programming of these motor skills in the volitional production of speech sounds and sequencing these sounds into combinations that form words.

Disruptions in motor speech programming were described as early as 1861 by Broca. There have been a number of terms used to refer to impairments of this nature, including anarthria, motor aphasia, peripheral motor aphasia, apraxia, dysarthria, verbal aphasia, sensorimotor impairment, afferent motor aphasia and efferent motor aphasia. Despite the differences in nomenclature, observers were noting types of behavior that had certain characteristics in common.

Apraxia of speech results from disruption in brain functions needed for volitional programming and execution of articulatory movements. There is no impairment of any part of the speech-generating mechanism when applied to reflexive or automatic acts. Deficits arise when volitional speech movements are undertaken to produce given speech sounds. The major area of deficit is usually in articulation, with errors often characterized by unpredictability and variability. Substitutions, additions and repetitions are typical error patterns. Difficulty in producing speech often increases with increase of the length of the unit attempting to be produced. Prosodic disturbances may arise in compensation for the continuous articulatory difficulty. Speech articulation appears effortful and it often appears that the individual has "forgotten" where to place articulators to make speech sounds. Oral apraxia (difficulty with volitional performance of oral nonspeech and sequence tasks) may occur in conjunction with apraxia of speech. Reduced oral sensation and perception may also be noted in some individuals. Apraxia of speech may also co-occur with impairments in auditory retention and perception.

Dysarthria results from disturbances in muscular control, characterized by some degree of slowness, weakness, incoordination or altered muscle tone. Impaired innervation of speech musculature lies at the heart of this group of problems. There are a number of different classifications for dysarthrias, based on:

- age of onset (congenital, acquired)
- etiology (vascular, neoplastic, traumatic, inflammatory, toxic, metabolic, degenerative)
- area of neuroanatomic impairment (cerebral, cerebellar, brain stem, spinal; central vs. peripheral)
- cranial nerve involvement (V, VII, IX, X, XII)
- speech processes involved (respiration, phonation, resonance, articulation, prosody)
- disease entity (ALS, Parkinsons, myasthenia gravis, etc.)

The generation of purposeful behavior (attending, interacting, communicating, etc.) must be considered as the functional result of the integrity of the system as a whole. The purpose or idea behind the motor act must be retained until the act can be planned, programmed and performed, and while the end results are monitored to discover if the purpose has been accomplished. Failure to develop a proper concept or inability to retain the concept for a sufficient amount of time have been termed *ideational apraxia,* which may co-occur with other disorders.

In order to accomplish the purpose of a motor act, one must have a good somatosensory map (body scheme), awareness of spatial requirments of the act, and the temporal sequence required by various components of the act. The perceptual information associated with an act and the concepts that are appropriate to the performance are typically mediated by the posterior part of the left hemisphere of the brain. Lesions in this part of the brain can cause a condition which has been called *ideokinetic apraxia*, which results in a breakdown of the planning process, interfering with the translation of the idea into plans for purposeful performance.

IM provides a unique application of technology to evaluate and enhance services to those who have motor planning and sequencing difficulties contributing to speech-language disorders.

V. SLP Scope of Practice & Sensory-Motor Intervention

by Lisa L. Nelson, M.A., CCC/SLP

The revised SLP Scope of Practice will be voted on at the LC meeting, March 31-April 1. Review resolution LC 7-2001 at http://professional.asha.org/ if you have not already done so. Basically, the World Health Organization (WHO) 2000 Framework has been adopted to provide a "...common language for discussing and describing human functioning and disability" (WHO, 2000). A continuum of function is used to express each component of the framework.

Body functions and structures, activity and participation are assessed on a continuum and related to contextual factors (environmental and personal). For example, body structures and functions can range from normal variation to complete impairment, activity can range from no activity limitation to complete activity limitation, and participation can range from no participation restriction to complete participation restriction. Contextual factors can interact with body functions and structures, serving as either barriers or faciltators to functioning. Speech-language pathologists work to improve quality of life in all components and factors identified in the WHO framework. We seek to reduce impairments of body functions and structures, reduce activity limitations and participation restrictions, and minimize environmental barriers to the people we serve.

The first item on the scope of practice list for speech-language pathology involves "providing prevention, screening, consultation, assessment and diagnosis, treatment, intervention, management, counseling and follow-up services for disorders of: speech (i.e., articulation, fluency, resonance and voice including aeromechanical components of respiration); language; language processing; cognitive aspects of communication (e.g., attention, memory, problem solving, executive functions); sensory awareness related to communication, swallowing, or other upper aerodigestive functions" (p.7, LC 7-2001 document, ASHA). It would seem clearly within our scope of practice to use procedures, products and programs that assist in this process.

ASHA has additional information on "How to Evaluate Procedures, Products or Programs" (see http://professional.asha.org/information/evaluation.htm).
This document outlines considerations that may assist in the decision making process before using a treatment procedure, purchasing a product, or attending an educational program. These are good questions to ask yourself when evaluating any assessment or treatment procedure (whether "hi-tech" or "low-tech").

With agencies and entities that provide reimbursement for costs associated with provision of diagnostic and treatment procedures moving toward ever more stringent requirements for documentation of impairment and response to course of treatment, it behooves us as practitioners to look at tools we can use that provide legitimate numbers. We all know that numbers (going up or going down, depending on desired outcome) are often key to successful reimbursement. Numbers can come from standardized assessment batteries, and from acoustic or physiologic instrumentation used for assessment. The problem we often encounter is that perceptual tools (such as the eyes, ears and touch of a skilled SLP) often don't have "numbers" associated with them. We may use our clinical skills to assess the distinguishing speech characteristics of a motor speech disorder (such as a hypokinetic dysarthria associated with Parkinson's disease) but these evaluative judgements are often viewed as "subjective". We might be able to say that alternating motion rates (AMR's) are rapid and blurred, but we often can't attach a number to define the degree of variance. No score will tell us if a patient is apraxic or dysarthric - these are diagnoses based on behavioral observations. Progress in treatment is also often measured behaviorally, which can make reimbursement a more difficult issue.

Motor planning and sequencing are vital to many processes, including attention, engagement, purposeful actions, complex problem-solving, ideational formation and thinking/reasoning skills (Greenspan, 2000).

Speech-language pathologists often work with individuals who have impairments in motor planning and impaired motor capabilities. Many of the treatment procedures we use are designed to teach individuals *how to learn to move* (control and quality of movements, ease and effectiveness of movements) and *how to move to learn* (using movement as a means to an end, to help the individual gain better understanding of himself and his environment). As perceptual-motor theorist Raymond Barsch wrote back in 1967 "Man moves. Man learns. He learns to move. He moves to learn."

IM provides a unique application of technology to enhance services to those who have motor planning and sequencing impairments contributing to speech-language limitations.

VI. Documenting Sensory and Motor Progress

by Lisa L. Nelson, M.A., CCC/SLP

When working with motor speech disorders, the *quantification* of progress has often seemed difficult to capture. We may use perceptual features to indicate progress: increases in ease of articulatory movement, improved vocal quality, improved prosody, increased alternating movement rates (AMR's), increased sequential movement rates (SMR's). We also use observational data to provide information on "attention to task" or "auditory attention." These can be difficult to *quantify,* however, as are the changes in these skills. We can measure pre- and post-treatment speech intelligibility, quantify types of articulatory errors and frequency of errors, and use structured tasks (such as reading passages or conversational speech) to gain error rates. What we might have trouble with is gauging a client's response to a treatment procedure, and knowing with any certainty and immediacy if the exercises or methods are producing positive results. One of the advantages of IM is that it gives you a number of quantifiable measures that indicate progress. Pre- and post- testing (Long Form Test Battery Scores)are completed before starting, at the half-way point and after completing IM therapy, and Short Form scores are used at the beginning of each session. Average response times also give you an indication of each client's progress and "personal best" - and these measures are indicated both during the performance of tasks and summarized following task completion. This ability to have immediate, accurate feedback about performance and efficacy are unique in my experience of therapeutic tools.

Quantifiable change is critical when dealing with third party payers, and when faced with accountability and cost containment measures. It is always nice to have patient reports that "I believe my communication improved because of the SLP services", but we often need something a bit more *precise* to satisfy reporting requirements. There is a need for continued development of tools that can help our profession satisfy these requirements. IM is one tool that we have available, and ongoing research efforts are being conducted to identify measures of therapeutic effectiveness for a variety of presenting problems.

More emphasis is being placed on treatment outcomes and efficiency/effectiveness of treatment modalities. This is reflected by the establishment of a national outcomes database for speech-language pathologists and audiologists by The National Center for Treatment Effectiveness in Communication Disorders . Data collection efforts are underway for a number of populations, including pre-school age children, K-6 school aged students and adults in health care settings. The key to this system is use of a seven-point Functional Communication Measures (FCMs) system, scored by a certified professional upon admission and discharge of a client. For instance, functional progress in adults is measured in areas such as memory, comprehension, expression, swallowing and motor speech. The idea is to use outcome-based measures to supplement documentation of progress through standardized tests. Most therapists have had the experience where a client improves on pre/post test measurements using standardized assessments, but has made limited functional gain in day-to-day activities, or vice versa. The use of functional objectives and outcome measures helps solve this problem. As the national database grows, numerous questions about speech-language pathology services could be answered. Right now, we use peer-reviewed published journal articles, professional experience of ourselves and peers, information from policy/procedure manuals and trial and error to answer many of these questions. Entrance and dismissal criteria, expectations for progress, expected duration of therapy, optimal frequency of therapy, most efficient methods of therapy given specific diagnostic criteria - all of these questions are ones that we deal with on a daily basis. Use of assessment and treatment tools that provide built-in databases to work with are a step in the right direction in helping therapists cope with demands for documentation of services.

IM is a clinical education tool that provides a focused and systematic way to exercise underlying motor planning and sequencing capacities within the brain. IM uses relatively simple physical motion exercises to help a trainee
(a) learn smooth, continuous control of each of the IM exercise motions,
(b) learn to consciously recognize and correct timing errors and inefficient movement habits,
(c) learn to achieve and maintain focus on the metronome beat sound.
The movements are "outward, physical" habits used as a catalyst to help a trainee directly exercise and improve "inward" mental functions.

VII. Motoric & Rhythmic Bases of Communication

by Lisa L. Nelson, M.A., CCC/SLP

Many processes influence motor planning, and in turn motor planning interacts with other factors to influence important learning, cognitive and social skills. How well we function in different contexts is influenced by environmental factors, learning opportunities, and the integrity of underlying central nervous system mechanisms. Today we'll look at various aspects of communication that are influenced by rhythmicity and motor regulation, starting with attention.

Rhythm is a factor that must be considered in *all* sensorimotor assessments. Rhythm provides a temporal component to sense thinking and to somatosensory constructs (mental body map). Rhythm involves a sense of internal timing coordinated with an auditory, visual, tactile, kinesthetic and proprioceptive component. In order to make skilled, directed movements one has to have an internal directional focus - an internal reference for three-dimensional space. We have to be able to coordinate and integrate sense information from all sections of the body, and develop mental schemes for directing movements. By age six, a child should be developing these internal references for movement, and will gain the foundation needed for right-left concepts necessary for literacy learning in our culture. Many kids who have reversal problems have not appropriately developed internal and external visual-spatial skills.

Rhythm and timing are involved in a number of skills critical to communication: attention, eye contact (knowing *when* to look and *how long* to look, *where* to look), two-way purposeful interactions, gestural communication, imitation skills, creating ideas (imaginative play, realistic play, symbolic play sequences, responding to others, prediction of how others will feel or act in given situations), articulation, syntax, auditory processing, problem-solving skills, graphomotor skills.

Attention and memory are critical for successful functioning in even the most basic aspects of everyday living. The term *attention* has been used in the literature to refer to a broad array of states, processes and abilities. Aspects of attentive behavior include very basic processes, like the normal sleep/wake cycles, and higher levels of attention such as integrity of orienting responses to novel stimuli. Duration or maintenance of attention over time (vigilance), speed of information processing, speed of responding and problems of working memory have all been related to attentional capacity and control. Distractibility, inability to inhibit responses to irrelevant information, and tendency to over-process redundant stimuli are also considered as attentional problems ("inattentive behaviors"). Problems with higher-level attentional control include difficulties with set shifting (cognitive and behavioral flexibility) and with "multi-tasking" (dual task processing or divided attention). We have developed both externally focused interventions (modifying the environment by minimizing distractions, organizing workspace, providing visual cues like checklists) and internally focused interventions (restorative and compensatory approaches) for helping alleviate attentional deficits. We have used behavioral approaches for increasing attentive behaviors and direct retraining approaches (repeated opportunities to practice and exercise a variety of attention-dependent skills or processes).

The type of intervention you choose will be related to the cognitive theories of attention you utilize as a working model. Most models of attention define it as a multidimensional cognitive capacity that directly affects ALL dimensions of cognition - new learning, memory, perception, communication and problem solving. There are hierarchical levels of attention that include focused attention, sustained attention, selective attention, alternating attention, and divided attention (Sohlberg & Mateer. 1989. Introduction to cognitive rehabilitation: theory and practice. New York: Guilford Press.)

The article recently published by Shaffer, Jacokes, Cassily, Greenspan, Tuchman and Stemmer in AJOT (Vol. 55, Number 2, p. 155-162) suggests that IM can be used as a tool to improve attention, motor and perceptual-motor functioning in children with major attentional problems. Use of IM as a complement to existing interventions for this population should continue to yield data from which we can work with even greater confidence.

PATHWAYS CENTER
FINAL STATISTICAL ANALYSIS

Interactive Metronome, Inc.

Prepared by Lee E. Jacokes, Ph.D.

May 2004

Introduction

Below is the final analysis of Pathways Center data sent to Interactive Metronome. The data was obtained from 13 clients of Pathways Center.

The study design was a pre-post one-group design. Three pre-tests were performed for each subject to assess pre IM training capacities followed by IM training and then followed by three assessments: an immediate posttest and then reassessment at three and six months. This design allows for the assessment of immediate changes due to IM training and then an assessment of how long the IM training impact remains at the three and six month periods.

Since the design does not include a comparison group receiving no training, the ability to assess whether observed changes in the IM group are specifically due to IM training, maturation changes or other factors is a limitation of this design.

A total of eight instruments were administered by Pathways' staff, including the following:

1. CLEF-3: Clinical Evaluation of Language Fundamentals, Third Edition.
2. Bruininks-Oseretsky Test of Motor Proficiency.
3. Sensory Profile – Care Giver Questionnaire.
4. Interactive Metronome Parent Questionnaire.
5. Self Perception Survey.
6. Handwriting Evaluation Tool.
7. The Listening Test

8. Draw A Person.

Results of Analysis

Attached to this report are relevant statistics used to assess the results of IM training. To determine whether statistically significant changes occurred between the pretest and the three post testing periods, paired-samples t-tests were conducted for each of the subtests within each instrument. P values of 0.05 or lower were used as a rejection criterion for all t-test comparisons. The table presents the means for each of the four assessment periods. The pre-test mean was computed using the means of three pretest assessments (Test 1, Test 2 and Test 3). This established a pre-IM training base performance level for each subtest. The Posttest (Test 4) was given immediately after completing IM training while the 3-month (Test 5) and 6-month (Test 6) were given at three-month intervals.

The table also presents the paired differences standard error and the t-test p values for each comparison of the pretest mean with each of the three-posttest assessments. These statistics establish the level of statistical effects produced over the study duration.

Clinical Evaluation of Language Fundamentals (CLEF-3)

CLEF-3 assesses the relationships among semantics, syntax/morphology, and pragmatics (form, content and use) and the interrelated domains of receptive and expressive language. It is authored by Eleanor Semel, Ed. E,, Elizabeth H. Wiig, Ph.D. and Wayne A. Secord, published by The Psychological Corporation and is a nationally normed test.

The Concepts and Directions and the Word Classes subtests of the CLEF were administered. Inspections of the table shows little significant IM training impact. Though the Concepts and Directions subtest showed a statistically significant difference between the pretest mean and the 3-month mean (p = .040) as did the Word Classes between the pretest and 6-month means (p = .028), there is little consistency in IM influences over the span of the study. IM training apparently did not have affect on these two language fundamentals. For both subtests, the means increase over the four assessment periods but more likely reflect normal maturation affects.

Bruininks-Oseretsky Test of Motor Proficiency (B-O)

The Bruinicks – Oseretsky Test is an individually administered test assessing the motor functioning of children from 4.5 to 14 years of age. It is comprised of eight subtests and provides a comprehensive index of motor proficiency as well as providing separate measures of both gross and fine motor skills. It is published by the American Guidance Service and is a nationally normed test.

For this study, five subtests of the B-O were used: Balance, Bilateral Coordination, Upper-Limb Coordination, Response Speed and Upper-Limb Speed and Dexterity. Two of these five subtests produced significant differences. The Balance subtest produced p values of .037, .023 and .004 when comparing the pretest mean of 17.27 to the means of the three posttest periods. Similarly, the Bilateral Coordination subtest showed pre vs. posttest statistically significant differences with p values of .027, .046 and .001. This suggests that IM training produced immediate posttest effects and that these effects remained during the ensuing 3 and 6-month periods. For both subtests, the 6-month means continued to improve, perhaps reflecting a continued improvement due to the IM training and/or reflecting normal maturation not related to IM affects.

The performance improvements in Balance and Bilateral Coordination are consistent with the numerous IM training exercises which emphasize these two subtest skills; however, Upper-Limb Coordination and Speed and Dexterity are not emphasized in IM training exercises. The Response Speed subtest measures quick reaction times to a falling stimulus whereas IM training emphasizes long term repetitive and consistent estimation of a timing interval, not the ability to quickly respond to a stimulus. Thus, it is not surprising that these three subtests show no IM affects.

Sensory Profile – Care Giver Questionnaire

This instrument asks a caregiver of the client (usually a parent) to assess the subject's performance on 23 subscales (See table). It is a normed instrument developed by Winnie Dunn. Ph.D. and published by the Psychological Corporation. These subscales are divided into four general categories: Sensory Processing, Modulation, Behavior and Emotional Responses and Factor Clusters.

Ten subscales showed similar statistically significant patterns of increase over the pre-post assessment periods. These subscales included:

- Sensory Processing
    1. Auditory Processing.
    2. Touch Processing.
    3. Multisensory Processing.

- Behavior and Emotional Responses
    4. Behavior Outcomes.

- Modulation
    5. Endurance/Tone.
    6. Body Position and Movement.

- Factor Clusters
    7. Low endurance.
    8. Inattention/Distractibility.
    9. Poor Registration.
    10. Sensory Sensitivity.

For all ten subscales, the general pattern shows the pretest means compared to the immediate posttest means to be statistically significantly different, showing an increase in performance. These performance increases are maintained after 3-months. At 6-months, all ten subscales show increases in performance above the 3-month means. These increases could be either IM affects and/or normal maturation. See the table to inspect the means and p values for each subscale.

The improvement in the sensory processing category suggests that IM training is perceived by caregivers as lowering subject sensitivity and distractibility to auditory and touch stimuli and improving their capacity to integrate multiple sensory inputs into more coherent patterns. The Behavior Outcomes subtest of the Behavioral and Emotional Responses category suggests IM training may have improved subject capacities to be more self directed and efficient and more tolerant of environmental changes and disruptions. The two modulation subtests of Endurance/Tone and Body Position and Movement point to possible IM training affects improving physical strength/endurance, capacity to physically move and coordinate body movements while reducing accident proneness and improving physical balance and stability. The four Factor Clusters reinforce the improvement in Endurance (Low Endurance), and in capacity for Registration and improved Sensory Sensitivity. Of great interest are the perceived improvements in Inattention/Distractibility, improvements duplicated by earlier IM research with ADHD boys.

Two additional subscales from the Sensory Processing and Modulation categories show possible IM affects: Vestibular Processing and Visual Input Affecting Emotional Responses and Activity Levels. Both subscales produced significant but gradual increases in mean performance from pretests through the 6-month assessments. This points to improved balance, stability and spatial orientation and/or less seeking of exaggerated movement experiences and improvements in appropriate eye contact with other people. This suggests IM training may be having a gradual affect; however, normal maturation affects could also produce similar performance increases.

Four subscales did not show any statistically significant improvements from the pretest through the immediate posttest and 3-month assessments; however, significant 6-month increases were observed. It is difficult to say whether these 6-month improvements are IM affects or maturation affects; however, maturation is the more likely explanation.

Parent Questionnaire for Interactive Metronome

This questionnaire consists of 17 scales based upon a four point Likert Scale ranging from very easy, easy, difficult and very difficult. Parents were instructed to rate their child on each of these scales by checking the appropriate scale point. The questionnaire was developed by Pathways Center personnel and is not normed. The seventeen scales included:

Ability to Concentrate
Ability to Pay Attention
Ability to Transition Between Tasks
Ability to Follow Multi-step Directions
Ability to Calm Self
Handwriting
Idea Fluency - Spoken
Idea Fluency - Written
Memory
Athletic Ability - Running
Athletic Ability - Ride Bike
Athletic Ability - Swim
Athletic Ability - Dribble a Ball
Musical Ability Play Instrument with Appropriate Timing
Ability to Play Video Games
Social Interactions - Children/Peers
Social Interaction - Adults

Of the 17 scales, five produced evidence of the positive impact of IM training. Ability to concentrate shows statistically significant differences between an initial mean of 2.11 compared to the posttest and the 3 and 6 month retests with p values of .067 (slightly higher above the 0.05 criterion rejection p value), .001 and .016. The ability to pay attention scale had similar significant differences for all three posttest periods showing significant p values of .015, .006 and .006 with a pretest mean of 2.13. The profiles for each of these scales show significant increases immediately after IM training followed by continued maintenance of these increases over the three and six month periods.

Three scales revealed possible IM training affects - ability to transition between tasks, idea fluency – spoken and idea fluency - written. The ability to transition between tasks shows a non-significant increase from a pretest of 2.62 to 2.91 at the immediate posttest (p value of .378, though only 11 subjects were present in this test compared to 13 subjects for the other two posttests). The 3 and 6 month posttests found significantly different means at p values of .046 and .027 possible suggesting IM training took longer to impact on task transition capacities; however, maturation affects might also explain this increase.

The idea fluency – spoken scale had both immediate posttest and 6-month test p values of .034 and .012 while the 3-month test was not significantly different (p value of .162). This suggests IM training had an immediate positive impact on written idea fluency but its long-term impact is less clearly established. A related scale, idea fluency – written showed a non significant difference (p value of .365) between the pretest mean of 1.77 and the immediate posttest mean of 2.00; however the 3-month posttest showed a significant p value of .037 while the 6-month test reached near significance at a p value of .079. This suggests IM training may possibly have improved written fluency, however, the evidence is less substantial. These two scales of idea and written fluency, though showing less clear impact, may suggest IM training can positively impact the cognitive and motor capacities underlying these two abilities. These findings of improved fluency are similar to the findings of improved reading and math fluency in the Flanagan High School Study.

Self Perception Profile

This is a 36-item questionnaire that asks children to select between polar opposite descriptions of children's behaviors and feelings. The profile was developed by Susan Harter, Ph.D. of the University of Denver and is not normed.

Answers to these items are reported out in the six scales below:

Scholastic Competence

Social Acceptance
Athletic Competence
Physical Appearance
Behavioral Conduct
Global Self Worth

None of the six scales were found to show any significant patterns of improvement when comparing pretest means to the three-post test periods. This suggests that the subjects did not perceive any differences in their self-perception over the course of the study or that the Self Perception Profile was not sensitive to such changes.

Evaluation Tool of Children's Handwriting (ETCH)

ETCH is an assessment of handwriting skills in six areas. It is a criterion-referenced tool designed to evaluate the handwriting skills of children in Grades 1 through 6. It was constructed by Susie Amundson, Ph.D. and published by O.T. Kids, Inc. For this study these areas were assessed:

1. Alphabet Writing - Lower Case and Upper Case Letters.
2. Near-Point Copying
3. Dictation

There is some evidence that IM training may influence on selected handwriting skills. Lower case legibility percentages showed statistically significant improvement when comparing the pretest mean of 83.00% to the immediate and 3-month posttests (p values of 0.008 and 0.013). At six months this improvement declined to a mean of 88.70 (p value of .084, just above the criterion p value of 0.05).

There is also the possibility that IM training may have resulted in delayed handwriting improvement for Upper Case Letter Legibility Percentage, Near Point Copying Speed and Dictation for Letter/Numeral Legibility percent. Upper Case Legibility Percentage showed gradual but non-significant increases in performance through the first two pretests, reaching a significant difference at the 6-month postesting (mean of 87.83, p value of .002). Near Point Copying

Speed reached significant differences with the initial pretest mean of 37.58 letters per minute at the 3-month and 6-month post tests reaching p values of 0.031 and .000. Similarly, Dictation for Letter/Numeral Legibility Percent reached a significant difference by the 3-month posttest and just missed reaching significance at the 6-month posttest. The writing improvement shown by these three measures might also be influenced by maturation processes as well as by IM training – it is not possible to determine which might be operative. The remaining five subtest measures showed no significant patterns of writing improvement.

The Listening Test

The Listening Test evaluates children's' (ages 6 to 11) abilities to listen and attend to a variety of classroom language tasks. Results reveal strength and weaknesses in these listening areas: main idea, details, concepts, reasoning, and story comprehension. For this study, only the concepts and reasoning subtests were administered. The Listening Test is authored by Mark Bartrett, et. al., and is published by LinguiSystems.

Both concepts and reasoning subtests showed statistically significant improvements between the pretests and the three posttest periods. The concept pretest of 10.41 compared to three posttests means had p values of .003, .001, and .003 respectively. Even stronger significant differences were found for the reasoning pretest mean of 9.10 compared to the three postest means with p values of .001, .001, .000 respectively.

These results strongly support the possibility that IM training may have influenced the underlying cognitive processes necessary for effective concept development and reasoning.

Draw A Person Test (DAP)

The DAP asks the subject to draw three figures: a man, a women and him/her self. Each figure is then scored using a 14-item checklist that quantifies the subject's performance producing raw scores, which are transformed into standard scores derived from a standardized population. The test is authored by Jack Naglieri and published by the Psychological Corporation.

Analysis found no significant evidence of drawing improvement patterns for any of the three figures or for the drawing total score that combines the results of the three individual drawings. Thus, there is no evidence that IM training affected the subjects' capacity for drawing.

Summary

There is little evidence that IM training had any significant impact on the Language Fundamentals subtests. However, two of the Bruininks-Oseretsky Motor Proficiency subtests did suggest IM training might have influenced significant performance improvements for Balance and Bilateral Coordination.

Caregiver evaluation of subject improvement found ten subscales of the Sensory Profile with significantly improved performances. These performance levels were maintained over a 6 month period. Two subtests also showed gradual increases in performance over the pretest and three posttest periods; however, it is not possible to know if these increases are due to IM affects and/or normal maturation.

Additionally, The Parent Questionnaire for Interactive Metronome found two scales for which parents indicated significant positive impact of IM training: ability to concentrate and ability to pay attention. IM training may also have positively impacted subject behaviors including the ability to transition between tasks and spoken and written idea fluency. IM trainees did not reflect any changes in their self-perception over the course of the research.

There is also some indication that IM training assisted in improving handwriting skills, specifically improved letter legibility, copying speed and taking simple dictation. Of particular interest is the strong significant improvement found for auditory processing related to concepts formation and reasoning tasks. The improvements in handwriting and auditory processing of concepts and reasoning tasks suggests IM training has a significant positive impact upon underlying cognitive and executive processes related to the performance of these behaviors.

Of particular interest is the concurrence of performance improvements between the objective measures of Balance and Bilateral Coordination of the Bruininks-Oseretsky Motor Proficiency Test and the caregiver perceptions of improvements in both Sensory Profile and the Parent Questionnaire for the Interactive Metronome subtests. Caregivers report and the objective measurements affirm subject improvements in balance and physical coordination. This suggest that underlying sensory integration, attention, and ability for concentration may have improved, leading to better capacity to plan and sequence actions which in turn lead to improved environmental interactions in the physical, emotional/social and cognitive domains.

A singular contribution of this study is the 6-month follow-up of subjects. The results help to confirm that IM training has not only immediate positive affect but also can maintain these affects at least over a six-month period. This was especially true for balance, bilateral coordination, parental assessments of sensory processing, self-direction, and attentional abilities and objective measures of handwriting, concept development and reasoning abilities.

The above results supports the hypothesis that IM training has impact upon balance, physical coordination, attention, concentration, motor planning and sequencing and the more complex cognitive capacities of planning, sequencing; concept formation and reasoning. Results further confirm other IM practitioner reports and previous formal IM studies. Though the design does not allow for experimental control group comparisons, it does add additional weight to previously confirmed IM affects and tentatively supports the permanence of some of these positive changes

Processing speed and motor planning: the scientific background to the skills trained by Interactive Metronome$^{®}$ technology

Susan J. Diamond, Ph.D. Dec. 2003

Dr. Susan Diamond is a licensed psychologist in private practice in British Columbia. She specializes in remediation of learning difficulties and attention deficit disorder. She is a member of CPA & APA. She has spent thirteen years studying the psychophysiology of learning, including brain electrical activity and educational kinesiology, and is a new user of Interactive Metronome. Email to diamonds@intergate.bc.ca

This paper will summarize scientific findings that explain why a movement based repetition program, made with feedback in millisecond precision, might be influential in improving brain efficiency, and hence, cognition. This paper was volunteered independently, by its author, to answer queries about the brain interactions behind this technique. Interactive Metronome® (IM) likely increases speed of brain processing, and reduces "noise" or variability, making it more efficient as a signal processor. Efficient signal processing has been demonstrated to be associated with higher IQ scores (e.g. Jausovec, 2000, 2001), and better task performance (e.g. Sifft & Khalsa, 1991). These points will be developed below.

This author has reviewed the literature for brain plasticity, hemispheric interaction, motor planning, attention, memory and language, the role of the evoked potential electrical signal, and the role of soft signs. The psychophysiology of learning is not well understood in psychology and education, and rarely taught in graduate schools. This is a brief overview of key studies that help explain the role of a movement re-education program in learning (for an in-depth review, see Diamond 2003 a, b). Objectives of this paper include that: clinicians understand specific processing difficulties faced by ADHD subjects in daily activity (most instructions include a movement component); review the specific brain structures and networks activated by a systematic movement menu; and, identify sources in the scientific literature for further study. A review of motor difficulties in ADHD is included.

The ability of the brain to reorganize, through plasticity, has been established (see Clifford, 1999), as is the idea that a well exercised brain retains cognitive function and myelinates through the lifespan (see McDowell et al, 2003). These factors are important to the rationale of movement, efficiency and integration technologies, such as Interactive Metronome® or Educational Kinesiology techniques. Computer based functional brain imaging techniques such as MRI, PET scans and regional cerebral blood flow studies have demonstrated very specific networks of brain activation associated with contralateral and homolateral body movements. Motor maps elaborate in very specific ways, as tasks are learned, and look quite different in people who have achieved mastery than they do in novices. An example is the brain of an expert musician. Hundreds of studies, using many neuroimaging techniques, examine brain activation upon specific movements, its effects on within-and-inter-hemispheric function, and differences for successful versus unsuccessful task completion. A few are described here.

What brain regions are activated by a precise menu of movements?

Sanes and Donoghue (2000) have written a review article on plasticity and the motor cortex. They make the points that primary motor cortex (MI) controls voluntary movements, through distributed networks not discrete representations, and that they are capable of modification in adult mammals. MI representations and cell properties show considerable plastic changes, with everyday experiences "including motor skill learning and cognitive experience." The substrate for this map reorganization is probably intrinsic horizontal connections in MI, which show activity dependent plasticity (Sanes & Donoghue, 2000). Sadato and colleagues (1996) studied regional cerebral blood flow (rCBF), an important index of brain metabolism, in simple and complex sequential finger movement tasks. They found these tasks to equally, and consistently, activate the following regions: bilateral primary sensorimotor area, left ventral premotor cortex, posterior supplementary motor area, right superior part of the cerebellum, and left putamen. Brodman's area 6- right dorsal premotor cortex, and right precuneus, Brodman area 7, which show increased activation as complexity increased. Possibly these areas help with storage of motor sequences in spatial working memory and in producing ongoing sequential movement with reference to that of buffered memory. Cerebellar vermis and left thalamus activity also increased with complexity, and left inferior parietal lobule decreased at that time (an area associated with short term phonological storage).

Numerous studies of brain activation in bimanual coordination (finger movement) tasks have been done. Stephan et al (1999) used functional magnetic resonance imaging (fMRI) to study finger to thumb movements, noticing a strong contralateral activation of primary sensorimotor cortex, with midline activity lateralized to the left in right-hand movements and to both sides in left-hand movements. Frontal midline activity was not specific only to bimanual movements but even operates in unimanual movements and increases in complex movement control tasks. When studying the cyclical coordination of ipsilateral (same side) wrist and foot movements using fMRI, (Debaere et al., 2001) found that for flexion-extension movements of foot, and wrist to an auditory paced rhythm, a distributed network was responsible for inter-limb coordination activities. Activations involved the supplementary motor area (SMA), cingulate motor cortex, primary sensorimotor cortex, premotor cortex, and cerebellum. These activations exceeded the sum of each action independently. Coordination of limbs in different directions activated the SMA more than movement in similar directions. The SMA is suggested to be more important for less stable, parallel, instead of mirror movements, and its role may be for higher-order on-line planning of movement sequences as well as their execution (Debaere et al, 2003). These are similar tasks to the IM program, and the activation has been shown to be greater than the sum of parts (see also Karni et al, 1995).

Motor planning is intimately connected to sensory processes

Rossini and Pauri (2000) says that the use of sensory perception to assess motor plans involves large brain areas. These include the primary somatosensory, visual, motor, cortices as well as secondary sensory and motor areas. "Basal ganglia and thalamic relays significantly contribute to motor planning, sensory performance and sensorimotor integration. Supplementary motor and premotor cortices have a pivotal role in motor preparation and execution which, on their own, are carried out via corticospinal fibres from primary motor cortex. Cerebellar relays constantly monitor the motor output and

motor execution." Movement is controlled by a network of neurons distributed throughout the MI (motor) cortex. There are both spatial and temporal overlaps of multiple representations underlying the motor functions (reference in Rossini and Pauri, 2000). Sensory flows modulate both excitatory and inhibitory mechanisms of motor cortical circuits. Neural re-organization, in event of accident, is assisted or inhibited by this fact. Plastic reorganization during sensorimotor learning is accomplished by: changes in neuronal membrane excitability, removal of local inhibition, or by changes in synaptic efficacy (excitatory, based on Sodium/Potassium channels, for short term changes, and, on Long Term Potentiation as well as NMDA receptor activation for longer changes. Potentiation and inhibition significantly affect the "amplitude of cortico-cortical EPSP's, IPSP's, and reflect the changes of synaptic efficiency" (Rossini and Pauri, 2000).

Learning acquisition and retrieval stages differ, and are influenced by which side of body is engaged.

Sakai's results suggest that the acquisition of visuomotor sequences requires frontal activation and the retrieval of visuomotor sequences requires parietal activation, which might reflect the transition from the declarative stage to the procedural stage (Sakai et al, 1998). Jancke et al (2000) studied bimanual and unimanual hand activations in tapping tasks at variations in speed, and is an excellent resource. SMA and SMC activations were studied. SMA should strongly activate to tasks which involve both sequencing and bimanual integration. Results indicated a marked activation, not asymmetrical, for the bimanual task, with a rate effect (SMC contralateral to the faster hand is activated most). SMA is more responsive to bimanual than unimanual activity. SMA activations appear to favor the left hemisphere consistent with theory that there is a functional asymmetry in right-handers and that the left hemisphere is therefore more prominently involved in motor planning than the right hemisphere. (Jancke et al., 2000, cites Ajersch & Milner, 1983; Peters, 1985; Liepman, 1905).

Widespread task activations occur with even simple movements, and affect brain activities including memory and sequencing as well as sensory input areas.

A study by deGuise et al (1999) indicated the importance of the corpus callosum and the frontal cortical areas for the procedural learning of a visuomotor skill. Bimanual and unimanual key pressing to a visual stimuli prompt with recall tasks, to assess knowledge of the sequence was established. Visuomotor learning is "a subdivision of procedural memory which refers to the ability to acquire a motor skill or cognitive routine through practice (Cohen & Squire, 1980). This acquisition is expressed by significantly reduced reaction time or errors over trials. This type of memory can be dissociated from declarative or explicit memory, which is the ability to store and consciously recall or recognize data in the form of words, visual pictures or events (Tulving, 1983; Squire, 1986)."

The two types of memory are anatomically independent. The declarative memory system, is mediated by a corticorhinothalamocortical circuit (see Mishkin and Appenzeller, 1987); and the procedural memory system, about which, less is known. Frontal lobes are implicated in skill acquisition especially for ordered sequences (Moscovitch et al, 1993), programming of spatial learning (Vilkki and Holst, 1989), and bimanual coordination of parallel movements (Pascual-Leone et al, 1994, all cited by de Guise et al, 1999). "The frontal cortex is known to have strong projections to the striatum. The striatum, on its part, projects to the internal portion of the globus pallidus, which in turn projects to thalamic nuclei. The latter projects back to the frontal area of origin (Heilman and Watson, 1991). Unilateral visuomotor learning requires the integrity of these structures as well as that of the cerebellum" (see de Guise). Transfer of unilateral procedural learning seems to require the integrity of the corpus callosum, which would connect the two separate neural loops. By studying which types of learning were possible in subjects with various callosal damage, authors have concluded that the frontal lobes were important for unilateral procedural learning and that the anterior part of the corpus callosum, which connects these lobes, is crucial for integration and transfer of a procedural visuomotor skill. Declarative and procedural systems, as Squire reported in 1992, are in fact independent (de Guise, 1999).

Motor routines alter hemispheric interactions in specific ways

Inter-hemispheric coupling was studied in a task involving learning bimanual coordination (Gerloff, 2002). Establishment of a motor routine, as the task is mastered, is associated with dynamic changes in the hemispheric interaction. In learning a novel task, the hemispheric interaction is especially important in the early phase of command integration. In the repetition of mastered sequences and in the learning of a uni-manuual task, it is not so important. It is the novel task that is affected in this way since mastery does not depend on the inter-hemispheric coupling. Probably, once learned they become part of a motor routing. A modulation of inter-hemispheric communication is inferred that may regulate the reduction (inhibition) of mirror movements and suppresses (through GABAergic neurons transcallosal projections), the previously learned but not applicable, coordination tendencies (Gerloff, 2002).

The role of the corpus callosum:

Knyazeva et al., (1994) studied children using EEG measures, to understand the hemispheric interaction in speeded finger tapping with one and both hands. They found that inter-hemispheric alpha coherence levels can be regarded as an index of the inter-hemispheric activity in bimanual tapping. Geffen et al (1994) studied the control between the hemispheres in manual motor activity, reviewing findings in callosal patients. The corpus callosum does not seem to transfer explicit motor commands. Instead, it seems to transfer *premotor* commands, transferring lateralized information like verbal or visuospatial activity. Once movement begins, it also sends motor signal and feedback sensory signals to control bimanual movements that are not synchronized, and to inhibit the opposite hemisphere from interfering when a simple unimanual movement is required. This is a process of transfer of motor commands from one hemisphere to the other. There is a separate programming in each hemisphere of motor-act planning, and an asymmetrical transfer of information between the hemispheres. Transfer from the right to the left hemisphere is faster than the reverse (Geffen et al.1994, cites Marzi et al, 1991; Balfour et al, 1992).

Motor commands are transferred smoothly through excitatory or inhibitory processes. Bimanual movements require sensory feedback about the movement (vision, proprioception). This sensory information is transferred by the corpus callosum, and each hemisphere is informed of the output of the other through the corpus callosum, too. This process is verified by transcranial magnetic stimulation study of interhemispheric transfers between motor cortex areas (Meyer et al 1995). If one motor cortex is stimulated it reliably leads to transcallosal inhibition of the other motor cortex in normal subjects.

The corpus callosum continues to develop through at least the first decade of life, so inter-hemispheric communication is limited by the functional capacities of the immature brain. This restriction has been demonstrated in many studies (see Knyazeva et al, 1994). Relatively independent functioning of the two hemispheres can be assumed prior to age 6-8. Late maturing brain structures include the frontal cortical areas and the rostral callosum (Knyazeva, 1994). The posterior part of the corpus callosum has been understood as the sensory window through which each hemisphere shares its own visual, sensory and motor information (cites Volpe, et al, 1982). Two pathways of motor information transfer are known, one through the left prefrontal cortex and anterior middle corpus callosum; the second crosses corpus callosum through parietal level and travels to the right hemisphere, this pathway in children can be assumed to be more reliably functioning, earlier.

Attention Deficit Hyperactivity Disorder (ADHD)

Central nervous system inefficiency is implicated in many learning and behavior disorders. Sources that show movement difficulties and processing speed concerns have also been found for other learning disorders, including dyslexia. Other sources document the relationship of movement skill and neurological soft signs to academic success, but space does not permit including them here. For ADHD, we review below research findings where motor difficult and corresponding performance weaknesses have been studied.

- Weak performance in frontal lobe tests; slow gross motor output in ADHD (Carte et al., 1996 reviews).
- Weakness in organizing a response, rather than the actual motor output activity itself, that may be the problem (Van Der Meere, 1992).
- Fine motor skills such as handwriting are a common deficit in ADHD (see: McMahon & Greenburg, 1977; Shaywitz & Shaywitz, 1984; Barkley, 1990; Doyle et al, 1995; Whitmont & Clarke, 1996).
- Longer Response times (RT), longer ITI (intertap interval), greater PF (peak force) output, and greater variation in both ITI and PF for ADHD subjects. Distinct timing and force dysfunctions of both output and variability (Pereira et al., 2000; Steger et al, 2001; Pitcher et al., 2002).
- Pereira (et al. 2000) also found impairments to sensory motor control. In agreement with this finding, a study by van der Meere et al (1992) showed undue reaction time delays in hyperactive children when incompatible instructions are given.
- Greater variability in grip force; greater variability of motor performance than controls. ADHD problems in adapting the grip force to various weights (a task of anticipatory control based on a memory image of the requirement) (Pereira et al., 2000).
- ADHD boys became increasingly slower than the control group with the finger portion of the task, having speed and quality differences (longer intervals, multiple force peaks, increased variability of force onset, and more errors). Force onset variability significantly differentiated the groups (Steger et al., 2001),
- Kinaesthetic acuity and fine motor performance issues (Whitmont & Clarke,1996)
- Significant difficulties with timing, force output, and greater variability in motor outcomes (Pitcher, Piek and Barrett, 2002). In boys aged 8-13 they used two tests specifically related to movement: (Movement Assessment Battery for Children, 1992, and the finger tapping task) which targets motor processing, preparation and execution. Boys with any type of inattention had significant difficulty with timing, force output and greater variability in motor outcome. Authors call for increased awareness of the relationship of ADHD and motor dysfunction.
- Motor output deficit hypothesis proposed by Sergeant and van der Meere, 1998;Van der Meere,1996; Van der Meere and Sergeant, 1988.
- Slow and inaccurate, in studies by Jennings et al, (1997) Oosterlaan & Sergeant, 1996; Scheres, Oosterlaan & Sergeant, 2001, especially where delayed motor processing is a core deficit (see also Sergeant & van der Meere, 1988; van der Meere, Vreeling and Sergeant, 1992).
- Reaction time variability is often greater in ADHD (see studies by Douglas, 1972; Jennings et al, 1997; Van der Meere & Sergeant, 1988).
- In primed and delayed Response Time tasks, ADD children have output difficulties (e.g. study by Leung & Connolly, 1997); though these are quite specific and did not extend to motor organization or execution stages.
- Timed finger tapping tests (speed) are sometimes included in neuropsychological batteries. Literature is mixed in this area. Some studies have found slower speeds in inattentive or hyperactives (Seidman et al, 1997), but others have not (Gordon & Kantor, 1979; Seidman et al, 1995).
- More complex motor sequences more frequently show problems in learning disabled and ADHD children, whereas fine motor skill/simple tapping speed tests do not (see
Breen, 1989; Grodzinsky & Diamond, 1992; Mariani & Barkley, 1997).
- Differences from controls in fast instructional set (Carte et al, 1996)
- Epileptiform discharges in 30% of ADHD children (Hughes, 2000)
- Early indicators of ADD-ADHD include speech delay, inattention, and soft neurological signs (Ornoy et al, 1993). 80% of children with these markers in age period 2-4, were later identified as with ADD-ADHD, when reexamined 7 years later.
- Kroes and colleagues (2002) published an excellent study in Developmental Medicine and Child Neurology. In reviewing the results of previous studies Kroes and colleagues noted that Denckla (1985), and Carte (1996) found that speed of movements is associated with ADHD, although a large group of studies do not find this association. (

Kroes et al, 2002; Grodzinsky & Diamond, 1992; Barkley, 1997; Leung & Connolly, 1998) and Steger et al, 2001). While ADHD children are in general slightly slower, this is not always a significant difference.

- fMRI was used to study motor control tasks in ADHD boys in comparison to non ADHD subjects. Findings indicated that, a stop task and a motor timing task led to lower power of response in right mesial prefrontal cortex in both tasks and also in right inferior prefrontal cortex and left caudate in stop task. Authors conclude that there is subnormal activation of the prefrontal systems required for higher-order motor control (Rubia et al., 1999).
- Di Scala and colleagues (1999) did a retrospective analysis of files of tens of thousands of hospital patients as part of a major study. They found that ADHD children were more likely to have severe injuries, more rehabilitation care, more multiple regions injured, and differing injuries- bike, pedestrian accidents, when compared to non-ADHD children, whose injuries were typically falls or sport related. This is another reason why treatments for ADHD are warranted.

Frontal problems are found in ADHD and motor difficulties would therefore be expected.

Frontal-striatal brain regions are implicated in poor executive processing and organization (Heilman, Voeller, Nadeau, 1991). As these authors have pointed out, motor abnormalities would be expected if these regions malfunction. It is not always assumed that the motor deficit is primary, but possibly areas of executive function and information processing may be faulty. If, however, activating these regions more effectively can be shown to improve most motor functions, it is presumed these pathways may be used for other functions and the general activation of frontal regions will be improved. Processing speed is a known difficulty in ADHD for complex tasks. Rubia et al. (1998) have suggested that *the* main deficit in childhood hyperactivity is of frontal-lobe mediated self-regulative functions such as inhibitory control.

Lazar and Frank (1998) investigated frontal system dysfunction in tests of inhibition, working memory, motor learning and problem solving, and finding that there were significant differences in the ADHD, ADHD +LD, and LD only groups, with the ADHD group performing the best on these measures, but with differing profiles among the groups. This study indicates that frontal dysfunction is not only found for ADHD subjects but is implicated in other learning problems of children.

Deficits in response inhibition are associated with ADHD, Tourette's, OCD and other disinhibition syndromes (sources, see Garavan et al., 1999).

When a person is asked to inhibit, or withhold a motor response (as for go-no go tasks), fMRI studies show that a distributed cortical network is responsible, including strongly lateralized right hemisphere activation. This is called "response inhibition", and it is often tested in ADHD. Regions involved include the middle and inferior frontal gyri, frontal limbic area, anterior insula, and inferior parietal lobe (Garavan, et al., 1999). A distributed network is implicated. Dorso-lateral prefrontal regions respond to target probability (Casey et al.); Anterior cingulate regions respond to accuracy in false-alarm situations (e.g. hold, its not the correct target on a go/no-go test); and the distributed area responsible for response inhibition is thought to include: Supplementary motor area, dorsal and ventral frontal regions, anterior cingulate and occipital and parietal lobes (references cited in Garavan). Heart rate measures were used in a study by Jennings et al. (1997), in a standard inhibition task. They found longer latencies in ADHD, the normal psychophysiological changes; however, careful attention to a task was more effortful and less successful for ADHD boys. In IM, one acts on the cowbell, but waits, or inhibits, the rest of the time. Commission errors on the TOVA continuous performance task are an index of response inhibition, which can be improved with training by various techniques, including neurofeedback.

Response speed, and the ability to inhibit responding appropriately, are both associated with learning, with ADHD, and with developmental difficulties.

Inefficient central nervous system activity can be described by many neurodevelopmental indices, including neuropsychological tests, and neurological "soft signs" (Spreen et al, 1996). Delays in the normal developmental sequence are associated with poorer performance on academic measures, weaker motor skills performance and increased risk for psychiatric disorder. In one study, five-year old children were followed-up at ages 7 and 10, for the study published by Whitmore and Bax (1990). They found that children with abnormal neurodevelopmental scores at age five were many times more likely to have learning disability or behavior disorders at follow-up. Prevalence was 4% and 8% respectively in the typical children, and was 25% and 46% in the subject children (cited in Kadesjo & Gillberg, 1999). Clumsiness is associated with a range of other issues including social problems in children, self confidence, behavior issues and affective disorders. This area is not treated in detail here, but is reviewed in Kadesjo & Gillberg, (1999). A range and variety of systematic and repeated movement activities can improve the circumstances of many children. Such interventions should be part of an integrated remediation program for children at risk.

Response times in discrimination tests can be improved by a movement program

Khalsa et al (1988), in their study of static balance in LD children, and Sifft et al (1991) in their study of simple response times and visual choice response times, have found that Brain Gym movements, and re-patterning, are effective for improving physical traits related to focus and attention. The Visual Choice response times task (how quickly and accurately can you decide about a target and respond?) such as that tested by Sifft, are a feature of Continuous performance tests (e.g. IVA, TOVA, CONNERS). Test performance on these tests has been shown to be related to cognitive abilities (for example, a timed multiple choice exam) and is one diagnostic measure for ADHD. Karni et al (1995) say that daily practice of a motor skill can improve both speed and accuracy in complex motor tasks. They found, using fMRI, that cortex areas enlarged for practiced sequences by week four of training, and suggest an experience-dependent reorganization of adult primary motor cortex, with changes that lasted several months. These changes were specific to the practiced task.

What are the brain activation processes in the steps of learning a motor skill?

Complex human movements have also been studied with fMRI (Rao et al, 1993). Functional changes have been seen in the primary cortex for simple activation tasks, and here, were also seen in the non-primary cortex in response to complex mental activities. Simple and complex finger movements using each hand separately were studied. Areas of activation support the idea that voluntary motor control is hierarchical in organization. Supplementary motor area (SMA) selectively activates in complex motor tasks, and, in imagined movements the premotor cortex also activates (planning and execution steps) (Rao, 1993).

Motor skill learning was studied using rCBF and PET scanning (Grafton et al., 1992). Motor execution was associated with activation of a distributed network involving cortical, cerebellar and striatonigral sites. Early motor learning of pursuit rotor activity resulted in speeded improvements with longitudinal increases in relative CBF in left primary motor cortex, left supplementary motor area and left pulvinar thalamus.

Early learning of skilled movements thus involves a subset of the same regions used for motor execution, and this is a widely distributed network

Tasks studied by Grafton (1992) were not learned to full automaticity, and in the early phase of skill acquisition, visual feedback would be important to acquisition of the motor set. These studies demonstrate that the regional activation for motor tasks is widely distributed and involves functions including motor planning, imagery, sensory integration, and inter-hemispheric communication. These abilities are inseparable from the brain's chemical excitatory and inhibitory processes. Learning these movement procedures involves known explicit and implicit memory activation, frontal and striatal structures, and others. The information cited here clearly indicates that a structured motor program involving procedural learning, repetition, rhythm, and precise, consistent feedback, which at the millisecond level is consistent with brain synaptic signal processing, can indeed create new learning, and richer network elaboration. The important role of precise, very fast feedback has not been evaluated here. This feedback probably enables the latency delays (these are electrical, evoked potential, stimuli-processing signals) noted in many learning-disabled populations to be improved to more typical speeds. This is akin to increasing the processing speed of one's computer. Interactive Metronome and similar programs likely also increase accuracy, by narrowing the variability range of the response speed also. The brain's signal processing becomes more efficient and more consistent, able to exclude irrelevant information. Future studies of this technique must demonstrate that the gains seen are transferable to cognitive processing (early studies and theory suggest this), and whether they sustain at long term follow-up.

Brain efficiency involves chemical and electrical brain signaling, and is associated with the general factor in IQ.

Hatfield and Hillman (2001) expanded the concept that the central nervous system will use less resources to perform the same work when it is more efficient, an extension of similar findings in the motor system. Consistent with the theories of Haier, and of Bates, increasing task demands and focused attention involves the group of more intelligent students actively excluding irrelevant neural networks. More selective and efficient mobilization of resources in higher intelligent individuals would also show higher P300 amplitudes (cognitive resources to stimulus processing) and shorter P300 latencies, reflecting the duration of the stimulus evaluation process (see Michie, 1995). Individuals in the study were all right handed. More highly intelligent individuals have a more spatially and temporally coordinated electrocortical activity when engaged with cognitive tasks.

Better IQ scores, according to the Jausovec & Jausovec (2000) study, relate to fewer but more specifically and simultaneously activated neural networks. Full scale IQ, verbal IQ, and Performance IQ correlated negatively with response times (RT) in visual and auditory oddball paradigms, as well as with P300 and N400 peak latencies (especially in auditory tasks). This is consistent with Jensen's (1992) theory that speed of information processing is an essential component of intelligence, and that a possible neurological basis for it is the speed of transmission through the nerve pathways.

Mortiani and deVries (1979) explained the relative efficiency of the motor unit recruitment in trained skeletal muscle such that the integrated EMG activity recorded from stronger muscle is reduced relative to that observed in the untrained state during similar work, termed "the efficiency of electrical activity of muscle" (EFA) (cited by McDowell, 2003). This is a primary characteristic of the nervous system after training and is also "expressed in the biomechanical quality of movement" (cites Sparrow, 2000).

"Movement results from a synergistic action of motor outputs, which are interconnected (Keller, 1993) by inhibitory and excitatory pathways. The balance of these connections is likely to govern the kinematics of voluntary movements and also of movements governed by cortical stimulation. This pattern of connectional weights is regulated by mechanisms that alter the efficacy of synapses (Donoghue et al, 1996; Markram & Tsodyks, 1996), and the neocortex is richly equipped with mechanisms for changing synaptic efficacies (Donoghue, 1995). Of these, short term potentiation or short term depression are mechanisms possibly related to the present results" (see Classen et al, 1998).

Movement plays a role in establishing patterns that go into long term memory

"The plasticity identified in this study may underlie the initial stages of skill acquisition for motor skills, a type of procedural memory, as well as in the recovery of function that follows rehabilitation from cortical injury." The primary motor cortex has been found to be involved in the acquisition of procedural knowledge (Karni et al, 1995; Pascual-Leone et al, 1994). Authors hypothesize that the storage and rehearsal of procedural information in short term memory promotes the formation and consolidation of information in the longer term. It appears likely that the motor cortex undergoes continuous plastic modifications. Frequently repeated movements reinforce particular network connectional patterns, but those patterns weaken if the movements have not been recently executed (Classen et al, 1998).

Brain electrical activity is another way to describe these changes. Chemical and electrical synapse activity is connected to cell polarization and is the language of network communication.

The role of the motor cortex in implicit and explicit learning was studied by measuring ERD (event related desynchronization of cortical potentials) by Zhuang et al., (1997). Right handed individuals performed a serial reaction-time task. A decline in alpha band power maximal over the contralateral central region was seen when initial learning took place. ERD reached a transient peak amplitude as subjects gained full explicit knowledge, peak at C3, and declined subsequently. Transient changes in cortical architecture may occur in conjunction with learning, some are expressed at the level of the synapse, others at the level of neural circuits (cites Lopes da Silva, 1979; Steriade, 1990). Authors found that repetitive trials with the same sequence produced both greater procedural learning and more explicit knowledge of the sequence.

Response speed is clearly connected to the stage of learning, and can be indexed in electrical activity measurements

Maximum improvement in response time is found when subjects were able to generate the entire learned sequence (consistent with Pascual-Leone, 1994). Progressive improvements in response time (RT) during task learning are accompanied by a change in the 10 Hz. ERD (Zhuang et al, 1999). Activity in the primary Motor Cortex increases in association with learning a new motor task and decreases after the task is learned. Cortical changes have been associated with motor skill learning in the studies of several authors (Merzenich et al, 1990; Sanes and Donoghue, 1992; Recanzone et al, 1992; Milliken, 1992, cited by Zhuang et al, 1999). People who have declarative knowledge of the task may hasten the acquisition of procedural knowledge, seen in a rapidly reducing response time. When a cortical area is preparing or processing information, alpha activity desynchronizes. This may be interpreted as a small neuronal assembly working in a relatively independent manner. According to Thatcher (1983), desynchronization may represent a state of both maximal readiness and information processing capacity, or active functioning. Coherent or synchronized alpha activity is found in a resting or idling brain over wide cortical areas. Information processing is reduced and little motor behavior occurs (Pfurtscheller, 1992).

Zuang et al (1997) summarizes some theories as to why learning related changes in cell properties and motor representation patterns may occur. Studies are cited to support each of these. The possibilities include: MI (motor cortex) maintaining a flexible relationship with muscles, excitatory horizontal connections between functionally different representations, a change in coupling thus creating new motor output architectures, activity dependent modifications in synaptic efficiency (e.g. long term potentiation and depression). Plasticity may occur by an LTP like mechanism and the literature on this is reviewed by Donoghue et al, (1996). Motor maps have been able to be altered by all of: electrical stimulation of MI, shifts in limb position, repeated limb movements and by morphological restructuring (see Zhuang, 1999, p.379). Blocking of NDMA receptors in the brain inhibited movement related reorganization of the primary motor cortex (Qui et al, 1990). Activity in primary motor cortex possibly increases with learning, as seen in studies with monkeys and humans (Suner et al, 1993 cited in Zhuang, 1999; Donoghue & Sanes, 1994; see also Sanes & Donoghue, 2000).

How these cell changes take place in learning …might represent a type of "short-term, activity dependent cortical plasticity," possibly related to improvement of skilled motor performances (Bonato et al, 1996; cites also Zanette et al, 1995). Post exercise MEP amplitude decreases may be triggered by priopriceptive afferent inputs to MI induced by muscle stretch during the execution of the motor tasks or by primary intracortical modulation of pyramidal cell excitability (Bonato et al, 1996; Zanette et al, 1995). The potential anatomical substrate of this post-exercise inhibitory modulation may be feedback or feedforward mechanisms involving the long-horizontal excitatory axon collaterals of cortical pyramidal cells activated during exercise (Bonato et al, 1996).

The same cortical circuits that are involved in motor execution are activated for imagery.

In a related piece of work, Fadiga and colleagues (1999) used TMS to find out whether the excitability of the corticospinal system is selectively affected by motor imagery. Mental simulation of motions of hand and arm flexion and extension was practiced. Motor evoked potentials were recorded. The same cortical circuits that are involved in motor execution are activated for imagery. Right motor cortex activated for contralateral hand only, whereas left motor cortex revealed increased corticospinal excitability for imagery of ipsi-and-contralateral hands. Certain neurons activate for visual presentation of an object such as one that might be grasped, and another group activates for observing another individual (monkey) actually performing a task similar to those this monkey can motorically perform (sources in Fadiga, 1999). An action vocabulary is stored in the ventral premotor cortex, which may strongly facilitate the execution of motor commands and also creates brain storage of action schemes related to action goals (Fadiga et al., 1999). The same pool of motor schemes can be reached visually, by an object or by seeing an action. These groups of F5 neurons are called canonical and mirror neurons.

Motor imagery and actual execution share many neural activation schemes

The literature supports the idea that motor imagery has substantial similarity to movement execution. Eight studies cited show that regional cerebral blood flow (rCBF) increases in cerebellum and cortical motor areas during motor imagery tasks, and these have been verified by MEG and evoked potential studies. These may relate to movement intention or to simulation. The left hemisphere is known to play a dominant role in motor imagery (see also Beisteiner et al 1995). Two Fadiga papers (1999; 1995) indicate that mental simulation of movements involves the same neural substrate that is addressed in action execution and during observation of actions performed by others. Neural encoding of apparent human movement was studied by Stevens (2000). See also Decety (1996).

Motor performance and motor imagery has been studied by others. Porro et al., (1996) using fMRI, found that motor imagery and motor performance involve overlapping neural networks in the peri-rolandic cortical areas. They say that debate continues over the extent to which there is overlap between the areas used in motor imagery and those in actual motor action. They conclude that local changes in hemodynamics in brain activation is thought to represent alterations in synaptic activity attributable to increased firing of interneurons (excitatory or inhibitory) and/or afferent fibers (cites Raichle, 1987; Roland, 1993). EMG has been found to increase in muscles that are involved in the imagined motor act, in many but not all relevant studies (see Porro, 1996). Shibata and colleagues (1997) investigated EEG coherence in a go-no go task paradigm and concluded that coherence between sites F3 and F4 became significantly higher in the No- Go condition, suggesting that synchronization between bilateral, dorsolateral frontal areas may play an important role in the motor inhibition process. Dynamic functional coupling occurs in these areas.

Mental simulation of sport activity has been shown to be beneficial (see Fadiga et al., 1999), and motor imagery is also used in microsurgery training. The motor system is helpful, according to PET activation studies, in tasks having no motor content, e.g. a judgment task of object rotation (see Parsons et al, 1995). Mental motor representations rely on the same neural circuits used for action generation. "Mental representations, traditionally ascribed to the cognitive domain, appear to be strictly linked, and possibly intrinsic to the "acting" and "perceiving" brain." (Fadiga et al., 1999).

Conclusion

A widely distributed, well studied brain activation occurs through a specific movement program. This creates neural network elaborations, with practice, and exercises many brain structures including those implicated in sensory processing, memory and imagery, as well as frontal structures responsible for executive functions and inter-hemispheric communication. Response times are associated with cognitive performance. Faster response times are associated with greater network efficiency and exclusion of irrelevant data. Delayed responding is characteristic of many learning disabilities. A practice tool such as the Interactive Metronome can be expected to increase efficiency and organization of central nervous system circuitry. Response speeds in activities using visual and auditory inputs should become less variable, and faster. The use of guide sounds helps in "choice discrimination", and that, along with feedback to modulate chronically early responses, would be expected to affect the response inhibition difficulties of hyperactive students. This remains to be established through specific study.

There are preliminary, though encouraging, findings for cognitive benefits in a few studies using IM. These include improved motor control and motor integration, and better attention in special education students (Stemmer et al., 1996); correlation between academic performance and IM scores in elementary school students (Schaffer et al., 2001); reading and math fluency increases in Title 1 students (Cason, 2003) and high school students. While promising, not all of these studies are independent, and the field can benefit from a variety of other new studies. Study designs should include well known continuous performance test measures (e.g. TOVA, IVA, Conners), and standardized motor movement measures such as the Bruininck's-Oseretsky, and others. Studies should include academic achievement measures, (e.g. WIAT), perhaps just prior to IM training, with a post-test one year follow-up. Direct measures of evoked potential function would also be helpful. Replication of the inhibition tasks of the studies cited in the ADHD section above would also be useful. It remains to be verified that timing gains are maintained on follow-up. Theories of brain plasticity, along with the activation evidence from a variety of neural imaging methods, are available to validate our use of this and similar techniques, as important tools in learning remediation.

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Learning Problems and the Left Behind

(Summary of a paper presented at the annual meeting of the
National Association of Elementary School Principals, Anaheim, CA, 2003
by Dr. Cindy Cason, Ph.D. Education)

Since 1973 and the enactment of Public Law 94-142, public schools have struggled with children who learn differently. Heterogeneous classrooms automatically mean comparison between children. This comparison becomes one between those who are "on" or "above" grade level and those who are "behind." The children targeted by the No Child Left Behind (NCLB) legislation of 2002 are from disadvantaged homes and have difficulty with cognitive development, acquiring vocabulary and learning the sounds required for learning to read. In addition, over ten million of these children nationwide have no health insurance and are educated in schools that are underfunded. These children are "left behind" years before they enter the realm of public education. Compounding that is the fact that, according to data reported in 2001 by the National Institute of Child Health and Human Development (NICHD), twenty percent of all elementary school students are at risk for reading failure. Five to ten percent of those at risk for reading failure have difficulty learning to read despite receiving the kind of reading instruction that is successful for most students.

The Learning Disabilities Association (LDA) highlights the fact that one in five American adults is functionally illiterate. One cause, according to LDA, is a neurologically-based learning disability that is often not recognized and/or dealt with appropriately. However, brain research conducted during the 1980s and advances in technology that followed during the 1990s can bring about a major improvement in educating children who learn differently.

One program that shows potential is Interactive Metronome® (IM). IM is an auditory processing program developed in the early 1990s by James Cassily. IM can be used to assess and rapidly improve the core brain processes of motor planning, sequencing and timing, which are the cornerstones of reading and math fluency. IM enables children to practice rhythmicity and timing and improve these vital skills.

The program, which is somewhat like a computerized version of a metronome, provides feedback indicating how closely a person's physical performance is synchronized to a program-generated reference beat. Recent research shows that IM training produces an average two-grade-level increase in reading and math fluency. The following research model, performed on Title I students, continues to demonstrate these dramatic increases.

Research Design

The study involved fourth and fifth grade students identified as Title I eligible and scoring in the lowest three stanines on the reading subtest of Stanford Achievement Test Edition Nine. Forty of the students participated in 12 sessions of IM training. Forty other students formed the Control Group and were matched to Research Group students on the basis of School Ability Index scores from the Otis Lennon School Ability Test.

Premise

According to the NCLB legislation, all students should be reading "on grade level" by the end of third grade. Therefore, the premise of this research is if students can increase their reading fluency they will be more apt to continue to read and strive to improve. Fourth and Fifth graders who are not reading fluently or doing their math fluently as compared to their peers are likely to "shut down" to avoid subjecting themselves to the peer taunts and jeers that go with being "slow."

Interactive Metronome Training

Forty students participated in a twelve-session protocol of the Interactive Metronome Training. The control students did not. Training consisted of three to four one-hour sessions per week for three to four weeks. Students progressed through the Interactive Metronome training in a four to one student-to-trainer ratio. Research and control groups were both pre- and post-tested with reading and math fluency subtest of the Woodcock Johnson III standardized test. Additionally, the STAR reading assessment was administered pre and post training and the Stanford Achievement Test results for the testing prior to training and post training were reviewed.

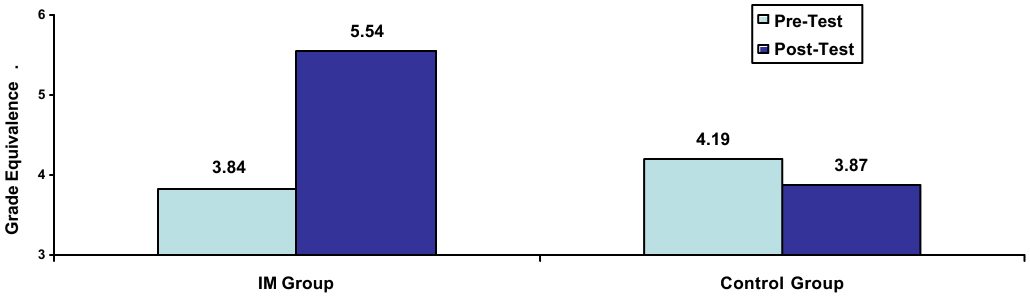
Results – Reading

Comparison of the IM trained group's pretest results with those of the control group reveals that both groups began the study with statistically equal performances on the reading fluency test ($p = .132$). After IM treatment, the IM group (mean = 5.54 GE) showed significantly higher posttest reading fluency performance (comparison $p < .000$) than did the control group (mean = 3.87 GE). Additionally, the IM group significantly increased its posttest performance (mean = 5.54 GE) over its pretest performance (mean = 3.84 GE), an increase of 1.71 grade equivalents ($p < .000$).

Interestingly, the control group experienced a significant decline in reading fluency from the pre- to post-testing (p = .0001).

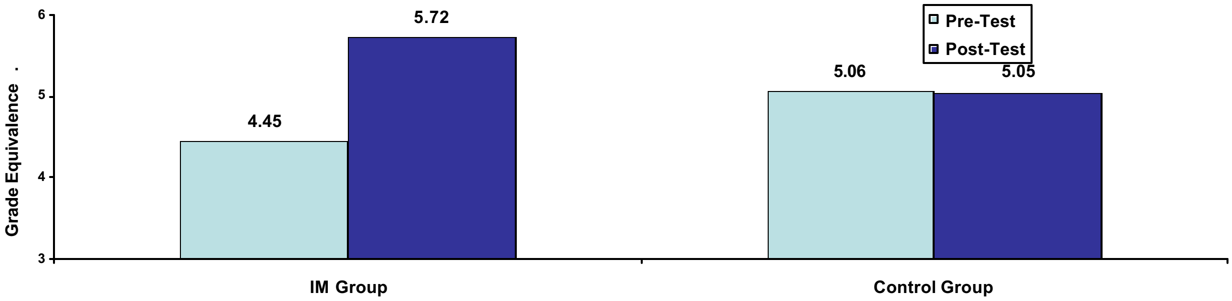
The STAR results showed that the students increased from an average of one to two grade levels. Students who received the IM training achieved a strong result in their fluency and comprehension during STAR testing. As a group, the students who received the IM intervention increased their Ability-Achievement Comparison (AAC) range on the Stanford Achievement Test from Low (below average) to Middle or High (above average). The control group, on the other hand, either remained at the Low or Middle range or decreased from Middle to Low (below average)

These results strongly support the conclusion that IM training significantly influences improvements in subjects' reading fluency performance.



Results – Mathematics

Comparison of the IM trained group's pretest results with those of the control group again reveals that both groups began the study with statistically equal performances on the mathematics fluency test (p = .086). After IM training, the IM group (mean = 5.72) showed a non-significantly higher posttest math fluency performance (p =.072) compared with the control group (mean = 5.05). However, the IM group significantly increased its posttest performance (mean = 5.72) over its pretest performance (mean = 4.43), an increase of 1.29 grade equivalents (p < .000). In fact, at the start of the study the IM group was 0.63 grade equivalent below the control group, but finished the study 0.67 grade equivalent higher than the control group. The control group showed no change in mathematics fluency from pre- to post-test (p = .935).



As a group, the students who received the IM intervention remained stable in regards to their Ability-Achievement Comparison (AAC) Range on the Stanford Achievement Test. The overall group result was in the Middle range both pre- and post- IM training. The control group, on the other hand, either remained at the Low or Middle range or decreased from Middle to Low (below average). These results strongly support the conclusion that IM training significantly influences improvement in subjects' mathematics fluency performance.

The results of this study indicate that powerful new interventions, such as Interactive Metronome, are now available that have a significant positive impact on students' academic development. These interventions, based on the latest technology, fundamentally improve students' cognitive capacity and performance. Educators should become knowledgeable of these tools and use them aggressively to reclaim the largest possible portion of their "at risk" student population.

RESULTS SUMMARY

INTERACTIVE METRONOME®
PERFORMANCE TRAINING

of

ST. THOMAS AQUINAS HIGH SCHOOL

Student - Athletes

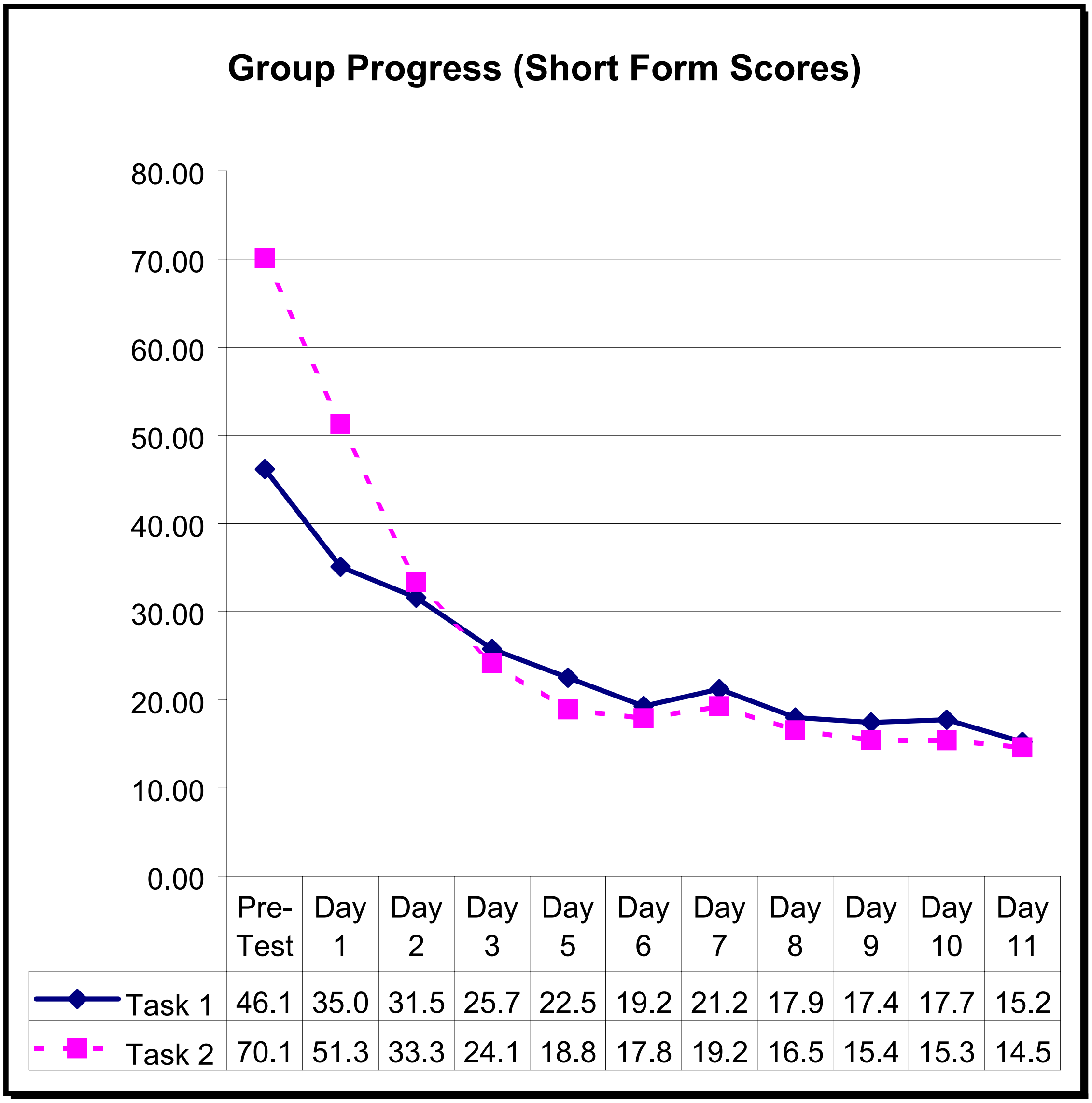
Background

Staff of Interactive Metronome, Inc. trained 29 student/athletes from St. Thomas Aquinas High School, Ft. Lauderdale, Florida. IM training was conducted on a group basis with 15-17 student-athletes working in each of two groups in a computer classroom. Training occurred over a span of 15 days. Timing and focus results produced and measured by the Interactive Metronome®. Mental processing results measured by a nationally standardized test for academic achievement. Functional improvements and execution results provided by the student-athletes themselves through a written survey conducted post IM training.

Index of Results

AUGUST/SEPTEMBER 2001

TEAM TIMING RESULTS


Group Progress (Short Form Scores)

	Pre-Test	Day 1	Day 2	Day 3	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11
◆ Task 1	46.1	35.0	31.5	25.7	22.5	19.2	21.2	17.9	17.4	17.7	15.2
■ Task 2	70.1	51.3	33.3	24.1	18.8	17.8	19.2	16.5	15.4	15.3	14.5

- Task 1 is the performance of a player matching the metronome beat with no feedback aid from the guide tones…pure timing ability

- Task 2 is the performance of a player matching the metronome with the feedback aid from the guide tones

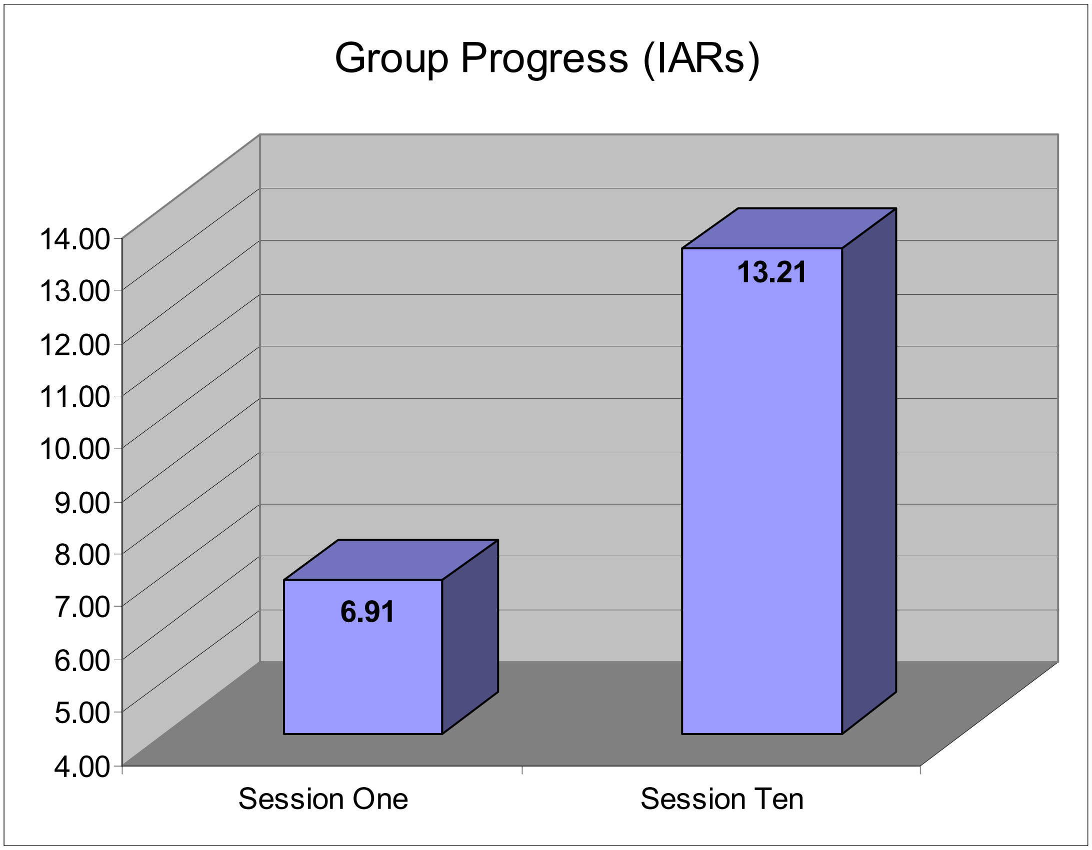
- 67% Improvement on Task 1 and 79% Improvement on Task 2

- Task 1 Pre-test average of 46.16ms ranks 55th percentile nationally

- Task 1 final day average of 15.23ms ranks 99th percentile nationally

- Top professional athletes and musicians score in the 18-22ms range on the Task 1, pure timing ability test

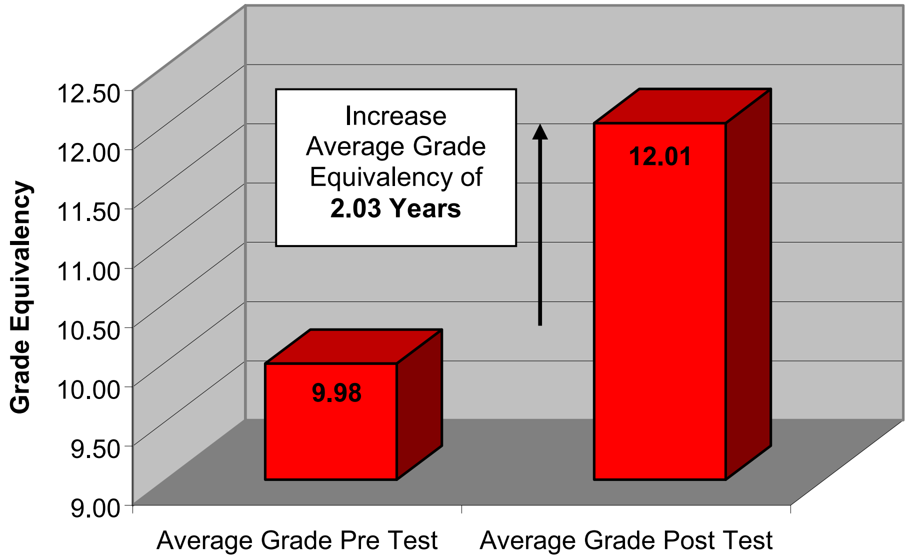
TEAM FOCUS RESULTS



- IAR (In-a-row) is the number of times consecutively a player can perform within a + or – 15ms range
- Indicates duration of time perfect mental state maintained
- Beginning score of 6.91 IARs equals 7.6 seconds
- Best group score of 13.21 equals 14.5 seconds
- Over 90% improvement
- Average length of football play <u>8-9 seconds</u>

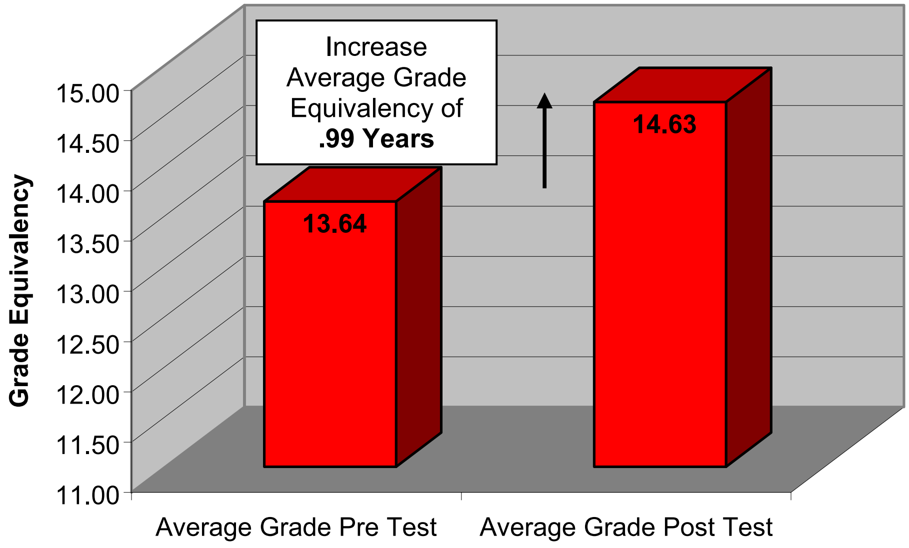
TEAM MENTAL PROCESSING RESULTS

Interactive Metronome/St. Thomas Academic Pre/Post Testing Results - *Reading Fluency*



Average Grade of Students = 11.41, Study Data n = 29, P=.000
Woodcock-Johnson, Third Edition

Interactive Metronome/St. Thomas Academic Pre/Post Testing Results - *Math Fluency*



Average Grade of Students = 11.41, Study Data n = 29 , P=.007
Woodcock-Johnson, Third Edition

TEAM EXECUTION SURVEY RESULTS

Team survey results showed:

Improved Team Focus by 45%

Increased Overall Team Synchronization/Timing by 62%

Raised Overall Team Execution by 56%

Decreased Offensive Miscues by 50%

Student/Athletes reported multiple benefits from IM training:

“I am in the right place at the right time.”

“I feel I get less mentally tired at practice since we started training.”

“I tend to have a better time of zoning out all that is around me aside from the task at hand.”

“I can adjust to a defense better, especially reading the blitz and calling audibles.”

I have been able to concentrate more at looking the ball into my hands.”

“My ability on defense to read routes and offensive formations and react to plays has improved greatly.”

“My reading concentration has improved and I now read much faster.”

“I feel my body is more in sync with my mind and it reacts better than prior to IM training.”

INTERACTIVE METRONOME – UNDERLYING NEUROCOGNITVE CORRELATES OF EFFECTIVENESS

Submitted by Dr. Patrick Gorman

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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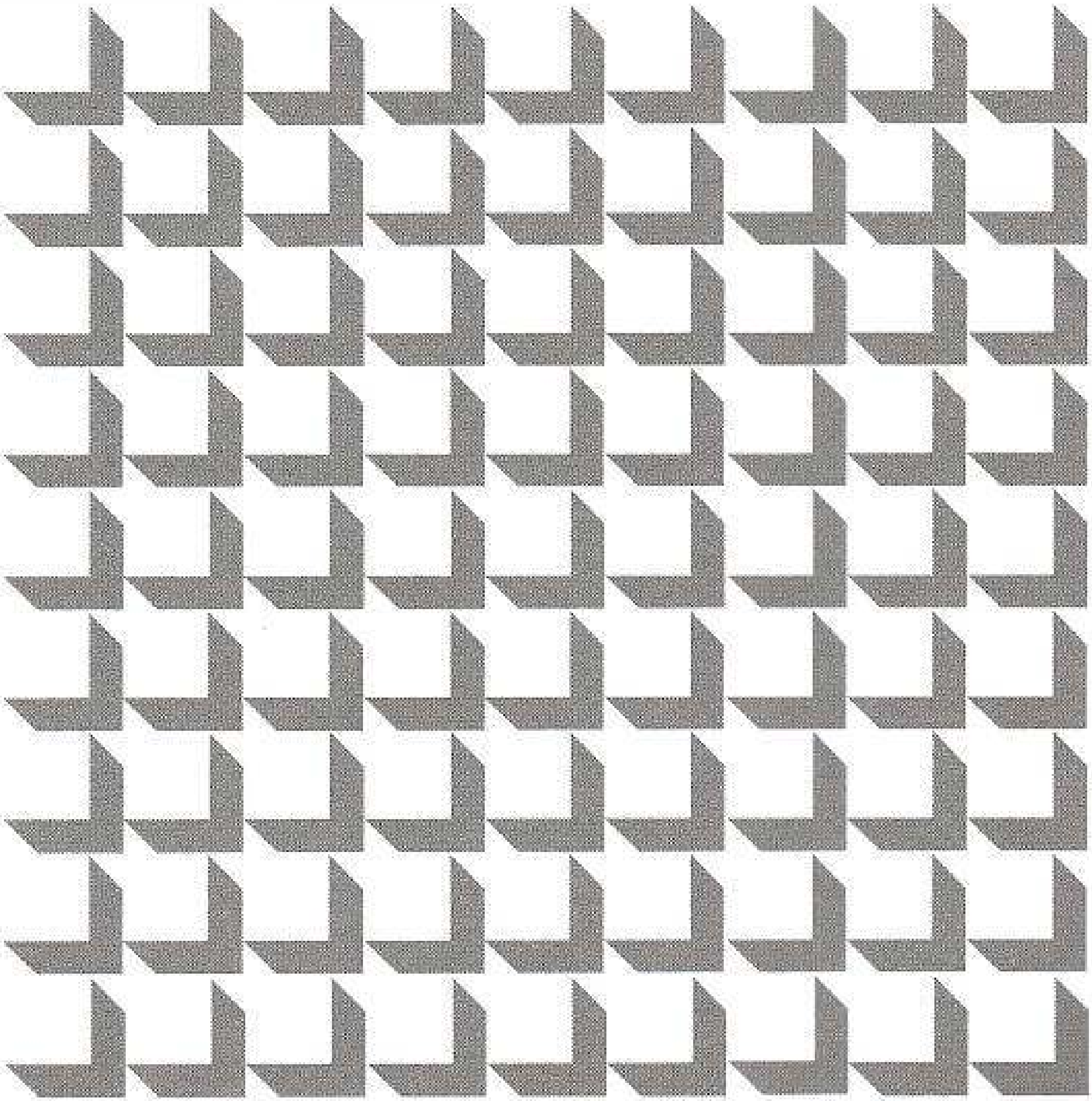

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Training in Timing Improves Accuracy in Golf

TERRY M. LIBKUMAN
HAJIME OTANI
Department of Psychology
Central Michigan University

NEIL STEGER
Preventive Health, Inc.
Grand Rapids, Michigan

ABSTRACT. In this experiment, the authors investigated the influence of training in timing on performance accuracy in golf. During pre- and posttesting, 40 participants hit golf balls with 4 different clubs in a golf course simulator. The dependent measure was the distance in feet that the ball ended from the target. Between the pre- and posttest, participants in the experimental condition received 10 hr of timing training with an instrument that was designed to train participants to tap their hands and feet in synchrony with target sounds. The participants in the control condition read literature about how to improve their golf swing. The results indicated that the participants in the experimental condition significantly improved their accuracy relative to the participants in the control condition, who did not show any improvement. We concluded that training in timing leads to improvement in accuracy, and that our results have implications for training in golf as well as other complex motor activities.

Key words: golf swing, performance, timing

GOLFERS are constantly looking for ways to improve their performance. One of the ways in which they attempt to accomplish this is through the use of the modern or "high-tech" golf club. Although it is not clear whether performance is enhanced with the modern club, this quick-fix approach is popular, as evidenced by the millions of dollars spent annually on such clubs. The second way of trying to improve performance is through instruction. This approach is also popular, as witnessed by the numerous swing instructors (the so-called swing gurus), schools and academies, magazines, videos, and books devoted to improvement in golf. However, as with the modern golf club, it is not clear what impact instruction has on performance.

Golf aids, commonly used in conjunction with instruction, are another way in which golfers try to enhance performance (Wiren, 1995). There are numerous golf aids on the market. For example, a golfer who believes that he or she has a problem with wrist movement may use an aid (worn on the hand and wrist) that allows only for the appropriate movement. This approach is also popular (witness the common caricature of the golfer weighted down with a multitude of golf aids) but, like the other performance-enhancing approaches, there is little, if any, evidence to support the efficacy of this one.

In contrast to the applied approaches directed toward the improvement of golf performance, there is another approach, in which researchers are more concerned with understanding the nature of the golf swing (e.g., Cochran, 1992, 1995; Cochran & Stobbs, 1968; Hay, 1978; Jorgensen, 1994). This approach implies that understanding the golf swing will lead to its improvement and ultimately to lowered golf scores. Also for researchers, the golf swing, because of its complex nature, poses some interesting intellectual challenges.

Cochran and Stobbs (1968) attempted to simplify the complexity of this phenomenon by modeling the golf swing as a double pendulum system in which two levers rotate about a fixed pivot. The fixed point is between the golfer's shoulders, and it is fixed only in the sense that it does not change planes. The one lever is an upper lever and corresponds to the arms and shoulders swinging around the fixed point. The other lever is a lower lever and corresponds to the movement of the golf club. The two levers are hinged in the middle by the wrists and the hands. A fundamental assumption of this model is that, for the levers to work effectively, it is essential that the levers be timed. In other words, to transfer the maximum amount of energy to the club head at impact, the lower and upper levers must work in synchrony. Therefore, acquisition of this skill, particularly at the expert level (Ericsson, 1996; Ericsson & Lehmann, 1996), requires extensive and effortful practice, not only to learn the basic swing movements but also to time them. Furthermore, we assume that without any additional major changes in the basic movements of the golf swing (for example, changing the golfer's swing plane through training or instruction), the skill must continue to be "fine-tuned" or timed for the golfer to maintain the high level of reliability that is required for successful performance. In fact, a basic assumption made by many professional golfers is that the only practice that should occur immediately before a competitive event is fine-tuning, and that the major downfall in actual competition (with its inherent stresses and pressures) is the failure to maintain proper timing.

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Address correspondence to Terry Libkuman, Department of Psychology, Central Michigan University, Mt. Pleasant, MI 48859; libku1tm@cmich.edu (e-mail).

It is important to emphasize that even though there is a scientific body of knowledge about the golf swing, there is little empirical literature concerning the timing properties of the golf swing. This is in direct contrast to the enormous importance that is attached to timing by instructors (e.g., Leadbetter, 1990, 1993) and golfers (e.g., Nicklaus, 1974; Watson, 1998). In fact, it would be a rare event to select any issue of any popular golf magazine (e.g., *Golf* and *Golf Digest*) and not find an article devoted to timing. In the present experiment, therefore, we examined this aspect of the golf swing. In particular, we asked whether extensive training in timing would improve performance accuracy. We chose accuracy over distance as the major dependent measure because even though distance is an important determinant of performance (Cochran & Stobbs, 1968), greens in regulation (an index of accuracy) accounts for more of the variance in golf scores than does any other single measure (Riccio, 1995).

There are at least three indications that training in timing might improve the golf swing performance. Jagacinski, Greenberg, and Liao (1997) found evidence that the age-related decline in golf performance may be explained by the differences in timing, rhythm, and tempo between young and older adults. The researchers referred to timing as those forces that are applied to the golf club during the swing. In contrast, tempo referred to the overall speed of the swing, and rhythm referred to the cycle of speeding up and down of the swing. In the Jagacinski et al. study, young and older adults were asked to swing an eight iron in order to hit a plastic ball that was placed on a rubber tee. The speed and force pattern of the club head was measured by a miniature accelerometer attached to the club head. Jagacinski et al. decomposed the swing by analyzing the force patterns into six phases: (a) beginning of the swing, (b) backswing, (c) downswing up to the maximum force, (d) downswing from the maximum force to impact, (e) impact to the resting level, and (f) the resting level to the maximum force during the follow-through. By measuring the duration of these phases, they were able to test the hypothesis that older adults swing the club too quickly or at too fast a tempo relative to younger adults. Their analyses partially supported the hypothesis: Older adults exhibited a shorter overall shot duration than did younger adults, even though the difference was only marginally significant. Rhythm, measured by the duration of each of the six phases, also showed age differences. The older adults, relative to the younger adults, exhibited shorter intervals during the beginning of the swing, from impact to resting, and from the resting level to the maximum force during the follow-through. Jagacinski et al. interpreted these results as indicating that for younger golfers, the club head reaches its peak maximal force just before impact, whereas for older golfers the club head reaches its peak maximal force earlier in the swing. The obvious implication is that getting the peak maximal force to occur just prior to impact for the older golfers should improve their performance. Interestingly, the amount of force was roughly the same for both groups. Thus, the findings of Jagacinski et al. indicate that timing is important in the golf swing and that age-related declines in golf performance may be due to this factor. On the basis of their results, these authors suggested that training in timing might improve one's golf swing. In particular, they suggested that slowing down the swing and maintaining this same tempo for all shots would be an effective strategy for improving performance.

Another indication that training in timing may improve the golf swing is based on studies that investigated the effects of transcranial stimulation on timing. These studies indicated that by stimulating the motor cortex, a voluntary motor act could be delayed without affecting the intention to act (Day, 1996). Day and colleagues (Day, Dressler, et al., 1989; Day, Rothwell, et al., 1989) administered transcranial stimulation in two ways. One was a short-duration, high-voltage electrical stimulus that passed through an electrode attached to the scalp; the other stimulus was a pulsed magnetic field delivered through a flat, circular coil held on the head. The stimulation was delivered 100 ms after the onset of a "go" signal. The results showed that both types of stimulation delayed the onset (approximately 50 ms) of the motor movement (i.e., wrist flex and wrist extension). Furthermore, the electromyographical pattern of agonist/antagonist muscle activation (i.e., contracting muscles that are resisted by other muscles) was similar between trials with or without the stimulation. The latter observation indicated that the stimulation did not affect the way in which their voluntary movement was produced. In contrast, stimulation to the peripheral nerve produced different results. When the median nerve at the elbow was stimulated, there was no delay in the onset of muscle activity. The stimulation suppressed only the first burst of agonist muscle activity. On the basis of these observations, Day and colleagues (Day, Dressler, et al., 1989; Day, Rothwell, et al. (1989) concluded that stimulation per se does not cause the delay. Day, Rothwell, et al. (1989) also asked whether the stimulation delays the onset of movement by delaying one's intention to act. To test this hypothesis, they instructed participants to flex both wrists while receiving stimulation to the motor cortex from only one side of the brain. The rationale for this treatment was that if the stimulation delays the participants' intention to act, then the unilateral stimulation would delay the activation of the muscles for both wrists. On the other hand, if the stimulation delays the movement by affecting an executive process that controls the nerve pathways, the unilateral stimulation would delay only the movement of the limb contralateral to the stimulation. The results showed that the delay of movement was greater for the contralateral limb than for the ipsolateral limb. They concluded that the cortical stimulation does not affect one's intention to act. Instead, stimulation delays movement by affecting the executive process that sends signals to the muscle.

Day (1996) interpreted these results to mean that transcranial stimulation inhibits the motor cortex to initiate the movement. However, this does not explain the result that the normal movement returned after the cortical inhibition was over. To explain this, Day proposed a hierarchical model of timing consisting of two partially independent components. One is a high-level process that prepares the movement and instructs the motor cortex to release the movement. The second is a subordinate level process that refines the precise timing of the movement. It is the second process that determines when the instructions to move relevant muscles would be sent. According to Day, the important property of this model is that "our limbs would not necessarily move when we tell them" (p. 233). For our purpose, this implies that practice may be needed to refine the coordination between one's intention to act and the precise timing of the act itself.

A more recent view of sensory and motor timing also proposes a common neural mechanism to represent temporal properties of perceived events and motor movements (Meegan, Aslin, & Jacobs, 2000). Research has suggested that the cerebellum may play an important role in representing sensory and motor timing (Ivry & Keele, 1989; Jueptner et al., 1995). In support of this view, Meegan et al. showed that motor timing could be improved by sensory timing training. In that study, participants were asked to use their right thumbs to press a button twice in succession with a prespecified interpress interval. The sensory training consisted of discriminating between a short and long interval between two tones. The researchers found that even though the sensory training did not involve motor movements, motor performance improved significantly after the training. On the basis of these results, Meegan et al. concluded that sensory timing training alters motor timing because a common neural mechanism is used to represent timing for the sensory and motor systems.

On the basis of the considerations mentioned in our literature review, we thought that it would be useful to examine the notion that extensive training in timing would improve performance in golf. The design of the present study was relatively simple. First, all participants were pretested, with accuracy as the measure of golf performance. Second, the participants were assigned to the experimental or control condition. The experimental-condition group received approximately 10 hr of training with a specialized metronome (Interactive Metronome®). The Interactive Metronome®, unlike other metronomes, uses auditory feedback to train an individual to match a variety of movements to a steady beat. The control-condition group read golf instruction literature. Third, after 5 weeks, both groups were posttested with the same procedure and measure that were used in the pretest. We hypothesized that training in timing would improve accuracy.

The more important consideration in the design of the study was the timing parameter. What value should be selected? Furthermore, should the value remain constant or should it vary across training? Because there are no known empirical studies that have tested for the effects of timing on golf, and little, if any, theoretical guidance, we had to set the timing parameter largely on the basis of experience and intuition. In agreement with the suggestion of Jagacinski et al. (1997), we fixed the value at a relatively slow pace of 54 beats per minute (bpm) for all of the motor tasks across all of the training sessions. We assumed performance problems associated with the timing of the golf swing were largely due to tempo, and that extensive training at the slow pace of 54 bpm would improve tempo. Finally, we did not ask participants to practice with a golf club because we assumed that movements are stored in the central nervous system as general motor programs (e.g., Schmidt, 1975), and therefore the training does not have to be task specific. A recent study by Meegan et al. (2000) also supports the assumption that training in timing does not require motor movements.

Method

Participants

We recruited participants via advertisements that were posted in local golf retail shops, at driving ranges, and in the pro shops of area country clubs. The advertisements stated that participants were needed for a golf training technology study and that the study was designed to evaluate the effectiveness of a golf skills training aid on golf shot accuracy. Participants were informed of the schedule and time requirements of the study. To qualify for participation, interested individuals had to be 25 years of age or older and had to possess at least a basic skill level in golf. The first 50 individuals who met these requirements were selected and randomly assigned to the 2 conditions with the restriction that each condition contained 25 participants. Of the 50 participants who started the study, 9 did not complete it. Further, 1 participant from the experimental group was randomly excluded to equalize the numbers of participants in the experimental and control conditions. The final sample therefore consisted of 6 women and 34 men who ranged in age between 25 and 61 years ($M = 37$, $SD = 11.57$). Unfortunately, the random assignment produced a significant age difference, $t(38) = 4.34$, $p < .001$, between the experimental ($M = 45$, $SD = 11.62$) and control groups ($M = 31$, $SD = 6.43$). (One participant in the control condition did not report her age.) To statistically control for this variable, we analyzed the data using age as a covariate. Participants were informed that, if they completed the study, they would receive a gift certificate for golf equipment or clothing and that they would be competing for two $100 bonus prizes. Finally, participants were informed as to the risks and benefits of participation before they signed informed consent.

Apparatus

Pre- and posttest accuracy was measured using a Full Swing Golf Simulator™ located in an indoor 10 ft × 10 ft × 20 ft booth in a local retail golf shop. The indoor booth allowed for a controlled testing environment. As the name implies, the Full Swing Golf Simulator™ allows the golfer to execute a full swing and to hit a golf ball onto a screen that contains a picture of a golf hole including the tee box, fairway, and green with a pin and flag. The golfer can play a simulated round of golf at a number of famous golf courses. The simulator estimates the distance and direction for each shot and records the score for each hole. The simulator also provides for each shot a visual ball path trajectory line or a visual image of the flight of the golf ball from impact until the ball is stationary. Particularly important for the present study, the Full Swing Golf Simulator™ contains a duel-tracking system that cycles more than 2 million infra-red beams per second. As a consequence, the simulator is able to accurately monitor ball flight within 0.1 in. The measure of accuracy used in the present study for each golf shot was the distance in feet between the golf ball and the pin. Finally, the simulator requires that the approximate box-to-pin yardage be estimated and preset for each club. For example, a golfer hitting a nine iron would estimate and set his distance at 125 yards, a five iron at 170 yards, and so forth.

The Interactive Metronome® was used to train and analyze the golfer's ability to match a variety of movements to a steady beat. The Interactive Metronome® is a computer program for Windows 95/98 with peripherals, which include standard stereo headphones and a set of motion-sensing triggers. The trigger set plugs into the computer's serial port and includes a hand glove and a footpad. One trigger is attached to the participant's hand with a Velcro™ strap. When the participant claps or pats a hand, the attached trigger sends a signal to the program. A second trigger is contained in a floor pad on which the participant steps or taps. The computer program produces an auditory fixed reference beat. The beat can be set at any number of beats per minute. Participants are required to complete various hand and foot exercises in synchrony with the beat. The objective on the part of the participant is to move his or her limb at the same time as that set on the metronome. In other words, the participant attempts to pat or tap his or her hand or foot at the exact moment of the beat.

The program immediately analyzes the timing relationship between the participant's movements and the beat to the nearest millisecond. The tone of the beat (C6) is in monophonic and thus is spatially perceived as occurring in the center of the headphones. Movements include variations of clapping hands together, tapping the right or left hand on the side of the leg, tapping both toes or heels on the footpad, or tapping the right or left toe or heel on the footpad. The program produces different discriminative sounds that are based on the pitch and placement in the headphones. These reference pitches are tailored to guide the participant. The program transposes the timing information of each movement into one of the recognizable sounds. Each sound is a representation of when the movement occurred in relation to the beat. An early movement (i.e., a movement that precedes the beat) generates a low pitch tone in the user's left ear. A late movement (i.e., a movement that follows the beat) generates a higher pitch tone in the right ear. A movement that matches the beat within ±15 ms generates a higher pitched tone in the center of the headphones and is simultaneously perceived in both ears. A participant's timing score is the difference in milliseconds between the moment the beat sounds and the participant's tap.

All of the experimental-condition participants received their training in a room that contained five desktop computers arranged at the points of a pentagon. The computers, monitors, keyboards, and other materials were placed on tables, each with a chair. There were no partitions between the stations. The spacing and arrangement of the stations allowed the participants to stare ahead and not see anyone else working. The participants were also not likely to be disturbed by extraneous sounds because they were wearing headphones.

Procedure

The participants were randomly assigned to the two conditions prior to the pretest. The pretest was completed for all participants on two consecutive Saturdays in the month of May. Each participant was scheduled for a 1-hr appointment on one of the Saturdays at his or her convenience. Participants were informed that the pretest would take about 1 hr and that they should bring their own golf clubs. They were also informed that the type of clothing and shoes worn during the pretest should be worn during the posttest. The participants played the same hole under the same conditions (Troon North Course, AZ, Hole #1) for all shots using the same balls, driving mats, and rubber tees. The pretest consisted of 15 shots each with their nine, seven, and five irons, and the driver for a total of 60 shots. There was a 1-min rest period between each set of 15 shots. The participants were permitted to go through their normal warm-up routine and take as many as 10 shots before beginning the pretest.

In the actual pretest, participants began by setting the distance from the tee box to the pin. The experimenters informed the participants that the selected distance for each club would also be used for the posttest and that they would be required to use the same club. The participants were then instructed to aim for the pin and to proceed at their own pace. The experimenter recorded each score (i.e., the distance in feet from the pin). Finally, all participants were informed that they were strictly prohibited from practicing with any of the clubs that were used during the pretest as well as receiving any instruction or lessons during the study.

The participants in the experimental-condition group ($n = 20$) received 10 hr of Interactive Metronome® training in 12 sessions of 50-min each. The sessions began the day after the completion of the pretest. They were scheduled throughout the day and early evening for the next 5 weeks. The schedule included weekdays and weekends. Participants scheduled the sessions at their convenience with the stipulation that they could not complete more than 1 training session per day, and that they needed to complete the entire training sequence by the end of the 5-week period. All of the experimental participants were trained in the same room that contained the five computer stations. An experimenter was present for all sessions. Up to 5 participants could be trained simultaneously with one experimenter monitoring their activities by sitting on a bar stool that was placed in the middle of the pentagon. Six experimenters (including the experimenter who collected the pre- and posttest data) were paid and trained in the use of the Interactive Metronome.® All of these experimenters had completed the actual training themselves. There was no attempt to balance experimenters with participants or training sessions. The experimenters simply signed up for scheduled times that were convenient for them and compatible with participant times. The primary duties of the experimenters were to greet the participants and ensure that they signed in and selected the correct daily training schedule. Experimenters also monitored and corrected, if necessary, any technical problems with the equipment, recorded data that were not recorded by the software program, and made sure that the participant scheduled his or her next training session before leaving. Finally, during the first session, experimenters modeled the use of the equipment and the proper technique for each of the prescribed motor movements that were later required of the participants.

Before each training session began, participants were required to sign in and select the appropriate training schedule for the day and to enter some demographic information (e.g., name, age, sex) into the computer. The experimenter attached the hand sensor to the participant's hand, and placed the headphones properly on the head. The experimenter stressed the importance of using controlled, smooth (nonballistic) motions in matching the movement to the steady reference beat. The experimenter also emphasized that participants should not aim, think about, adjust their motions, or listen to the guidance sounds, but rather focus their attention on the steady beat, and whenever they got off beat to refocus their attention on the beat. These instructions were also posted beside each computer station.

The beat of the metronome was set at 54 bpm for all 12 sessions. For each of the tasks within each of the 12 training sessions, concurrent, temporally based, guide sounds continually indicated that the participant was on target, early, or late. At the beginning of the first session and at the end of the last training session, participants were administered 30- to 60-s tests on each of the 13 movements that were used in the training sessions. Guidance sounds were not used during the testing, with the exception of one additional task (the 14th), which was a repeat of clapping both hands with the standard guide sounds. The test took about 10 min to complete. Two dependent measures were recorded for each task: One was the mean number of milliseconds across the 14 tasks the participant deviated from on-target performance, and the other was the highest number of times in-a-row (IARs) that the participant was able to stay within ±15 ms of the reference beat.

Before beginning the 10-min test, the experimenter placed the hand sensor on the participant's hand, and the foot sensor was placed on the floor. Then the experimenter modeled the appropriate movements. There were no exercises that paralleled the motions in the golf swing.

The first 4 tasks in the 10-min test involved the hands. In the 1st task (clapping hands), participants were instructed to make circles of about 10-in. in diameter with the hands coming together on the beat and to continue the circular path without stopping after the beat. The 2nd task was identical to the 1st with the exception that the early, late, and on-target guidance sounds were presented. The guidance sounds were presented only for the 2nd task in the 10-min test. The 3rd

TABLE 1
Training Schedule

Task	Session 1	2	3	4	5
Clapping hands	180 (1)	385 (1)	500 (1)	1000 (1)	1000 (3)
Preferred hand	180 (2)	385 (2)	500 (2)		
Nonpreferred hand	180 (3)	385 (3)		500 (3)	
Both toes	180 (4)	385 (4)	500 (3)	500 (2)	
Preferred toe	180 (5)	385 (5)			
Nonpreferred toe	180 (6)	385 (6)			
Both heels		385 (7)			
Preferred heel					
Nonpreferred heel^{a}					
Preferred hand and nonpreferred toe			250 (4)		500 (1)
Nonpreferred hand and preferred toe			250 (5)		500 (2)
Choice			500^{b} (6)	250^{b} (4)	
Free style					500^{c} (3)
Total beats	1080	2695	2500	2250	2500

Note. Value in each cell indicates the prescribed total number of beats that were to be completed. Value in parentheses indicates the order in which the task was presented. ^{a}The use of the nonpreferred heel occurred only in the both heels and free style tasks. ^{b}Participant could choose any task that had been previously performed. ^{c}Participant was required to start with clapping hands, move to preferred hand, then preferred toe, nonpreferred toe, and end with both toes, all within 500 beats. ^{d}Participant was required to complete three sequences: Sequence 1, 4 beats clapping hands alternating with 4 beats preferred hand for 250 beats; Sequence 2, 4 beats clapping hands alternating with 4 beats both toes for 250 beats; and Sequence 3, 2 beats clapping hands alternating with 2 beats both toes for 500 beats. ^{e}Participant was required to alternate between 8 beats clapping both hands and 8 beats both toes. ^{f}Participant could switch between any of the tasks with the restriction to limit switching to every 100 beats.

and 4th tasks involved using either the preferred or nonpreferred hand and required that the participant, using the same circular motion, tap his or her hand on his or her leg on beat. The next 3 tasks involved the toes. In the 5th task, participants were instructed to face the floor trigger with both toes about 2 to 3 in. away from the trigger. They were instructed to start by lifting one foot and tapping that toe on the trigger with the beat and to return that foot to the previous position between beats, then tap the other toe on the next beat, and so forth. Tasks 6 and 7 involved the same movement but with only the preferred or nonpreferred toe, respectively. The next 3 tasks involved the heels. In the 8th task, participants were instructed to face away from the floor trigger with both heels about 2 to 3 in. away from the trigger and to start by lifting one foot and tapping that heel on the trigger on the beat, and return that foot to the previous position between beats, and then tap the other heel on the next beat, and so forth. Tasks 9 and 10 involved

		Session					
6	7	8	9	10	11	12	Σ
1000 (1)		1500 (1)		2000 (1)			7565
	1000 (1)						2065
		500 (2)					1565
1000 (3)				500 (2)			3065
	500 (2)				250 (2)		1315
					250 (3)		815
500 (2)							885
		500 (3)					500
							000
			1000 (1)				1750
			1000 (2)				1750
							750
	1000^d (3)		500^e (3)		2000^f (1)	2000^f (1)	6000
2500	2500	2500	2500	2500	2500	2000	

the same movement but with only the preferred or nonpreferred heel, respectively. The next 2 tasks involved combinations of movements. In Task 11, the preferred hand and nonpreferred toe were combined. Participants were instructed to face the floor trigger, tap their preferred hand against their leg on one beat, then tap the toe of the opposite (nonpreferred) foot on the floor trigger on the next beat and then to continue to alternate. In Task 12, the nonpreferred hand and preferred toe were combined with the same movements outlined in Task 11. In the final 2 tasks, balancing was added. In Task 13, participants were required to balance on their preferred leg while tapping the toe of their other foot on the floor trigger on each beat, and in Task 14, they had to switch to the nonpreferred leg.

After the completion of the 10-min test, the training sessions began. The purpose of the training was to increase the timing accuracy. Table 1 provides the training schedule. The development of this training schedule was based on three assumptions. First, we incorporated variability in the tasks that were required because we thought it would be more likely to generalize or transfer to another motor activity (Schmidt, 1988), in this case the golf swing. In other words, participants would become more sensitive to the timing properties necessary to execute this motor response. Second, although the total number of beats was relatively consistent across sessions (the number of beats required for testing are not included in Table 1), we increased the number of beats per task and decreased the number of tasks across sessions, assuming that this type of extended training on

TABLE 2
Mean IAR and Deviation From the Target in ms as a Function of Task and Test, Pretest and Posttest

	IAR		Target deviation	
Task	Pre	Post	Pre	Post
1. Both hands				
M	3.40*	5.85*	48.86*	21.17*
SD	2.30	2.68	19.32	6.86
2. Both hands with sounds				
M	2.70*	6.30*	71.54*	19.85*
SD	1.81	1.94	43.70	6.30
3. Preferred hand				
M	2.75*	4.50*	42.12*	25.19*
SD	1.83	2.59	17.00	13.02
4. Nonpreferred hand				
M	2.50*	4.00*	41.67*	22.65*
SD	1.67	2.34	19.45	7.57
5. Both toes				
M	1.90*	3.60*	68.99*	26.40*
SD	1.25	1.47	48.26	10.67
6. Preferred toe				
M	2.05*	3.70*	53.24*	27.38*
SD	1.19	2.68	24.89	9.82
7. Nonpreferred toe				
M	2.00*	3.90*	58.32*	27.08*
SD	1.26	2.05	32.67	10.25
8. Both heels				
M	1.65*	2.90*	71.43*	32.17*
SD	1.09	1.83	36.02	16.66

(table continues)

a single task would lead to an increase in the ability to maintain focus on the task as well as when executing the golf swing. Third, because of the positive relationship between the amount of practice and skilled performance (Ericsson, 1996; Schmidt, 1988), we assumed that by providing 10 hr of training (a total of 28,025 beats plus the beats during testing), the training in timing would be more likely to transfer to the golf swing. Finally, because of the repetitive nature of the training, participants in the experimental group were provided with motivating instructions beginning with the 3rd session and ending with the 11th session. These instructions urged them to decrease their millisecond average and increase their IARs. Furthermore, participants were informed that their millisecond averages and IARs would be ranked and posted and that the top two performing individuals would receive a $100 gift certificate for golf equipment or clothing.

TABLE 2 (Continued)

Task	IAR		Target deviation	
	Pre	Post	Pre	Post
9. Preferred heal				
M	1.60*	2.85*	96.74*	36.08*
SD	1.43	1.50	99.04	15.62
10. Nonpreferred heel				
M	1.55	2.30	76.07*	38.37*
SD	1.32	1.49	49.77	18.52
11. Preferred hand and nonpreferred toe				
M	1.15*	2.15*	97.75*	42.14*
SD	0.75	0.93	41.76	16.24
12. Nonpreferred hand and nonpreferred toe				
M	1.15*	2.50*	100.10*	34.69*
SD	0.88	1.28	57.17	11.04
13. Balance with preferred foot and tap with nonpreferred toe				
M	1.65	2.75	70.63*	33.08*
SD	1.27	2.00	38.60	14.89
14. Balance with nonpreferred foot and tap with preferred toe				
M	1.55*	3.15*	61.64*	25.15*
SD	0.94	1.53	28.19	6.77

Note. IAR = number of items in-a-row.
$^*p < .05$.

In contrast to the participants in the experimental group, the participants in the control group received a letter indicating that the attached 12 pages of golf tips were to be read at least once a day before the posttest. The golf tips were taken from popular golf magazines and books and were authored by prominent professional golfers and instructors. The participants were also informed that after completing the posttest they would receive a golf certificate. The control participants were not contacted again until they were scheduled for the posttest.

Results

Unless otherwise specified, the significance level was set at .05 for all of the analyses. We first determined whether the participants in the experimental group made a significant improvement in timing. Table 2 shows how participants performed on the tasks in the 10-min test before and after the training. As mentioned earlier, IARs and the milliseconds from the target were used to index the participants' timing. The table indicates that for both measures, participants performed better on the posttest than on the pretest (see Table 2). A 2 (test: pretest and posttest) × 14 (task: 14 different tasks on the 10-min test completed) repeated-measures analysis of variance (ANOVA) on the IAR scores indicated that the effects of test, $F(1, 19) = 145.61$, $MSE = 2.56$, task, $F(13, 247) = 12.46$, $MSE = 2.80$, and the Test × Task interaction, $F(13, 247) = 2.40$, $MSE = 2.08$, were significant. The interaction simply indicated that the amount of improvement differed across tasks. A priori t tests performed on each task indicated that all tasks except for 2, tapping with the nonpreferred heel and tapping with the nonpreferred toe while balancing on the preferred foot, showed significant improvement from pre- to posttest. However, improvement was marginally significant for these 2 tasks ($p < .10$). Similar results were obtained with the deviation from the target measure. A 2 (test: pretest and posttest) × 14 (task: 14 different tasks on the 10-min test) repeated-measures ANOVA revealed that the effects of test, $F(1, 19) = 53.16$, $MSE = 4031.07$, task, $F(13, 247) = 9.48$, $MSE = 661.68$, and the Test × Task interaction, $F(13, 247) = 3.27$, $MSE = 675.39$, were significant. A priori t tests showed that all 14 tasks showed significant improvement from pre- to posttest. In summary, both measures indicated that the metronome training improved participants' timing.

Next, we analyzed the accuracy scores. We measured accuracy by the distance in feet between the pin and the ball's final resting place. The scores were averaged over 15 trials for each club for each participant. Table 3 displays the mean accuracy as a function of club, treatment group, and test (pre and post). As Table 3 indicates, the overall performance of the experimental group was better than that of the control group. Also, the accuracy differed between clubs. Figure 1 further shows the mean improvement that occurred between pre- and posttest as a function of club and treatment group. As shown, performance improved for the experimental condition for all clubs. In contrast, little or no improvement occurred for the control condition. These observations were confirmed by a 2 (group: experimental and control) × 4 (club: nine iron, seven iron, five iron, and driver) × 2 (test: pre- and posttest) mixed-design ANOVA. The results revealed that the main effect of club, $F(3, 114) = 106.14$, $MSE = 2323.48$, and the Group × Test interaction, $F(1, 114) = 4.42$, $MSE = 2598.87$, were significant. The main effect of group, $F(1, 39) = 3.10$, $MSE = 17308.23$, and test, $F(1, 114) = 3.13$, $MSE = 2598.87$, approached significance ($p < .10$). A priori independent t tests indicated that the treatment groups did not differ from each other on the pretest, $t(39) < 1$. However, on the posttest, the experimental group was significantly more accurate than the control group, $t(38) = 2.97$. Furthermore, paired-sample t tests indicated that there was a significant increase in accuracy between the pre- and posttest for the experimental group, $t(19) = 2.69$. No improvement occurred in the control group, $t(19) < 1$.

Because there was a significant difference in age between the experimental and control groups, we conducted another analysis on accuracy using age as a covariate. We also used the mean estimated distance across four clubs as a covari-

TABLE 3
Pretest and Posttest Mean Accuracy in Feet as a Function of Group, Club, and Testing

	Club									
	9 Iron		7 Iron		5 Iron		Driver		Overall	
Group	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Experimental										
M	66.32	57.00	76.95	58.31	114.45	82.14	186.86	158.87	111.15	89.08
SD	39.78	24.49	55.21	22.29	80.60	35.64	113.02	96.60	66.99	39.63
Control										
M	78.64	78.20	88.01	93.45	122.28	126.75	212.26	210.43	125.32	127.21
SD	44.81	32.97	43.88	38.77	62.86	66.61	70.52	66.20	48.77	41.59

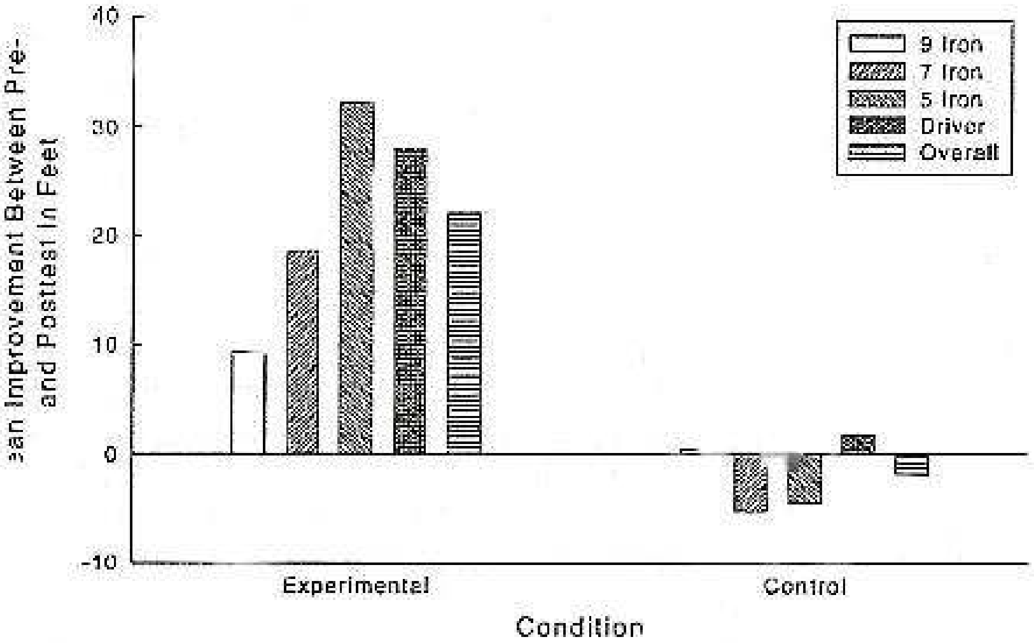

FIGURE 1. Mean improvement as a function of club and treatment group.

ate. As mentioned earlier, each participant determined at the pretest how far he or she would be able to hit the ball with each club. We expected the estimated distance to reflect each participant's expertise with playing golf. By using this variable as a covariate, we attempted to equate the level of expertise between the experimental and control groups. A 2 (group: experimental and control) × 4 (club: nine iron, seven iron, five iron, and driver) × 2 (test: pre- and posttest) mixed-design analysis of covariance (ANCOVA) indicated that the effects of club, $F(3, 105) = 6.35$, $MSE = 2318.47$, test, $F(1, 35) = 5.07$, $MSE = 2462.79$, and the Group × Test interaction, $F(1, 105) = 4.72$, $MSE = 2462.79$, were significant. Further analyses indicated that these results were similar to the previous accuracy analysis.

We also correlated age with IAR and millisecond deviation scores to rule out further that age was a factor in producing improvement. We computed a correlation between age and improvement that occurred in IAR and millisecond deviation scores between pre- and posttest (pre–post) on each task. None of the correlations except one was significantly different from zero. The only significant correlation occurred with the millisecond deviation score on the task that required tapping with the nonpreferred toe, $r = .55$. The positive correlation indicated that improvement was greater for older adults relative to younger adults. However, no other correlations reached significance, indicating that age was an unlikely source of improvement in overall timing. In summary, the results of this study indicate that the training in timing improved accuracy relative to a control group, which did not show any improvement.

Discussion

The results of the present experiment suggest that training in timing improves accuracy in golf. Furthermore, the improvement in performance was consistent across golf clubs. Why does training in timing on an activity that does not mimic the golf swing enhance accuracy in this activity? There are several possibilities.

One obvious answer is that the training improved the golf swing by fine-tuning the timing properties (i.e., tempo and rhythm) of the golf swing. As mentioned in the introduction, the golfing community has attached considerable importance to the notion that timing is an essential property in a successful golf swing. Unfortunately, in the present study, we can only speculate about which timing properties were changed because these properties were not measured. However, we specifically suggest that the training in timing leads to changes in tempo. In support of this notion, Jagacinski et al. (1997) demonstrated that older individuals have faster tempos than younger individuals. These authors also reported that the maximal force of the club head occurs earlier with an older adult than with a younger adult. Note that the mean age of our experimental participants ($M = 44$) falls somewhat in between the age range (mean ages were not provided) of older participants (60 to 69) and the younger participants (19 to 25) in the study of Jagacinski et al. Thus, it is possible that training improved the tempo of the golfers in our study.

The second possibility is that the training made the coordination between participant's intention and voluntary movement more precise. On the basis of the model of Day (1996), intention to act and voluntary movement are organized in a hierarchical fashion. As Day indicated, the important implication of this model is that our limbs may not move when we intend to move them. It is possible that even without external interference (e.g., transcranial stimulation), the coordination between the motor planning component and the timing component is not perfect. Therefore, fine-tuning between these components may be necessary to produce motor movements that require precise timing. Similarly, it is conceivable that sensory training using the Interactive Metronome® may have modified the temporal representation used for both sensory and motor systems. In support of this hypothesis, our results are consistent with the results of Meegan et al. (2000), which indicate that motor movements are not necessary to improve the temporal properties of the motor movements.

The third possibility is that the improvement was simply an artifact of demand characteristics. Participants in the control group were not asked to come to the laboratory to engage in activities that could possibly improve their golf swing. It is difficult to rule out this possibility without further investigations in which other groups would be tested using other motor exercises. However, we are inclined to believe that the improvement in accuracy had something to do with timing. It is a commonly reported experience that improvement in golf, as in any highly skilled behavior, requires extensive and effortful practice with feedback

(Ericsson, 1996). We therefore doubt that the transient nature of demand characteristics can account for our results. Furthermore, it is important to note that although participants in the control group were provided with golf tips, these participants failed to show any improvement.

In the present study, we provided extensive training by varying the total number of beats across a variety of tasks while maintaining the same number of beats per minute. In future studies, it would be interesting and important to examine the effectiveness of various schedules that include different tasks, durations, and beats per minute. These studies could provide data concerning the most optimal relationship between timing and golf performance. Within this context, it would also be important to include other measures of golf performance, for example, distance in driving and accuracy in putting. Furthermore, future studies should examine the relationship between timing and golf performance by directly measuring some of the temporal properties of the golf swing itself, something that was not done in the present study. Even more ideally, at an individual differences level, it may be possible to determine the number of beats per minute that is most effective in producing the tempo that leads to the most effective performance. In other words, effective performance may depend on temporal properties that are unique to each individual, and the training may need to be tailored to each individual.

Future studies could also take advantage of the golf simulator to separate the distance and direction of the shots. It is possible that training in timing would improve both. Furthermore, the golf simulator is capable of simulating both fairway and green shots. Perhaps timing is more important for one type of shot than it is for the other. Also, in our study, participants were told to ignore feedback (i.e., the guidance sounds) when they were trained with the Interactive Metronome.® It would be interesting to examine whether focusing on feedback would influence the effectiveness of the training.[1]

Finally, the present results provide some interesting implications for other motor activities. If training in timing improves performance by fine-tuning the timing components of a motor movement, then this type of training may be used to improve performance in other activities that require precise timing. Thus, it would be interesting to examine whether Interactive Metronome® training would improve movements in other sports (e.g., basketball, baseball, and tennis) as well as in other endeavors such as flying and typing.

In summary, the results of the present experiment indicated that training in timing improved accuracy in golf. Future research will be necessary for further delineation of the phenomenon and for development of a theory that can explain how the property of timing influences this complex motor activity. However, it is important to note that this is the first experimental demonstration of the effec-

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[1] We thank an anonymous reviewer for suggesting the future studies mentioned in this paragraph.

tiveness of training in timing on a complex motor activity, and that now there is evidence to indicate that training in timing may improve one's performance in golf. We envision that an instrument such as the Interactive Metronome® could be used not only for overall training in timing but also for fine-tuning one's swing before and during competition. Finally, we agree with Cochran and Stobbs (1968) that the terminology and concepts describing the temporal properties of the golf swing are elusive even though there is nothing more obvious than the gracefulness of a well-timed golf swing.

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TIMING IN CHILD DEVELOPMENT

Kristyn Kuhlman and Lawrence J. Schweinhart
High/Scope Educational Research Foundation
600 North River Street
Ypsilanti, MI 48198-2898

LarryS@highscope.org

Abstract

This study investigated the metronome and musical timing of 585 four- to eleven-year-olds in Effingham, Illinois. A computer system measured *metronome timing* by counting the number of milliseconds that responses differed from a steady beat not embedded in music. Raters measured *musical timing* from videotaped responses to the steady beat embedded in instrumental music. Both measures were internally consistent. They were correlated .5 with each other, suggesting that they measure different aspects of timing. Metronome timing was correlated up to .3 with achievement scores and placements in special educational programs, more strongly than was musical timing. Girls had significantly better musical timing, but not metronome timing, than boys. Both measures were correlated .4 to .5 with age and had statistically significant correlations up to .3 with handedness, attentiveness, coordination, dance and instrumental classes, and socioeconomic background.

TIMING IN CHILD DEVELOPMENT

A child's timing — ability to feel and express steady beat — is fundamental to both movement and music, affecting sports skills and musical performance, as well as speech-flow and performance of timed motor tasks. In addition, children's timing has been found to be positively related to children's overall school achievement, as well as mathematics and reading achievement (Weikart, Schweinhart, & Larner, 1987); self-control; and gross-motor skills (Kiger, 1994; Mitchell, 1994; Peterlin, 1991; Weikart et al., 1987). Many children enter elementary school lacking the ability to identify and express a steady beat. One study revealed that fewer than 10% of kindergarten children could independently feel and express the steady beat of recorded music (Wright & Schweinhart, 1994). Fewer than 15% of first graders tested had this ability (Mitchell, 1994). Fewer than 50% of the children in grades 4 through 6 could walk to the steady beat of a musical selection (Kiger, 1994).

Timing studies have examined children's personal tempo and its relationships to age, handedness, gender, and school achievement. Children's personal tempo improves with age (Ellis, 1992; Jersild & Bienstock, 1935; Osburn, 1981; Petzold, 1966). There is little evidence that children's personal tempo is related to handedness (Grieshaber, (1987), nor does it appear to be related to gender (Petzold, 1966; Walter, 1983). Children's personal tempo has been found to be correlated with achievement test scores of children in grades 1 and 2 (Weikart et al., 1987); gross-motor skills and reading group levels of children in grades 1, 3, and 5 (Kiger, 1994); and the language and mathematics performance of children in grade 1 (Mitchell, 1994).

The study reported herein was designed to assess the internal characteristics, reliability and concurrent validity of two measures of the timing of children — **metronome timing**, assessed by computer counts of the number of milliseconds that responses differed from a steady beat not embedded in music; and **musical timing**, assessed by ratings of videotaped responses to the steady beat embedded in instrumental music. Of particular interest were the relationships that these measures had with age and measures of school achievement.

Method

In this study, the Interactive Metronome™ measured metronome timing, and the High/Scope Beat Competence Analysis Test measured musical timing. The validity of these two measures was assessed using data from parent questionnaires (with variables such as child's gender, handedness, and age; and family configuration, parental educational status, household income, child's dance and instrument training); teacher questionnaires (with variables such as child's participation in various school-based programs), kindergarten-teacher child achievement reports, and California Achievement Tests for grades 1 through 4. The study participants were 585 children aged 4 through 11 years old in Effingham, Illinois.

The Interactive Metronome™

Synaptec, LLC, of Grand Rapids Michigan, has developed and patented the Interactive Metronome™, a computer program and input devices that quickly and precisely measure a person's metronome timing, that is, ability to match a movement to the steady beat of a metronome. The standard package has two motion-sensing triggers that are plugged into a personal computer's parallel port. One is strapped to a person's hand or foot and signals the computer program when the person claps or pats a hand or steps with a foot. The other is in a floor pad on which a person taps.

The Interactive Metronome™ produces a recurring beep which can be set at any tempo, that is, number of beats per minute. When using the metronome, the objective is to move the triggered hand or foot at the same tempo as that of the metronome, patting or tapping at the exact moment of the beep. The attached trigger signals the metronome program immediately, and the program registers the time between the metronome beep and the person's action, to the nearest millisecond. A person's timing score is the difference in milliseconds between the moment of the beep and the moment of the person's tap. The computer program averages these scores across the many tapping events involved. In the current study, a child's timing score was the average time in milliseconds between each of the 34 metronome beeps and the child's response to each by tapping the triggered hand or foot. A high timing score indicates a larger average number of milliseconds between the metronome beeps and a child's movements, hence, less accurate timing. The lower the timing score, the better the timing.

In this study, children completed seven movements paced by the metronome beeps—patting knees with both hands, clapping hands together, patting knees with alternating hands (triggered hand on each beep), patting knee with preferred hand, patting knee with nonpreferred hand, toe-tapping pad with alternating feet (triggered foot on each beep), and walking in place (triggered foot on each beep). These movements were modified from the High/Scope Beat Competence Analysis Test (Weikart, 1987) for use with the Interactive Metronome™. Children received a score for each of the seven items, the score representing their average timing over 34 beeps per item.

The High/Scope Beat Competence Analysis Test

A version of the High/Scope Beat Competence Analysis Test (Weikart, 1987), using the seven movements listed above, was used in this study to assess beat competence by observing an individual's performance of a series of seven movements to the steady beat of music. Although two pieces of recorded instrumental music of different tempos are generally used, only one piece of recorded instrumental music was used in this study, to allow time for the child's participation in the other assessment activities.

In this study, children performed the same seven movements used to assess metronome timing to the steady beat of a recorded musical selection. Of course, they did not have to use the several motion-sensing triggers. Their performance was videotaped and subsequently scored by eight trained raters. A rater gave each child a score of 1 through 5 on each of these items, the score representing the rater's assessment of each child's ability to identify and match the steady beat over a series of 36 beats. Raters characterized children's musical timing as follows:

1. Accurate and consistent, all but 0 to 3 beats matched
2. Fairly accurate and consistent; 24 beats matched
3. Sometimes accurate and consistent; 16 beats matched
4. Steady and even, but off the beat; 8 to 12 beats matched, 4 at a time
5. Uneven and off the beat; no beats matched

Several studies using the High/Scope Beat Competence Analysis Test provide evidence of the instrument's psychometric properties. Weikart et al. (1987) found the instrument to have alpha coefficients of internal consistency ranging from .70 to .79. The concurrent validity of the instrument was shown by its statistically significant, positive correlations with the Test of Gross-Motor Ability (Kiger, 1994) and school achievement (Kiger, 1994; Weikart et al., 1987).

Study Participants

This study was conducted in Effingham, Illinois, a city of about 12,500 people (Greater Effingham Chamber of Commerce and Industry, 1997). Children in preschool through grade four at three elementary schools and the early learning center of the Effingham school district participated in this study. Of the 609 children who returned signed permission forms, 605 were tested, 585 produced usable data on metronome timing, and 523 produced usable data on musical timing.

The percentages of children in the sample diminished steadily by grade, with 26% of the sample in preschool and 10% in grade 4. The children ranged from 4 years old up to 11 years old. Of the 585 children in the sample, 571 (98%) were Caucasian, 6 (1%) were Hispanic, 4 (1%) were Black, and 4 (1%) were Asian. Of 576 children for whom parents or guardians reported family configuration, 477 (83%) were in two-parent homes, including 30 (5%) living with either a stepfather or stepmother; 89 (15%) lived with their mother only, 6 (1%) lived with their father only, and 4 (1%) lived with other relatives. Of 1,056 parents and guardians reporting, 920 (87%) had at least a high school diploma — 525 (50%) had only a high school diploma, 170 (16%) had an associate's degree, 152 (14%) had a bachelor's degree, and 73 (7%) had a graduate degree. For the 537 families reporting, the median household income was $30,000 - $39,999. Of the 576 children, 85 (15%) received free lunches (available to those with annual incomes up to 130% of the federal poverty guidelines — $17,329 for a family of three in FY 1998).

Of the 585 children with parental reports, 77 (13%) had dance training and 45 (8%) had instrumental music training. These classes were almost certainly extracurricular, because the Effingham school district did not offer dance or instrumental music classes until fifth grade. Various school-based programs were available to children in grades 1 through 4. Of the 312 children in these grades, the following numbers and percentages were or had been in such classes: 33 (11%) in gifted and talented classes; 43 (7%) in the district's Title 1 Reading Recovery program; 36 (12%) in speech and language programs; 15 (5%) in classes for children with learning disabilities; 5(2%) in classes for children with educable mental handicaps. One child was treated for trainable mental handicap, two were visually impaired, one was hearing impaired, and one was behavior disabled.

Results

This section examines the internal structure and reliability of metronome and musical timing and their relationship to each other. Next it looks at their correlations with children's various characteristics, with special attention to age and school achievement.

Metronome and Musical Timing

Table 1 lists children's average scores on each item. Of the children tested, the metronome timing assessment and qualitative information were complete for 585 children — 316 boys and 269 girls. The table presents the items in order of their increasing difficulty. This order differs from the originally hypothesized order in two ways: (a) patting knees with alternating hands was easier than patting a knee with either the preferred or the nonpreferred hand; and (b) of the two locomotor items, tapping toe and stepping back was easier than walking in place. Children's timing scores were the sums of their scores from the seven items divided by the number of items completed. The 7-item metronome timing scale had a very respectable internal consistency, with an alpha coefficient of .889.

Table 1: Metronome Timing Items

Item	*n*	Mean	SD	Minimum	Maximum
2. Patting knees with both hands	585	145.7	98.8	17.0	514.4
3. Clapping hands together	585	153.9	107.8	21.0	517.0
4. Patting knees with alternating hands	585	161.4	97.5	24.4	396.4
5. Patting knee with preferred hand	585	166.8	108.0	18.0	501.9
6. Patting knee with nonpreferred hand	585	170.0	108.3	17.0	527.6
7. Toe-tapping pad with alternating feet	569	197.1	106.5	33.1	500.3
8. Walking in place	585	202.3	101.5	25.9	457.4
Metronome timing (mean of the 7 items)	585	171.2	80.7		

***Note*. A metronome timing score is the student's mean number of milliseconds off the beat of the Interactive Metronome™; thus, the lower the score, the better the timing.**

Although 569 children participated in the assessment of musical timing, 22 did not complete the testing procedure, and descriptive information was incomplete for another 24. Thus, the information and assessment was complete for 523 children, 279 boys and 244 girls. Table 2 presents counts and percentages of each rating and the mean ratings for each item. The item means vary between 3.14 and 3.79. Noting that equal percentages of ratings across five levels would place 20% of ratings at each level, it appears that children tended to be at the extremes, either fully accurate and consistent or uneven and off the beat, matching no beats. The percentages at these two extremes together varied from 61% to 70%, exceeding their allotted 40% by 21% to 30%.

Table 2: Musical Timing Items

Item	Rating						
	1	2	3	4	5	Mean	SD
1. Patting knees with both hands	119	64	58	85	197	3.34	1.61
	23%	12%	11%	16%	38%		
2. Clapping hands together	139	51	54	55	224	3.33	1.70
	27%	10%	10%	11%	43%		
3. Patting knees with alternating hands	133	63	57	70	200	3.27	1.65
	25%	12%	11%	13%	38%		
4. Patting knee with preferred hand	126	49	65	70	213	3.37	1.64
	24%	9%	12%	13%	41%		
5. Patting knee with nonpreferred hand	135	48	63	68	209	3.32	1.66
	26%	9%	12%	13%	40%		
6. Toe-tapping pad with alternating feet	154	46	69	81	173	3.14	1.65
	29%	9%	13%	16%	33%		
7. Walking in place	91	37	42	74	279	3.79	1.56
	17%	7%	8%	14%	53%		
Musical timing	73	80	89	135	146	3.37	1.33
	11%	12%	14%	21%	22%		

***Note*. *N* = 523. Rating 1 (1.00 to 1.49) = Accurate and consistent; 2 (1.50 to 2.49) = Fairly accurate and consistent; 3 (2.50 to 3.49) = Sometimes accurate and consistent; 4 (3.50 to 4.49) = Even but off the beat; 5 (4.50 to 5.00) = Uneven and off the beat. Thus, the lower the score, the better the timing.**

The musical timing ratings had a different order of difficulty from the metronome timing scores. The items listed 1-7 in Tables 1 and 2 are arranged in order of their difficulty in metronome timing, from easiest to most difficult. Their difficulty ranking for musical timing was 6-3-5-2-1-4-7. Only walking in place was found to have the same level of difficulty (most difficult) by both measures. Perhaps raters compensated for the varying degrees of inherent difficulty in assigning their ratings, because as presented below, they did reliably distinguish children with varying levels of musical timing. The internal consistency of the seven items was quite high, with an alpha coefficient of .915.

The correlations between metronome timing and musical timing suggest distinct but related abilities. The correlations between the same items measured both ways ranged from .243 to .399, and the correlation between the two total scores was .498 ($n = 523$, $p < .001$). While both metronome timing and musical timing had strong internal consistency, indicating the integrity of the constructs that they each measured, they clearly measured different aspects of timing.

Concurrent Validity of the Timing Measures

As shown in Table 3, both metronome timing and musical timing had statistically significant correlations in the expected direction with most of the variables examined for this purpose. Exceptions to this generalization are that metronome timing was not significantly correlated with gender, repeating a grade, or being treated for learning disability; and musical timing was not significantly correlated with reading or mathematics achievement or with placement in any of the compensatory or special education programs (Title I reading, speech and language, repeating a grade, learning disability, or mentally handicapped). Metronome timing had correlations of .3 or greater with physical coordination/motor skill, ability to attend over a period of time, age, and rated kindergarten achievement. Musical timing had correlations of .3 or greater with age. These discrepancies do not challenge the validity of either measure, but rather help define the difference between them.

Table 3: Correlations of Timing Measures with Validity Variables

Variable	Metronome Timing			Musical Timing	
	N	*R*		*N*	*R*
Gender (1 = male, 2 = female)	585	.060		523	.155[d]
Handedness (1 = right, 2 = left)	585	.146[d]		523	.182[c]
Physical coordination/motor skill	427	.303[d]		398	.241[a]
Pays attention during class	427	.244[d]		398	.195[a]
Ability to attend over a period of time	427	.330[d]		398	.244[d]
Dance classes	585	.122[c]		523	.184[d]
Instrumental music	585	.187[d]		523	.237[d]
Household income	537	.243[d]		478	.249[d]
Parents' highest level of schooling	575	.166[d]		513	.228[d]
Age	585	.491[d]		523	.426[d]
Grade	585	.498[d]		523	.426[d]
CAT total achievement, grades 1 - 4	303	.264[d]		279	.137[a]
CAT reading, grades 1 - 4	304	.231[d]		280	.125
CAT language, grades 1 - 4	304	.225[c]		280	.156[b]
CAT mathematics, grades 1 - 4	303	.273[d]		279	.107
Rated kindergarten achievement	112	.335[c]		109	.212[a]
Gifted & talented program	427	.150[c]		398	.243[d]

Title I reading program	427	-.150[c]		398	-.066
Speech & language program	427	-.119[a]		398	-.059
Repeated a grade	585	-.068		523	-.030
Learning disability program	427	-.091		398	-.081
Mentally handicapped program	427	-.132[b]		398	-.040

***Note*. The signs of correlation coefficients with metronome timing and with musical timing are reversed to reflect the fact that, on both measures, lower scores indicate better timing.**

[a]*p* < .05 [b] *p* < .01 [c] *p* < .005 [d] *p* < .001

The directions of timing findings for gender and handedness are interesting. Girls had better musical timing than boys, but no better metronome timing, suggesting that girls have greater ability to identify the beat of a musical selection than boys, but cannot track beeps better. Left-handers had better metronome and musical timing than right-handers, perhaps because left-handers are required to use their nonpreferred right hand more often than right-handers are required to use their nonpreferred left hand. In support of this explanation, while left-handers scored significantly better than right-handers on all 7 metronome timing items and all 7 musical timing items, patting knee with nonpreferred hand had the largest difference for metronome timing and only .04 of a point less than the largest difference for musical timing.

Children's Timing and Age

As Table 4 shows, older children had better metronome and musical timing than younger children. The metronome timing means ranked in order by age, except that 6-year-olds had better timing than 7-year-olds. The musical timing means ranked in order by age without exception. Post-hoc Bonferroni analyses indicated two metronome timing plateaus — the metronome timing of children aged 4 to 7 was significantly different from the metronome timing of children aged 8 to 10. A similar but more complex pattern was found for musical timing — each age mean was not significantly different from adjacent years, but was significantly different from any age more than one year above or below it.

Table 4: Metronome and Musical Timing by Age

Age	Metronome Timing[b]				Musical Timing[c]		
	n	*Mean*	*SD*		*n*	*Mean*	*SD*
4	83	234.6	46.0		65	4.41	0.76
5	95	221.2	54.6		81	3.91	1.07
6	117	161.8	72.5		110	3.47	1.22
7	97	168.6	83.3		93	3.31	1.34
8	73	142.7	76.1		69	2.76	1.51
9	61	118.4	79.7		52	2.68	1.32
10	59	115.1	70.2		53	2.63	1.33

***Note*. The year of age includes all children from that birthday to the day before the next one; for example, "4" includes children from 4.00 to 4.99. For both metronome timing and musical timing, the lower the score, the**

better the timing.

[a] *F* (6, 578) = 34.13, *p* < .001, two-tailed. Bonferroni post hoc analyses indicated that the metronome timing of children aged 4 to 7 was significantly different from the metronome timing of children aged 8 to 10 (*p* < .05).

[b] F = (6, 516) = 19.98, *p* < .001, two-tailed. Bonferroni post hoc analyses indicated that each age mean was not significantly different (*p* < .05) from adjacent years, but was significantly different from any age more than one year above or below it, for example, 4-year-olds had worse timing than 6- to 10-year-olds; 6-year-olds had better timing than 4-year-olds but worse timing than 8- to 10-year-olds.

Children's Timing and School Achievement

As shown in Table 5, children's metronome and musical timing were significantly related to their percentiles on the California Achievement Test. The relationship between metronome timing and these test scores was the stronger of the two, with consistently better means with increasing achievement test scores; children at or above the 80th percentile in achievement had significantly better metronome timing than children up to the 59th percentile. Although the overall relationship between musical timing and these test scores was also statistically significant, musical timing scores for children up to the 89th percentile varied only .05 of a point across categories, and none of the differences between categories were statistically significant.

Table 5: Metronome and Musical Timing by Children's School Achievement

	Metronome Timing[a]				Musical Timing[b]		
Percentile Category	*n*	*Mean*	*SD*		*n*	*Mean*	*SD*
Up to 59th	79	170.7	81.9		73	3.16	1.31
60th to 79th	69	140.5	81.0		58	3.09	1.31
80th to 89th	53	131.8	69.5		49	3.13	1.31
90th to 99th	102	116.9	73.9		99	2.60	1.36

***Note*. California Achievement Test total score percentiles for grades 1 - 4. For both metronome timing and musical timing, the lower the score, the better the timing.**

[a] *F* (3, 299) = 7.42, *r* = .264, *p* < .001; Bonferroni post hoc analyses found that children scoring at or above the 80th percentile in achievement had significantly better metronome timing than children up to the 59th percentile in achievement (*p* < .05).

[b] *F* (3, 275) = 3.34, *r* = .137, *p* < .05; Bonferroni post hoc analyses found no significant differences (at *p* < .05) in the musical timing of children differing in their achievement percentiles.

Discussion

This study's results present the reliability and concurrent validity of metronome timing and musical timing. Both measures were internally consistent and related in reasonable ways to the variables used to assess their concurrent validity. Is one better than the other or should they be used together? An analysis of their partial and multiple correlations revealed no clear-cut empirical advantage to using one or the other or even both together.

While both measures of timing had the same seven items, metronome timing used a computer and input devices to measure responses to unembedded beeps, while musical timing had observers measure responses to beats embedded in instrumental music. Metronome timing requires available equipment and competent operators, while musical timing requires trained observers. Equipment error is mechanical or electrical, while observer error comes largely from their subjective judgments - two very different types of error. If girls really did have better timing than boys, for example, the musical timing measure was more sensitive to this difference than was the metronome timing measure. On the other hand, if girls really did not have better timing than boys, observers' subjective bias towards girls influenced the musical timing scores.

This study has established that children's timing can be measured with reliability and concurrent validity. Its reliability was established by its high internal consistency, whether assessed as metronome timing or as musical timing. The .5 correlation between the two measurement techniques suggests that timing is a multifaceted construct. By both measures, timing had statistically significant correlations of .43 to .49 with age and .15 to .33 with handedness, physical coordination/motor skill, paying attention during class and ability to attend over a period of time; participation in dance classes, instrumental music classes, and gifted and talented classes; and household incomes and parents' highest level of schooling. In addition, one or the other measure of children's timing was significantly correlated about .15 with gender and remedial education classes and as high as .34 with measures of school achievement.

The generalizability of this study is limited by the constituency of its sample, of whom 98% were Caucasian, 87% had parents with a high school diploma, and 83% lived in two-parent families. Similar research should be carried out with diverse ethnic groups, children whose parents did not complete high school, and children of single parents. This study was correlational. It could suggest, but not establish, causal relationships. It was not designed to say whether improving children's timing will definitely improve their reading achievement or other aspects of school achievement. However, the substantial relationships found between children's metronome timing and their school achievement and the relationships found between both metronome and musical timing and children's ability to pay attention are consistent with these possibilities. One fruitful area for further research is a training study in which children experience a program to improve their timing. Not only their timing but also their ability to pay attention and their school achievement could be assessed before and after this program. Then, after verifying the improvement in children's timing, the study would be in a position to see if improvements in timing led to improvements in ability to pay attention, reading achievement, and other aspects of school achievement. Such High/Scope studies are currently under way in Effingham, Illinois, and Dayton, Ohio.

It is worth noting that in this study, metronome and/or musical timing were more strongly correlated than household income and parents' highest level of schooling with children's ability to pay attention. Schools that want children who pay attention can do little to affect their household income or parents' schooling. They can, however, offer training programs in timing. Although the significant correlations between timing and ability to pay attention do not guarantee that improved timing leads to improved ability to pay attention, it is highly plausible that it does. Similarly, children's metronome timing was statistically significantly correlated with their participation in special and compensatory classes. These are high-cost programs, much higher in cost than programs that train teachers to provide children with activities to improve their timing. If improving children's timing could reduce their need for special or compensatory classes, it is plausible that such teacher training (e.g., Weikart, 1995, 1998) could eventually pay for itself in this way.

Children's timing is important in its own right. It is important because it is a key factor in sports, music, and dance, in speech and general life functioning. Movement educators have also detected signs of a relationship between improvements in children's timing and improvements in their reading. If further research confirms such a relationship, the perceived educational importance of timing programs will increase, and we will have obtained one more tool in our efforts to achieve our national goal of having all young children complete third grade with the ability to read.

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Effect of Interactive Metronome® Training on Children With ADHD

Robert J. Shaffer, Lee E. Jacokes, James F. Cassily, Stanley I. Greenspan, Robert F. Tuchman, Paul J. Stemmer, Jr.

Key Words: attention deficit disorder with hyperactivity • coordination training • motor control

Objective. *The purpose of this study was to determine the effects of a specific intervention, the Interactive Metronome®, on selected aspects of motor and cognitive skills in a group of children with attention deficit hyperactivity disorder (ADHD).*

Method. *The study included 56 boys who were 6 years to 12 years of age and diagnosed before they entered the study as having ADHD. The participants were pretested and randomly assigned to one of three matched groups. A group of 19 participants receiving 15 hr of Interactive Metronome training exercises were compared with a group receiving no intervention and a group receiving training on selected computer video games.*

Results. *A significant pattern of improvement across 53 of 58 variables favoring the Interactive Metronome treatment was found. Additionally, several significant differences were found among the treatment groups and between pretreatment and posttreatment factors on performance in areas of attention, motor control, language processing, reading, and parental reports of improvements in regulation of aggressive behavior.*

Conclusion. *The Interactive Metronome training appears to facilitate a number of capacities, including attention, motor control, and selected academic skills, in boys with ADHD.*

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The ability to attend, which begins early in life, is a vital part of the capacity to learn, concentrate, think, interact with others, and master basic academic skills (Greenspan, 1997; Greenspan & Lourie, 1981; Mundy & Crowson, 1997). Relative deficits in sustaining attention, inhibiting competing impulses, and engaging in joint attention can be found in attentional, learning, and developmental disorders. These deficits are part of several clinical disorders, including attention deficit disorder (ADD), pervasive developmental disorder (autistic spectrum disorders), language disorders, motor disorders, and specific learning disorders involving reading, math, and writing (Barkley, 1997a; Mundy, 1995).

Increasing evidence suggests that broad constructs such as motor planning and sequencing, rhythmicity, and timing are relevant to attentional problems. Barkley (1997b) postulated that deficits in inhibition and executive functions, which involve the regulation and sequencing of motor patterns and behavior, are important in understanding attention deficit hyperactivity disorder (ADHD). Additionally, several investigators have postulated important relationships between attention and aspects of motor

Robert J. Shaffer, PhD, is Adjunct Assistant Professor of Pediatrics and Human Development, College of Human Medicine, Michigan State University, Ann Arbor, Michigan.

Lee E. Jacokes, PhD, is Professor of Psychology, Aquinas College, Grand Rapids, Michigan.

James F. Cassily, is Director, Neural Technology Research Center, 3090 Dawes, SE, Grand Rapids, Michigan 49508; cassily@interactivemetronome.com.

Stanley I. Greenspan, MD, is Clinical Professor of Psychiatry, Behavioral Sciences, and Pediatrics, George Washington University Medical School, Washington, DC.

Robert F. Tuchman, MD, is Professor of Neurology, University of Miami Medical School, Miami Children's Hospital, Miami, Florida.

Paul J. Stemmer, Jr., PhD, is Director, Center for Research, Madonna University, Livonia, Michigan.

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when one hand was tapped on the thigh. The other trigger, a flat plastic pad placed on the floor, sensed when a toe or heel was tapped on it.

When the participant tapped a limb in time with the steady metronome reference beat sound heard in the headphones, the trigger sent a signal via a cable to the program. The Interactive Metronome analyzed exactly when in time the tap occurred in relation to the reference beat and instantaneously transposed the timing information into guidance sounds that the participant heard in the headphones as each tap occurred. The pitch and left-to-right headphone location of the guidance sounds precisely changed according to each tap's accuracy. The program-generated rhythmicity accuracy scores (Interactive Metronome scores), displayed in milliseconds on the screen, indicated to administrators how close in time the participant's responses were to the reference beat as they occurred. After each exercise, the participants were shown their scores. This feedback appeared to motivate them to do better.

The object of the Interactive Metronome treatment was to help participants improve their ability to selectively attend, without interruption by internal thoughts or external distractions, for extended periods. Simple limb motion exercises were used as systematic external catalysts to an underlying mental focus–improvement process. Each participant underwent 15, 1-hr Interactive Metronome treatment sessions, one session per day, spread out over a 3-week to 5-week period. Each session included 4 to 8 exercises that were repeated a specific number of times as prescribed in the daily treatment regimen guide. Exercises were done at a preset tempo of 54 repetitions/min, and the number of repetitions per exercise increased from 200 during the first session to a maximum of 2,000 during the ninth session.

The 13 Interactive Metronome treatment exercises were designed to help the participants put their efforts toward improving mental concentration rather than toward developing new physical motion techniques. The exercises included clapping both hands together, tapping one hand alone against the upper thigh, alternating toe taps on the floor, alternating heel taps on the floor, tapping one toe or heel alone on the floor, alternating between tapping one hand on the thigh and the toe on the floor, and balancing on one foot while tapping the other toe.

Before beginning their first Interactive Metronome treatment session, participants were given an automated Interactive Metronome pretest to quantify their ability to recognize timing patterns, selectively attend to a task, and make simple motion corrections. The pretest also indicated whether each participant had one or more rhythmicity deficiency patterns that needed to be addressed during their initial stage of treatment. Interactive Metronome treatment regimens were designed and accomplished in stages according to instructions in the daily treatment regimen guide.

During the first stage, the administrators helped the participants break the existing rhythmicity deficiency patterns that were identified during the pretest. The six rhythmicity deficiency patterns most frequently identified were the following

1. *Disassociative:* Three participants' responses were chaotic and random and not related to the beat in any way.
2. *Contraphasic:* Within a few beats, six participants' responses consistently moved to in between the beat rather than on the beat.
3. *Hyperballistic:* Sixteen participants used inappropriate snappy ballistic-type motions.
4. *Hyperanticipatory:* Eighteen participants' responses continually occurred much before the reference beat.
5. *Hypoanticipatory:* One participant's responses continually occurred much after the reference beat.
6. *Auditory hypersensitivity:* Seven participants were exceptionally distracted by the computer-generated guide sounds that were added to the headphone mix during the last test task, as indicated by their Interactive Metronome scores on that task, which were two to three times less accurate then those of the previous 13 tasks done without the guide sounds.

The initial Interactive Metronome treatment sessions were devoted to helping the participants learn how to discriminate between the sounds triggered by their own actions and the steady metronome beat. They were instructed to make smooth, controlled hand and foot motions that continuously cycled through a repeating pattern without stopping at any time between beats. Participants were repeatedly instructed to focus on the metronome beat and to try not to be interrupted by their own thoughts or things happening around them. When the participants had broken their existing rhythmicity patterns and were able to achieve the Interactive Metronome score average prescribed in the daily treatment regimen guide, they were considered to have achieved the adequate control and accuracy necessary to begin a second distinct phase of the Interactive Metronome treatment.

During the second treatment phase, participants were instructed to focus their attention only on the steady reference beat and ignore the computer-generated guide sounds, internal thoughts, and unrelated stimuli around them. They were also instructed to keep repeating their motion patterns without making any deliberate adjustments whatsoever. Doing so usually resulted in obvious improvements in the participant's Interactive Metronome score, and the entrainment experience of staying on beat without trying seemed to have a positive motivating effect. From session to session, participants increased the length of time they could selectively focus on the metronome beat without interruption, and their Interactive Metronome scores improved correspondingly. Most participants appeared to be highly motivated to achieve the best score possible during their Interactive Metronome training regimen. According to the Interactive Metronome scores, each participant improved his rhythmicity and was able to stay on task without being interrupted for significantly longer periods by the end of the training.

Video game group. Five commonly available PC-based, nonviolent video games were used as a treatment placebo for the video game group. Each game involved eye–hand coordination, advanced mental planning, and multiple task sequencing. In each game, the participant played against the computer, and at each new level achieved, the game became increasingly more difficult to play.

The test administrators followed a daily treatment regimen guide in the same manner as they did for the Interactive Metronome group. The prescribed video game exercises provided the participants with the same type of supervision, attention, and support as was received by the Interactive Metronome group. Each participant underwent 15, 1-hr video game training sessions, one session per day, spread out over a 3-week to 5-week period. Each training session involved a number of video game exercises, and the length of time they spent on each video game exercise typically increased from the first session to the last session.

Results

Sampling Design

After completion of pretesting of all 56 participants, a matched random assignment process was used to form the three treatment groups (i.e., Interactive Metronome, video game, control). Three factors were used in the matching process: medication dosage (mg/body weight), age, and severity of ADHD as measured by the TOVA. An analysis of variance (ANOVA) of these matching variables revealed no significant differences at the $p \leq .05$ level among the treatment groups. Chi-square analysis of three demographic variables—race, parental education, and parental household income—revealed no significant differences at the $p \leq .05$ level, suggesting that the treatment groups were equal for these socioeconomic factors.

An ANOVA of the 58 pretest factors revealed only one significant difference among the treatment groups. Sakoda, Cohen, and Beall's (1974) table for tests of significant difference revealed the probability of this one significant difference in 58 significance tests occurring by chance to be $p > .50$, establishing this single occurrence to be likely a chance difference. The other 57 factors produced values in excess of $p > .05$, establishing the treatment groups' statistical equality.

Pattern Analysis

Pattern analysis of the 58 pretest factors examined the overall direction of mean differences between pretest and posttest phases for each group. In performing the analysis, the means for each test were computed, and the mean differences between the tests were determined. Each mean difference was dichotomized by whether the change represented an improvement or a decline in the desired direction for that test. For example, the posttest–pretest mean differences for the Wechsler Digit Span subtest for each treatment group were the following: Interactive Metronome = .473, control = –.278, and video game = –.054. The mean differences revealed improved performance in the Interactive Metronome group, whereas the control and video game groups showed decreased performance. Similar analyses were completed for all 58 test scores.

To statistically test the pattern, a binomial test was used to determine whether the proportion of dichotomous pairs (improvement vs. decline) was likely a chance occurrence (where the probability of either an improvement or decline = .50) or whether the directional proportion was so unusual as to reflect a non-chance event. The rationale for using a binomial test rests on the assumption that if a large number of variables collectively showed an unusual directional propensity (e.g., improved performance), this represented an overall pattern of change worthy of notice. The binomial test allows detection of a combined directional pattern that individual variables, taken one at a time, do not detect.

The pattern analysis revealed that the control group had 28 scores improve and 30 decline. Such a result has a high probable chance occurrence of $p = .8955$ and suggests that no significant combined directional pattern is present (Norusis, 1993). Analysis of the Interactive Metronome and video game groups produced significant improvement–decline patterns. For the Interactive Metronome group, 53 of the 58 variables showed improvement ($p \leq .0001$). For the video game group, 40 of 58 variables showed improvement ($p \leq .0058$). Both groups showed significant pattern increases in performance over the control group. The Interactive Metronome group experienced significantly better improvement than the video game group, suggesting that the Interactive Metronome treatment produced significant additional benefits above and beyond the experience of the video game and control group participants.

Significant Difference Analysis

The pattern analysis identified the overall improvement–decline characteristics of the test mean differences but did not address the magnitude of these differences. Because a pretest–posttest repeated measures design was used, an ANOVA for repeated measures (SPSS, 1988) was performed separately on each of the 58 variables. This approach was chosen to view the effects of the three treatment groups on each test score individually. However, one possible disadvantage of the approach is its potential of increasing Type 1 error.

Of the 58 test scores analyzed, 12 either had significant interaction effects (p = .0001–.047), suggesting that some combination of treatments and subgroup means were different, or there were significant pretest–posttest differences. Twelve significant differences out of 58 significance tests had a $p \leq .001$ at the .05 level of confidence (Sakoda et al., 1974), suggesting that these are not chance differences. Additionally, Keppel's (1973) calculation for the potential number of Type 1 errors over 58 separate experiments is 2.9. Thus, these 12 significant differences far exceed the calculated potential of 2.9 Type 1 errors, suggesting that these differences are real, significant differences.

Among the significant effects, seven significant differences between-phase effects were found (p =.0001–.023). This analysis finds the Interactive Metronome participants significantly improving their performance in identifying similarities and differences between concepts and in experiencing declines in aggressive behavior, as reported by their parents. Both the Interactive Metronome and video game treatments produced significant improvements on three Sensory Profile subtests, suggesting that both groups benefited from the attention and activities provided in these treatments. Parental reports on the Child Behavior Checklist also revealed significant declines in aggressive behavior for the Interactive Metronome group, a nonsignificant improvement for the video game group, and no improvement for the control group.

The remaining five tests had significantly different interaction effects (p = .0001–.047). These five tests were the WRAT 3 Reading subtest and four tests of the TOVA, including Omissions, RT (Response Time) Variability, Response Time Variability Total STD (Standard) Deviation, and ADHD Total Score. The significant interaction effects suggest that the posttest Interactive Metronome performances, though not significantly improved over the pretest performances, were significantly higher than the control and video game posttest performances. For all five tests, the patterns of differences were identical: Interactive Metronome performances improved, whereas both control and video game performances declined.

In summary, the pattern analysis revealed that both the Interactive Metronome and the video game groups experienced significant improvement patterns across the 58 test scores. Additionally, the Interactive Metronome group had a significantly stronger improvement pattern than the video game group, showing improvements over 53 test scores compared with 40 for the video game group. This finding supports the hypothesis that Interactive Metronome training produced a stronger improvement pattern than the video game group for boys with ADHD.

Analysis of test means found 12 factors with significant quantitative changes among the various group and treatment combinations. The Interactive Metronome group showed significant pretest–posttest improvement in identifying similarities and differences and reduction of aggression problems compared with the other two treatment groups. Both the Interactive Metronome and the video game groups showed significant improvements in three sensory processing tasks and in parental reports of impulsiveness and hyperactivity. Only parents of the Interactive Metronome participants, however, rated their children as significantly less aggressive ($p \leq .001$) after the treatment period. Additionally, five tests measuring reading and four characteristics of attention revealed that the Interactive Metronome group had significantly higher posttest performances than the other two groups.

Discussion

The results indicated that boys with ADHD who received the Interactive Metronome intervention improved significantly more in areas of attention, motor control, language processing, reading, and ability to regulate aggression than boys receiving either the video game treatment or no treatment. Participants who received video game treatment improved more than the participants in the control group on a number of measures as well, demonstrating that focused perceptual activities and support alone may be helpful for selected areas of functioning. The video game group, however, showed decreased performance in selected areas involving modulation and control, such as consistency of concentration, reaction time, and overall attention.

Interactive Metronome treatment, on the other hand, only showed improved performance, including significant positive gains, over the video game treatment on a series of TOVA attentional tasks measuring lack of errors and distractibility, consistency of reaction time, and overall attention; selected language (i.e., similarities and differences); academic tasks (reading); and control of aggression. In addition, pattern analysis was used to control for the effect of using a large number of assessments and demonstrated that the differences between the group patterns were significant. The National Institutes of Health (NIH, 1997) asserted that studies on ADHD interventions must properly control for the positive overall effect of attentive adult interaction, alone. Consistent with NIH guidelines, two of the three groups in this study received adult attention during the treatment period.

Limitations

Only male participants in a defined age range were included to minimize age and gender variation, thereby limiting generalizability to the other gender and age groups. The variables measured by the assessments are limited to selected aspects of attention, motor control, language, cognition, and learning.

In this study, Interactive Metronome training influenced a number of performance capacities. A possible explanation for the positive changes is the central role of motor planning and sequencing in each performance area.

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Theoretical and Clinical Perspectives on the Interactive Metronome®: A View From Occupational Therapy Practice

Jane Koomar, Jeannetta D. Burpee, Valerie DeJean, Sheila Frick, Mary J. Kawar, Deborah Murphy Fischer

Key Words: attention deficit disorder with hyperactivity • coordination training • motor control

Jane Koomar, PhD, OTR/L, FAOTA, is Executive Director, Occupational Therapy Associates–Watertown, P. C., 124 Watertown Street, Watertown, Massachusetts 02472; Koomar@msn.com.

Jeannetta D. Burpee, MEd, OTR, is Director, Jeannetta D. Burpee Institute, Blue Bell, Pennsylvania.

Valerie DeJean, OTR, is Director, Spectrum Center, Bethesda, Maryland.

Sheila Frick, OTR, is Director, Therapeutic Resources, Inc., Madison, Wisconsin.

Mary J. Kawar, MS, OTR, is Director, Mary Kawar & Associates, San Diego, California.

Deborah Murphy Fischer, OTR, is Director, Rockland Occupational Therapy for Children, P. C., New York, New York.

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For many years, occupational therapists have observed motor planning difficulties in a variety of populations, including those with learning disabilities, attention deficit disorder (ADD), central auditory processing disorders, autism, Down syndrome, and cerebral palsy. The research presented by Shaffer et al. (2001) provides important evidence that an updated interactive version of the metronome may be helpful in improving timing and rhythmicity related to motor planning and sequencing. In the study, various measures commonly used by the occupational therapy, psychology, and educational communities showed that improving rhythmicity through Interactive Metronome® training may also bring about improvements in behaviors and skills that are important for occupational performance in many areas. Emerging clinical experience, together with Shaffer et al.'s study, suggest that the Interactive Metronome may have potential usefulness in a wide range of clinical conditions and, therefore, may complement existing interventions currently being used by therapists to address these areas. Further systematic studies are encouraged.

Ayres (1985) described motor planning as a part of praxis. *Praxis* is defined as an action based on will, originating from the Greek word for doing, acting, deed, and practice. Ayres described praxis as being a uniquely human process that involves three aspects: (a) conceptualization or ideation, (b) planning or organizing, and (c) execution of new or nonhabitual motor acts. Children who appear to have problems with praxis (dyspraxia) are reported to have difficulty with a variety of occupational performance areas, such as difficulty with self-care skills, poor handwriting, and difficulty with sports (Gubbay, 1979, 1985).

When assessing and developing intervention plans for children with dyspraxia, occupational therapists have most commonly used a sensory integrative theory base, a "bottom–up" approach that addresses the foundational skills needed to develop the ability to plan and sequence. However, there also has been a growing use of "top–down" approaches within the profession, such as those used in cognitive rehabilitation training (Toglia, 1998) to assist in developing cognitive strategies for tackling new or nonhabitual motor tasks. Frequently, the two approaches are used in combination. Within a sensory integrative frame of reference, it is often deemed appropriate, after evaluation, to begin therapy with an emphasis on enhancing somatosensory discrimination to increase body scheme awareness while improving postural control (Koomar & Bundy, 1991). It is theorized that "internal maps" are developed from which to plan actions more effectively. As therapy progresses, activities are employed to improve bilateral coordination, timing, and sequencing to enable the child to increase the complexity of projected action sequences and move to higher levels of adaptive response.

It appears that the Interactive Metronome program provides a systematic method to improve timing and rhythmicity related to planning and carrying out a variety of actions and sequences (Shaffer et al., 2001). Although the expected outcomes are similar to those anticipated from a bottom–up approach, the actual training sessions for the Interactive Metronome are very different from sessions focusing on a sensory integrative approach. Each session has predetermined goals to reach and specific ways to perform the required movements. These goals are a means to an end, with the true goal being a change in a variety of areas of occupational performance.

In addition, it is useful to consider the Interactive Metronome program in terms of dynamic systems theory. As a dynamic system (Kielhofner & Forsyth, 1997), occupational performance emanates not only from the internal factors of the individual human system (i.e., musculoskeletal, cognition, motivation), but also from the task presented and the environment that the human system occupies. All the factors contribute to the organization of behavior (Kamm, Thelen, & Jensen, 1990). Each time an occupational action (behavior) occurs, the human system, or the environment, experiences a change in its status, requiring the human system to reorganize to allow for accommodation and, ultimately, to reach higher levels of self-organization (Spitzer, 1999).

The Interactive Metronome program appears to have much in common with dynamic systems theory. The human system (child) is being asked to perform a task (i.e., 13 movement exercises that require timing and sequencing in relation to the sound of a metronome). The environment is enhanced by providing the child with auditory input (the computerized metronome beat) to which the child is asked to tap his or her hand, foot, or both at the same time as the beat. Computerized guide sounds are provided via headphones to assist the child in fine tuning his or her movements. The Interactive Metronome trainer structures the activity in a meaningful manner that is intrinsically motivating for the child. Variations of the movements can be developed to accommodate each child's need, and games can be created that provide the child with a sense of competition and fun, such as assigning certain points to the child and others to the trainer or an imaginary opponent. Behavioral disorganization can occur during and after Interactive Metronome sessions; however, this temporary disorganization is typically followed by greater improvement.

Clinical Challenges

Occupational therapists often report that children with sensory integration dysfunction have a great deal of difficulty with daily tasks because of the conscious control needed to do many things that same-aged peers do easily and automatically. For instance, many children with sensory integration difficulties, including some children with ADD, have difficulty screening out extraneous sensory information, staying seated because of poor postural control, and performing motoric acts automatically. All of these processes may be carried out with cognitive monitoring at a high energy cost to the child. Interactive Metronome training appears, initially, to facilitate control of the body on a conscious level and then to relegate these postural–motor actions to an unconscious or automatic response level. The Interactive Metronome offers an opportunity to repeatedly practice rhythmic, repetitive movements, using extensor and flexor muscle groups, in a smoothly timed and sequenced manner. It may be useful as a complement to other occupational therapy approaches to enhance the capacity to organize our movement patterns through time and space.

Gilfoyle and Grady (1981) defined spatiotemporal adaptation as "the continuous ongoing state or act of adjusting those bodily processes required to function within a given space at a given time" (p. 48). Many of the children occupational therapists evaluate from a sensory integrative frame of reference are "out of sync" with the spatiotemporal aspects of their environments. They often lack the internal sense of timing that is necessary to regulate sleep and their physical and social interactions with the world. In addition, they often have difficulty with visuospatial and constructional praxis skills that are highly dependent on accurate perception of temporal and spatial cues. It is possible that if the Interactive Metronome is used as a technique along with sensory integration, there may be an improved ability to benefit more fully or to achieve further gains from the sensory integration approach. For children who are old enough to follow the Interactive Metronome training directions (usually 5–6 years of age), the program currently appears to be a useful adjunct to the sensory integration approach. As with sensory integration interactions, however, Interactive Metronome training often requires skillful coaching to master the tasks.

Central Role of Timing and Rhythmicity

The underlying theory of the Interactive Metronome is that motor planning processes of organizing and sequencing are based on an internal sense of rhythmicity. Rhythm acts like the string bass of an orchestra; it provides the foundation of timing upon which the conductor can then organize and sequence the individual instruments that make up the piece of music. A child may have developed some ability to organize and sequence, yet if his or her internal sense of time is highly inaccurate, no foundation exists from which to organize and sequence. Sequencing alone is not enough; it must be done within the context of correct timing. A dancer may perform all the steps perfectly, yet if the dance is not to the beat, the piece is disjointed.

Inaccuracy in timing is increasingly being implicated as a major factor in cognitive processing disorders (Harnadek & Rourke, 1994). In studies of children with and without language disabilities (Merzenich et al., 1996; Tallal & Piercy, 1973), findings revealed that both groups were able to discriminate and sequence tones. The group with disabilities, however, required hundreds of milliseconds, whereas the group without disabilities only required tens of milliseconds. It was postulated from this research that differences in processing rates were affecting the brain's ability to organize and categorize the building blocks of language.

With the advent of high-speed computers and the development of the Interactive Metronome, we are able to measure our clients' response speed. Using the Interactive Metronome, we can measure how accurately clients can perform a movement, such as clapping their hands to a rhythmically presented tone. Response time for clients with disabilities is typically in the hundreds of milliseconds. Through training sessions with the Interactive Metronome, however, the response time can be reduced to the tens of milliseconds. The ultimate question is whether our clients are merely learning to play one computer "game" more efficiently or whether they are actually enhancing the praxis processes of organization, sequencing, and execution. Shaffer et al.'s (2001) findings suggest that boys with attention deficit hyperactivity disorder experienced gains from their Interactive Metronome training sessions that extended to areas of performance that depend on praxis. Clinical case explorations, as well as additional research, are needed to confirm these results.

Clinical Case Illustration

Kyle, a 9-year-old boy, was diagnosed with a nonverbal learning disability. He was referred to occupational therapy to assess and treat suspected sensory integration difficulties. Kyle was having difficulty attending in a noisy environment and in coordinating motor-related skills, especially fine motor and visual-motor tasks. At home, his sleep patterns and activity level were out of sync with the rhythms of his family. He had difficulties making friends due to his lack of awareness of the timing of social interaction. Phonemic awareness, reading, and math skills were difficult for him. Kyle often needed to use his fingers to complete math computations, causing his completion of math assignments to be slow and laborious.

Because of his challenges, Kyle was thought to be an appropriate candidate for the Interactive Metronome, but the training was initially frustrating for him. The guide sounds confused him, and he was unclear about which sounds to tune in and which to tune out. Tears and refusals were common. Creativity was needed to find a way to motivate Kyle. He became a "coach," and the motor exercises were the "signals" to his "team." Clarity and precision in the "signals" was needed in order for his team to win. After just three sessions using this intrinsically motivating approach, progress was noted in his attention, use of pragmatic language, and motor skills.

Over time, Kyle showed many signs of improvement that his therapist attributed to the Interactive Metronome program because he was not receiving any other new services in addition to ongoing school-based occupational therapy. Kyle's mother reported an increase in his ability to focus from 20 minutes to a remarkable 5 hours on a computer task. Math was becoming easier for Kyle, and changes in his conversational abilities were also noted. Kyle became better able to remain focused on a topic and to take appropriate "social" turns within a conversation. Word retrieval skills were advancing as well. Finally, Kyle's ball-handling skills were noted to improve. He began to throw with rotation at his shoulder rather than flinging the ball.

Extending Clinical Applications

As the authors of this article explore the use of Interactive Metronome technology in our own practices, we are beginning to think of expanded applications. One of the authors has had excellent success within her sensory integration intervention when she uses goal-directed activities developed to specifically tap a combination of oculomotor, auditory, vestibular, and cervical components involving dynamic, integrated performance strategies. This therapist has found that coupling this combination of components with activities that elicit rotation–counterrotation of the shoulder girdle and pelvis around the central core of the body during movements of the extremities has further enhanced the effectiveness of her therapy. She reports observing excellent improvements in total body coordination and integration as well as in reading, writing, spelling, and communication. She would like to suggest that Cassily and colleagues consider some possible modifications in the Interactive Metronome activities to incorporate some of these integrated strategies.

Currently, all of the 13 Interactive Metronome patterns are done without rotation or crossing of the body midline. One simple example of adding a rotational component is to use the foot plate as a hand plate and require the client to sequentially touch specific stickers located in a particular pattern, visually guiding reach across the midline of the body with each hand and with the eyes. This pattern can also be done with the feet. Additional trunk rotation can be elicited by having the client touch the designated spots on the hand plate with the elbows rather than the fingers. Such activities help to refine neurodevelopmental and sensory integration patterns, which frequently are addressed in other ways in therapy before the commencement of the Interactive Metronome program. In short, we anticipate that the exercises used with the Interactive Metronome can be elaborated to further enhance the observed results.

Conclusion

From a clinical perspective, Interactive Metronome training provides a promising new tool that may be helpful in improving timing and rhythmicity related to praxis;

improved timing and rhythmicity may serve as a foundation for improvements in complex problem-solving behavior in school, at home, and in social relationships. Both continuing clinical experience and systematic studies, such as Shaffer et al.'s (2001), will make it possible to explore the Interactive Metronome's potential usefulness across the age span with a wide range of clinical conditions that share the common feature of difficulties in timing, rhythmicity, and motor planning and sequencing. ▲

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Computer-Based Motor Training Activities Improve Function in Parkinson's Disease: a Pilot Study

Daniel M. Togasaki, M.D., Ph.D.

The Parkinson's Institute, 1170 Morse Avenue, Sunnyvale, CA 94089

Tel. (408) 734-2800

Fax (408) 734-9208

dtogasaki@att.net

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Abstract—*Objective:* This pilot study examined the effect of computer-based motor training activities upon the severity of signs and symptoms in patients with mild or moderate Parkinson's disease. *Methods:* Thirty-six subjects were randomly assigned to train using the Interactive Metronome (IM) device, which provides training for rhythmicity and timing, or to a control regimen consisting of motor activities directed by a rhythm or a computer (e.g., clapping or exercising to music or to a metronome tone or playing computer games). The severity of parkinsonism was compared before and after 20 hour-long training sessions as measured by the Unified Parkinson's Disease Rating Scale (UPDRS) part 3 and, as secondary measures, the UPDRS part 2, the Hoehn and Yahr stage, a timed finger tapping test, and the timed "Up & Go" test. *Results:* Twelve subjects completed training with the IM device and nine completed the control regimen. Both groups improved in the scores on the UPDRS part 3 and the two timed tests. Those patients trained on the IM device showed slightly more improvement, but the difference between the two groups was not statistically significant. The IM-trained group improved in the UPDRS part 2 score, but the control group did not. Neither group changed in the Hoehn and Yahr stage. *Conclusions:* These results suggest that computer-based motor training regimens might be useful for improving or retaining motor function in Parkinson's disease.

Parkinson’s disease is a neurodegenerative disorder that impairs motor function. There are a number of pharmacologic therapies that are effective in alleviating the symptoms, but these drugs all have side effects that can limit their use. Non-pharmacologic treatments can thus play an important and useful role in this disease. In fact, approaches of this type are frequently sought out by many patients who are looking for therapies that do not involve taking medications.

Exercise (as part of a regimen of physical therapy and otherwise) has often been recommended as a component of the overall treatment program for Parkinson’s disease, and there are a number of studies suggesting that it can be beneficial (1-11). This improvement in parkinsonism does not appear to be related to a direct and immediate effect, insofar as single episodes of exercise do not appear to affect motor function (i.e., “limbering up”) or influence levodopa pharmacokinetics (12-14). In those studies demonstrating improvement, the change was seen after multiple sessions. Various types of exercise regimens have been beneficial: resistance training can increase muscle strength (15, 16); both physical therapy (5-10) and music therapy (11) has been shown to provide beneficial effects; and exercise alone has been shown to improve motor function (1-3). More recently, animal studies have suggested that exercise might improve the neurochemical deficits in parkinsonism as well as the behavioral deficits (17-20), an intriguing possibility that suggests that motor training might induce plasticity changes in the brain that could partially correct the lesion in Parkinson’s disease.

The Interactive Metronome (IM) device is a timing and rhythmicity training apparatus that is thought to improve the execution of motor programs (21). It employs a metronome beat to set a rhythm that the subject uses to time motor tasks. A computerized system provides auditory feedback to the subject to illustrate the accuracy of synchronization between his motor performance and the cueing beat. This device has been used by children with attention deficit hyperactivity disorder (ADHD), with improvement in both motor and cognitive activities after finishing training (22).

To test its utility for treating Parkinson's disease, this study examined the effect of training with the IM device by comparing motor performance before and after training, as measured with Part 3 of the Unified Parkinson's Disease Rating Scale (UPDRS) and with other clinical and timed tests. Comparison was made with a control group that underwent a similar amount of computer-guided physical activity, but without the feedback provided by the IM device.

Methods. *Participants.* Participants were recruited from the patient population seen at The Parkinson's Institute and from support groups in the surrounding geographic area (south San Francisco Bay area). Close proximity to The Parkinson's Institute was necessary because of the number and frequency of the training sessions.

Patients were eligible for enrollment in the study if they had a diagnosis of idiopathic Parkinson's disease, were between 30 and 80 years old, and were Hoehn and Yahr stage 3 or less. They could not be receiving any other experimental therapy during the time of their participation in the study.

Patients were excluded from the study if they had cognitive dysfunction that impaired their ability to give informed consent, if they had a medical condition that would preclude their ability to properly participate in training (e.g., unable to hear, unable to tolerate physical activity) as judged by the enrolling neurologist, or if their clinical condition for parkinsonism was unstable such that it would likely require medication changes during the period that training would be given.

This study was conducted in accordance with Good Clinical Practice guidelines and the protocol and consent form were approved by an independent institutional review board (Western Institutional Review Board, Olympia, Washington). All patients signed written consent prior to participation.

Objectives and Outcome Variables. The primary objective of this study was to determine the effect of movement training using a computer-based device (the IM device) on the severity of the signs and symptoms of Parkinson's disease. The effect was measured by comparing the total scores before and after training for the motor subsection of the Unified Parkinson's Disease Rating Scale (UPDRS part 3). Additional outcome variables that were examined included the following: the total score for the activities of daily living subsection of the UPDRS (part 2), a timed finger tapping test, the timed "Up & Go" test, and the Hoehn and Yahr stage. All clinical neurologic examinations were performed by a Movement Disorder Specialist. The examiner was blinded regarding the group assignment of the subject being evaluated, except for seven subjects enrolled as a separate open-label group.

Interventions. The IM device (Interactive Metronome, Weston, Florida) consists of a computer, a controller box, headphones, and a set of pressure-activated sensors (Fig. 1). The subject wears headphones that are connected to the controller box. A rhythmic tone sounds at a rate of 54 beats per minute. The subject performs motor tasks attempting to keep in synchrony with the tone. These tasks were performed according to a predetermined protocol and included clapping, toe tapping, thigh slapping, and other similar types of movements, which, at various times, involve each of the four limbs. In making each movement, a sensor is activated. For example, a button is affixed to the palm by a strap wrapped around the hand. With each clapping movement, the button is pressed. For leg movements, a footpad containing a built-in sensor was used. The controller box detects each activation of the sensor and records the accuracy of the synchronization with the provided rhythmic tone. The time differences are stored on the computer. The controller box also provides an audio tone as feedback to the subject when the sensor is activated to indicate how accurately the movement coincides with the rhythmic tone. If the sensor is activated in close temporal proximity to the provided rhythmic tone, the feedback sound is a pleasant bell-like noise. As the accuracy of the movement decreases, and the time between the sensor activation and the rhythmic tone increases, the feedback sound morphs into a more unpleasant buzzing-like noise. This feedback allows the subject to become progressively more accurate in these motor tasks. Throughout each session, a trainer guides and assists the subject in a one-on-one interaction, providing suggestions and recommendations to increase accuracy.

The training protocol for the IM device used in this study was provided by the manufacturer based upon preliminary trials they did with several parkinsonian patients. In the course of that pilot project, they initially used their standard protocol for children affected with ADHD, which was then was modified (*i*) to take into account the decreased ability of these patients to tolerate the physical activity required and (*ii*) to allow additional time for the patients to achieve the level of expertise sufficient to be considered proficient in using the device. Generally, patients with Parkinson's disease fatigue more easily, so that the amount of activity possible during a single 1-hour training session had to be reduced. Accordingly, the total number of training sessions was increased from the 15 normally used in other subjects to 20 for these patients. That training protocol was supplied to The Parkinson's Institute and used to design this study.

The control group underwent a similar amount of training (20 sessions each lasting 1 hour). Their activities consisted mostly of motor activity, but without the auditory feedback. This was accomplished by having them make movements (*i*) to music played through the computer (20 minutes), (*ii*) to the tone from the IM device without the sensors and thus without the feedback cues (15 minutes), and (*iii*) by playing computer arcade games (25 minutes). Each subject was guided through the control session by a trainer providing one-on-one assistance. The trainers for the control sessions also were trainers for the IM sessions.

Study Design. This was a single-blind, controlled, parallel-group study conducted at The Parkinson's Institute. Patients were randomly assigned to either the group receiving training with the IM device or to the control group (by coin flip). The participants in the control group were kept unaware that theirs was not the study group, as all subjects were told that this was a study of computer-based movement training. An open-label group of seven patients all received training with the IM device and were included in a separate analysis.

At baseline, each subject underwent neurologic examination to determine the UPDRS part 3 motor exam score and the Hoehn and Yahr stage. They also underwent evaluation for timed finger tapping (23) and the timed "Up & Go" test (24). Finger tapping was performed by having the subject alternately press a lever on one of two counters mounted 12 inches apart. The total number of taps completed in 60 seconds is recorded for the dominant hand and averaged over 3 trials. For the timed "Up & Go" test, the seated subject is timed for how long it takes for him to arise, walk ten feet, and return. The score from the activities of daily living section of the UPDRS (part 2) was determined from the answers recorded by the subject on a self-administered questionnaire (25). These evaluations were repeated following completion of the 20 training sessions.

Training Protocol. After enrollment into the study and initial evaluation, each patient underwent a series of training sessions. Each session lasted approximately 1 hour, but it was not unusual for the sessions to last up to an additional 15 minutes to allow the subject extra rest time between tasks (due to fatigability). The schedule for the sessions differed among subjects because of individual circumstances, but the general guideline was training two or three times weekly without large gaps between sessions. Because the patients differed greatly in their stamina, and because of the difficulties scheduling the large number of sessions, there was a relatively wide range of times the subjects needed to complete training: the control group took from 39 to 119 days, except for a single outlier at 190 days, with an mean of 87 days; and the IM group took from 42 to 134 days with a mean of 93 days.

All subjects, both in the IM group and in the control group, were trained by persons who were Interactive Metronome certified providers.

Sample Size and Statistical Analysis. This study was designed as a pilot study, as there was no previous information for performing a power calculation to determine sample size. Our initial goal was to enroll 20 subjects in each group (40 total).

Baseline comparisons of the variables between the treatment groups were performed by *t*-tests or by chi-square analyses. The effect of each intervention was determined by *t*-tests on each of the variables. Statistical analyses were performed using StatView for Windows version 5.0.1 (SAS Institute Inc., Cary, North Carolina). For all analyses, $P < .05$ was considered statistically significant. All results are reported as mean (SEM) unless specified otherwise.

Results. *Study Population and Treatment Groups.* The subject flow is diagrammed in Fig. 2. Seventy-seven patients were screened for entry into this study. Two subjects were excluded and 39 declined to participate. The major problem causing subjects to decline participation was the logistical difficulty of having to attend 20 training sessions over approximately 2 months. The 36 subjects that entered the study were randomly assigned to one of the two groups. Nine patients in the IM group and six patients in the control group discontinued from the study. One patient in the control group withdrew after suffering a heart attack, which was deemed unrelated to his participation in this study. The remaining subjects completed their course of training. Subjects that did not complete the training were excluded from analysis. One of the control subjects that completed training was excluded from analysis of the UPDRS part 2 scores because of missing data and another was excluded from the timed "Up & Go" test analysis for the same reason. Two subjects from the IM group also had missing data, but both patients dropped out of the study and were thus excluded from any analyses. An additional seven subjects, all of whom completed their training, were assigned to the IM group in an open-label extension of the study and were included in a separate analysis.

The demographic and baseline disease characteristics for the study population are presented in Table 2. The first patient was enrolled in June 2003 and the last was enrolled in March 2004. The last evaluation was performed in July 2004.

Safety. A single subject in the IM group suffered a serious adverse event—a heart attack. This occurred at night while the subject was at home, and did not appear to be related to any activity associated with the study. He was treated with angioplasty and recovered without further incident. He was withdrawn from the study, although he expressed a strong desire to resume training. An additional subject in the IM group withdrew because of fatigue, i.e., being unable to tolerate the physical demands. Two subjects in the IM group and one subject in the control group withdrew because of needing adjustment of their antiparkinsonian medications.

Efficacy. Paired *t*-tests indicated that there was an improvement in the UPDRS part 3 scores for both of the groups (Fig. 3A). The IM group improved by 4.4 (1.9) points ($P = .0415$), and the control group improved by 3.7 (1.2) points (*P* = .0166). Although the IM group scores improved slightly more, a direct comparison of the two groups indicated that there was no statistical difference between them (*P* = .7924).

The timed tests also improved for both groups (Fig. 3B,C). The number of finger taps increased by 24.6 (5.9) taps per minute for the IM group and by 13.2 (4.7) for the control group. The time required to perform the "Up & Go" test improved by 1.5 (0.4) seconds in the IM group and by 1.3 (0.3) in the control group. Again, although the IM group improved slightly more for both measures, there were no statistical differences between the groups (finger tapping, *P* = .1675; timed "Up & Go" test, *P* = .7100). The UPDRS part 2 scores improved in the IM group by 1.3 (0.6) points (*P* = .0412); the control group showed a slightly larger improvement of 2.2 (1.3) points, but this change did not achieve statistical significance (*P* = .1252). There were no statistical differences between the groups (*P* = .4528). The Hoehn and Yahr stages (Fig. 3E) did not change for the IM group (*P* = .7545) and the control group (*P* = .3466).

These analyses were repeated with the inclusion of the seven subjects that were assigned to the IM group in the open-label extension. Both sets of analyses had very similar outcomes, with only one difference: the change in the UPDRS part 2 scores for the IM group with the additional seven subjects did not show a statistically significant improvement when compared to baseline (*P* = .3512).

Discussion. In this controlled pilot study, computer-directed movement training, both with the IM device and with the control training activities, was found to improve the motor signs of parkinsonism, both on clinical examination (UPDRS part 3) and in objective timed tests (finger tapping and the timed "Up & Go" test). This is the first direct demonstration that these types of exercises can improve parkinsonism, lending support for the phrase “use it or lose it” that is often quoted to patients. Non-pharmacologic interventions such as these are highly attractive to patients, and they help to foster a sense of higher personal control over the disease. The use of such interventions is generally embraced by patients with Parkinson’s disease (sometimes with a little “irrational exuberance”).

Seven additional subjects were enrolled in an open-label extension of the IM treatment group. A second set of analyses was carried out that included these seven subjects. The results of this second analysis were essentially the same as the first. The only difference was that the improvement in the UPDRS part 2 scores are found to lose statistical significance for the IM group, perhaps suggesting that less weight can be given to this being a true effect.

The motor subscore on the UPDRS (part 3) was prospectively chosen as the primary outcome measure in this study, as it is the standard measure of the severity of parkinsonism. It involves, however, subjective evaluation, so that the observation of improvement with this instrument was buttressed by the observation of improvement using the objective measures of the finger tapping test and the timed “Up & Go” test. That these additional tests confirm improvement provides a greater degree of comfort that the finding is valid. That there is a lack of change for both the ADL subscore of the UPDRS and the Hoehn and Yahr stage for the subjects does not detract from this result. This is especially true for the Hoehn and Yahr stages, as they are relatively broad categories, and were not expected to improve with this type of intervention. The use of a self-administered questionnaire for the UPDRS part 2 subscore, as opposed to an interviewer, is not expected to be a detracting factor, as (*i*) this instrument correlates well with live interviews, and (*ii*) it was used both before and after training, so that there should not have been any bias introduced.

These observed improvements in motor function were only in patients with mild and moderate Parkinson's disease, as more severely affected patients were excluded. The subjects had to have sufficient motor control and dexterity to perform the exercises needed in both treatment arms. Because of the nature of the tasks, patients with great difficulty with balance or with marked motor complications were self-selected out of the study. Furthermore, performance of these tasks required cognition to be relatively intact, and participation would be impossible with dementia. As such, these findings cannot be generalized to more severely affected patients, who, in any case, would not be candidates for this type of intervention. Given that the subjects in both treatment arms derived benefit, future studies would be important that examine the effects of motor training using simpler tasks that can be performed by patients with more severe parkinsonism or cognitive difficulties.

This study also was not designed to examine how long the benefits provided by training might last. The post-training evaluations generally occurred within a few days of the last training session. One previous study investigating the effect of an exercise regimen on parkinsonism found that the beneficial effects were still present 6 weeks later (1). Another study found that 6 months after finishing a course of physical therapy the beneficial effects had been lost, although this might have occurred because the patients had stopped their home exercises despite being instructed to continue with them (7). Another study found a loss of benefit from a course of physical therapy after 6 weeks, but that a second group following the same training regimen supplemented with sensory cues (visual, tactile, and auditory with a metronome) retained their gains (5). This suggests that sensory cues, and possibly feedback, might play an important role in retention of benefit. Determining whether there are long-term effects from these computer-based training regimens would certainly be an area for further investigation in any study undertaken as a follow-up to this one.

The IM device is of great interest as a treatment because part of its effect is improvement in utilization of motor programs (21), which is an area thought to be deficient in patients with Parkinson's disease (26). Previously, this device has been shown to improve both motor and cognitive function in children with ADHD (22) and to improve performance accuracy in golf (27). As such, it seemed ideally suited as a treatment for parkinsonism. This study, however, did not find a difference between the two treatment arms. Parkinsonism did improve slightly more in the IM group, but the difference was not statistically significant. Both groups went through a substantial training regimen, although that for the IM group was more structured than for the control group. Of note, in neither group was the training aimed specifically at improving the movements tested with the UPRDS or at improving gait and balance. This suggests that participation in any physical activity regimen providing a concentrated degree of motor training might benefit parkinsonism. Alternatively (or additionally), the interaction between the subject and the trainer might play a role, although the theoretical basis for how this might improve motor function is less obvious.

The rhythmic nature of the exercises might contribute to or be a necessary part of their ability to improve motor function. There have been studies demonstrating that repetitive and rhythmic movements as rehabilitative therapies following a stroke can improve arm paresis (28), and might induce reorganization of motor networks within the central nervous system (29). The investigators used a technique called bilateral arm training with rhythmic auditory cueing (BATRAC). They suggest that important components of BATRAC include bilaterality, rhythmicity, and sensory feedback. If rhythmicity is a necessary component of this therapeutic approach, it could explain the trend toward greater improvement with the IM regimen as a dose effect, since the subjects in this treatment arm received longer training with rhythmic activities.

Another advantage that was provided by the IM regimen over that of the control group was greater retention of subjects. A lower percentage of withdrawals occurred among the IM trainees (9/28 = 32%) than the control group (6/15 = 40%). This, surprisingly, might be related to the more regimented structure of the training. Anecdotally, the IM group experienced a higher sense of accomplishment, leading to a higher degree of motivation, as was evidenced by the subject who strongly desired to resume training even after suffering a heart attack. Interestingly, subjects in some prior studies of the effect of exercise and activity on parkinsonism reported improvement in a sense of mood and well-being, when such measures were collected (2, 3, 11), although this improvement was not universal (7).

A recent report indicated that whether negative or positive feedback is more effective for motor training in a patient with Parkinson's disease depends upon his or her treatment state (30). Patients learn better with positive feedback when their dopaminergic medications are working, but learn better with negative feedback when their medications have worn off. Because the IM device uses both positive and negative feedback, it might have an advantage as a training tool since it would be effective regardless of the medication state of the subject.

The logistics of attending frequent training sessions proved difficult, so that many potential subjects declined participation, and a portion of the enrolled subjects withdrew because of scheduling conflicts. In many cases, participation in this study required a considerable commitment of time over 2 or 3 months. Training exercises that could be performed at home would make it much easier for patients to complete the full number of sessions. Along these lines, Interactive Metronome has recently developed and released a version of their device that can be used for self-training at home. Comparing the effect on motor function between two groups undergoing similar training regimens, one with a trainer and one self-directed, might also provide a way to separate the contribution of the physical activity and the contribution of the subject-trainer interaction.

In summary, this investigation demonstrated improvement in motor function in patients with mild and moderate parkinsonism with the use of computer-directed motor training. This training utilized music therapy, computer games, and the IM device. These types of therapeutic interventions are welcomed by patients and could provide a useful supplement to pharmacologic treatments for Parkinson's disease.

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TABLE 1. *Study protocol and training session activities*

Control group	IM group
Baseline evaluation (UPDRS 2 and 3, H&Y stage, timed tapping, timed Up & Go test)	
20 1-hour sessions	
Movement to music (20 min) Preselected songs	Movement to tone with feedback (60 min) IM device with feedback
Movement to tone (15 min) IM device without feedback	
Computer arcade games (25 min) Patient selects from a list	
Baseline evaluation (UPDRS 2 and 3, H&Y stage, timed tapping, timed Up & Go test)	

Each subject underwent training for 20 1-hour sessions.

TABLE 2. *Subject demographics*

Characteristic	Control group n = 15	IM group Randomized n = 21	IM group Open label n = 7	IM group All n = 28
Age	67.3 (7.4)	65.3 (8.2)	67.4 (8.4)	65.9 (8.2)
Male gender, n (%)	7 (47)	16 (76)	5 (71)	21 (75)
Caucasian race, n (%)	15 (100)	17 (81)	7 (100)	24 (86)
UPDRS Motor subscale (part 3)	12.0 (5.7)	13.6 (8.3)	18.9 (8.8)*	14.9 (8.6)
UPDRS ADL subscale (part 2)	10.2 (6.1)	10.0 (4.8)	14.1 (3.6)†	11.1 (4.8)
Hoehn and Yahr stage	1.9 (0.3)	1.8 (0.6)	2.0 (0.3)	1.8 (0.5)
Finger Taps per min	111.4 (25.0)	122.6 (27.2)	135.2 (26.2)	126.0 (27.0)
Timed “Up & Go” Test in sec	10.2 (2.3)	10.2 (3.8)	9.6 (2.5)	10.0 (3.5)

Data are mean (SD) unless otherwise indicated. UPDRS, Unified Parkinson’s Disease Rating Scale; ADL, activities of daily living. There were no statistically-significant differences between the control and IM-randomized groups. *Differs from control group, *P* = .0384. †Differs from IM-randomized group, *P* = .0481.

FIG. 1. The Interactive Metronome device.

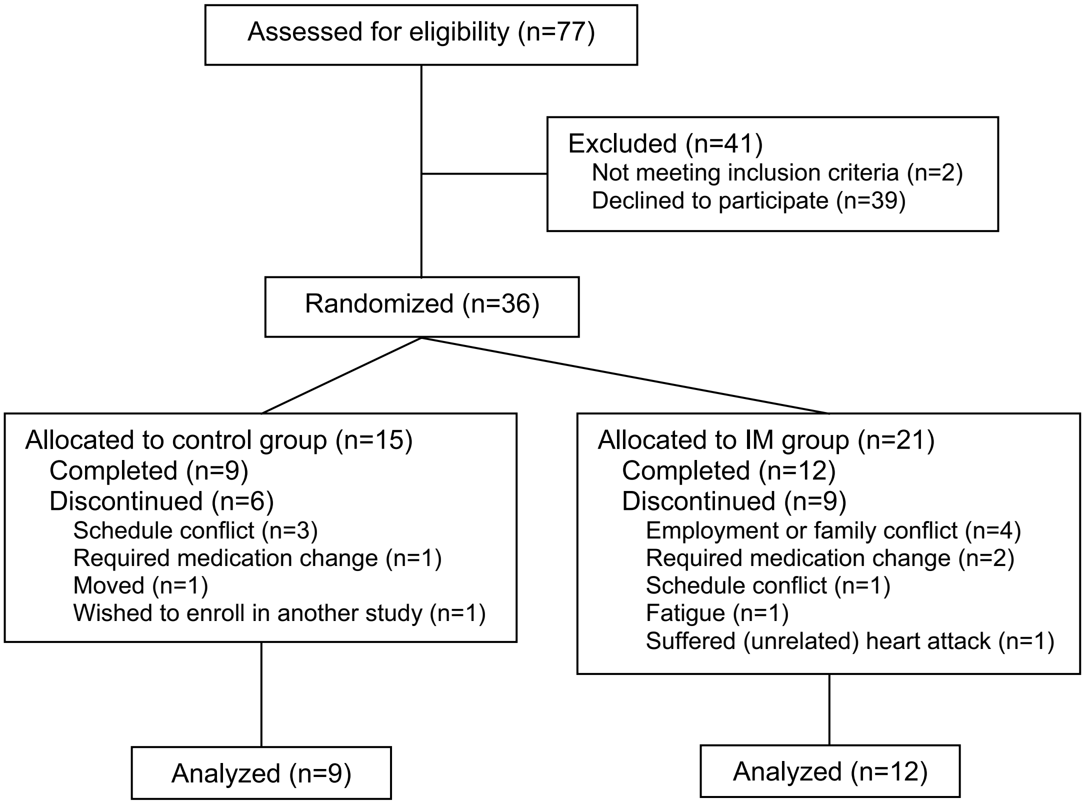
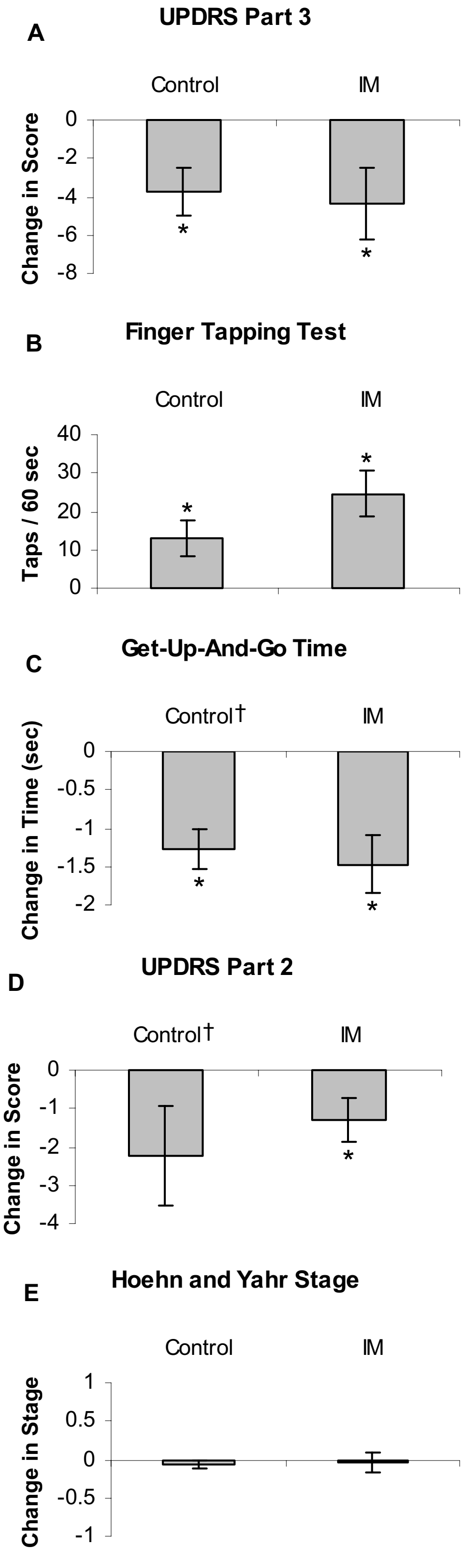


FIG. 2. Flow diagram of subject progression from screening to study completion.



A UPDRS Part 3

B Finger Tapping Test

C Get-Up-And-Go Time

D UPDRS Part 2

E Hoehn and Yahr Stage

FIG. 3. Changes from baseline in measures of parkinsonism in subjects trained with the IM device (n = 12) or the non-feedback control regimen (n = 9, except †n = 8). Data expressed as mean ± SEM. *p < .05.

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