interactive metronome®

IM Specific Research & White Papers

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2013	**Poster presented at AOTA 2103**	**A Collective Review of Completed Research Projects Evaluating the Effectiveness of the Interactive Metronome as an Occupational Therapy Intervention** The purpose of this project was to compile the different pilot studies that have been conducted of the last 5 years in regard to using the Interactive Metronome and identify the strengths and weakness of the outcomes and feasibility of using the Interactive Metronome as a viable treatment modality in the clinic. • Study 1 looked at normal individuals over the age of 55 and compared pre and post test IM scores and those of the NHPT. Notable improvements ave. 24% and above were achieved. • Study 2 compared those clients following standard of care Active ROM exercise program compared to those who received the IM for 8 sessions. The percentage of change was 24%for the IM participants as compared to 10% following the in home ROM • Study 3 looked at 2 CVA cases – Both making notable changes with 30 days longevity retest and 2nd series of IM provided demonstrated performance improvement • Study 4 showed compared 22 individuals both Post CVA and Healthy Individual groups. There were no significant differences in percentage of improvement between groups, which indicates IM may be just as effective with individuals who are post-CVA as in healthy aging individuals		1
2012	**Communication Disorders Quarterly**	**Reading Intervention Using Interactive Metronome in Children With Language and Reading Impairment: A Preliminary Investigation** This study shows that after only 4 hours of IM training, larger gains were made in most areas of reading achievement over the control group. In a 4 week time period, the IM group did 15 minutes of training before a traditional reading intervention while the control group just did the traditional reading intervention. The improvements over the control group are listed below. • Reading Naturally +5.48 • DIBELS-6 +5.77 • GORT4-rate +0.96 • GORT4-fluency +0.32 • GORT4-comprehension +0.77	Michaela Ritter, Karen A. Colson, & Jungjun Park	2

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2011	**International Journal on Disability and Human Development**	**Effects of motor sequence training on attentional performance in ADHD children** This study addresses the lack of motor coordination in ADHD children and suggests that going through IM training would have a significant effect on improving focus in ADHD children.	Gerry Leisman & Robert Melillo	**4**
2009	**Journal of Sports Science and Medicine**	**Improved motor-timing: effects of synchronized metronome training on golf shot accuracy** This European study is an independent recreation of earlier IM research studying golfers. This new study showed the same results: working with IM's timing exercises improves golfers' control of their swing and improves shot accuracy.	Marius Sommerand & Louise Rönnqvist	**5**
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2006	White Paper	**The Effect of Interactive Metronome Training on Children's SCAN-C Scores** This pilot study by Joel Etra, PhD, SLP measured the effects of IM on children diagnosed with Central Auditory Processing Disorder. It showed that IM statistically significantly improved 4 areas of auditory processing in all the children tested. The largest increases occurred in dichotic listening, a measure of selective attention.	Joel L. Etra	8
2005	Physiotherapy Theory and Practice	**Interactive Metronome® training for a 9-year-old boy with attention and motor coordination difficulties** This case study shows IM's training results for a 9-year-old boy with attention and motor coordination difficulties being treated by physical therapists.	Melinda L. Bartscherer, PT, MS & Robin L. Dole, PT, EdD, PCS	9
2004	White paper presented at national PM&R conference 2004	**The Role of Functional MRI in Defining Auditory-motor Processing Networks** A summary of a study using fMRI in defining the organs of the brain activated in repetitive auditory-motor training and the potential of IM to make improvements in those areas.	Dr. Neal Alpiner: MD	10
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2003	**White paper presented at the annual meeting of the National Association of Elementary School Principals**	**Learning Problems and the Left Behind** This study of 40 4th and 5th grade "at risk" children showed dramatic gains in reading and math fluency in only 4 weeks. 40 similar students in the control group showed no improvement at all.	Dr. Cindy Cason, Ph.D.	**14**
2003	**White paper**	**Interactive Metronome - Underlying Neurocognitive Correlates of Effectiveness** A white paper by psychologist Dr. Patrick Gorman explaining the underlying neurocognitive mechanisms of IM training.	Dr. Patrick Gorman	**15**
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2002	**High/Scope Press**	**Timing in Child Development** A study of 585 children found significant correlations between the students' mental timing as measured by IM and their academic performance in reading, math, language, science, social studies and personal study skills. This study shows that brain timing plays a foundational role in a child's academic performance.	Kristyn Kuhlman & Lawrence J. Schweinhart	**17**
2001	**American Journal of Occupational Therapy**	**Theoretical and Clinical Perspectives on the Interactive Metronome®: A View From Occupational Therapy Practice** This published white paper includes the perspective of six Occupational Therapists describing IM's usefulness in addressing school, home and social relationship problems in children.	Jane Koomar, Jeannetta D. Burpee, Valerie DeJean, Sheila Frick, Mary J. Kawar & Deborah Murphy Fischer	**18**
2001	**American Journal of Occupational Therapy**	**Effect of Interactive Metronome® Training on Children with ADHD** A study of 56 pre-teen boys diagnosed with ADHD found that those using IM showed statistically significant improvement in attention and concentration, motor coordination, language processing, reading and math fluency and the ability to control impulsivity.	Robert J. Shaffer, Lee E. Jacokes, James F. Cassiy, Stanley I. Greenspan, Robert F. Tuchman & Paul J. Stemmer, Jr.	**19**

A Collective Review of Completed Research Projects Evaluating the Effectiveness of the Interactive Metronome as an Occupational Therapy Intervention

Synopsis:

The purpose of this project was to compile the different pilot studies that have been conducted of the last 5 years in regard to using the Interactive Metronome and identify the strengths and weakness of the outcomes and feasibility of using the Interactive Metronome as a viable treatment modality in the clinic.

Study 1 looked at normal individuals over the age of 55 and compared pre and post test IM scores and those of the NHPT. Notable improvements ave. 24% and above were achieved.

Study 2 compared those clients following standard of care Active ROM exercise program compared to those who received the IM for 8 sessions. The percentage of change was 24%for the IM participants as compared to 10% following the in home ROM

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Author:

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A Collective Review of Completed Research Projects Evaluating the Effectiveness of the Interactive Metronome as an Occupational Therapy Intervention PO 5052

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ABSTRACT

Purpose: The purpose of this project was to compile the different pilot studies that have been conducted of the last 5 years in regard to using the Interactive Metronome and identify the strengths and weakness of the outcomes and feasibility of using the Interactive Metronome as a viable treatment modality in the clinic.

INTRODUCTION

Interactive Metronome: Interactive Metronome® (IM) is a switch-activated computer program that uses the brains neuroplasticity to improve coordination and timing. IM relies on the body's internal rhythm and reaction to feedback in order to retrain the brain for motor behavior.

Stroke: Stroke is the leading cause of disability in the United States. With new technology, more individuals are surviving stroke, which is driving up healthcare costs. Specifically, occupational therapists focus on upper extremity functioning, fine motor skills, and cognitive functioning for participation in activities of daily living (ADLs) and other occupations, which makes IM a valuable tool in occupational therapy.

METHODS & INSTRUMENTATION

Each of the studies that were conducted were done follow the same methods and design. A baseline pre test was given on each participant. These included the IM Long Form and different standardized instruments. The most consistent of these was the Nine Hole Peg test; which was used with all groups of participants and studies. In addition each participant followed pre-established protocol. The protocols were established based on a piloted project measuring stamina and endurance of 12 individuals over the age of 65 as well as length of time constraints established by third party payers. In addition surveys identifying personal opinion of the participants perception of change were conducted.

DISCUSSION

It might be inferred that the IM is a justifiable intervention to use with individuals post-stroke for improving fine motor capabilities. While no statistical significance was found for the NHPT, the t-value was notable and finings identified were very close to being significant. However, the data is still clinically meaningful because it suggests a correlation between using the IM and improved scores on the NHPT. While this trend in improvement still needs to be researched further, it suggests that there may be increased fine motor function after using IM. The survey indicated an overall perception by the participants' belief that the IM is an effective treatment in therapy. Results of the survey showed that the participants would be willing to continue use of the IM, even if it required a reasonable fee. While this trend in improvement still needs to be researched further, it suggests that there may be increased fine motor function after using IM.

The researcher notes that while the IM can be shown to be an effective modality for use in clinic settings it should be used in conjunction with more occupational based interventions.

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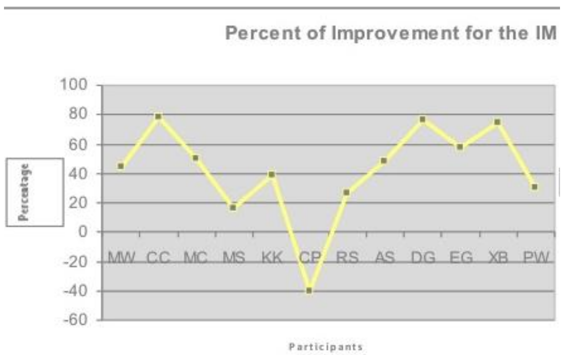
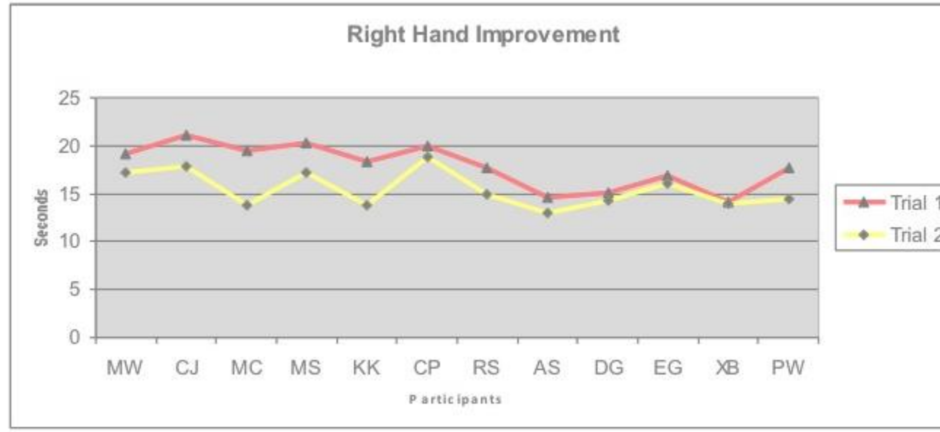
RESULTS of Multiple Pilots

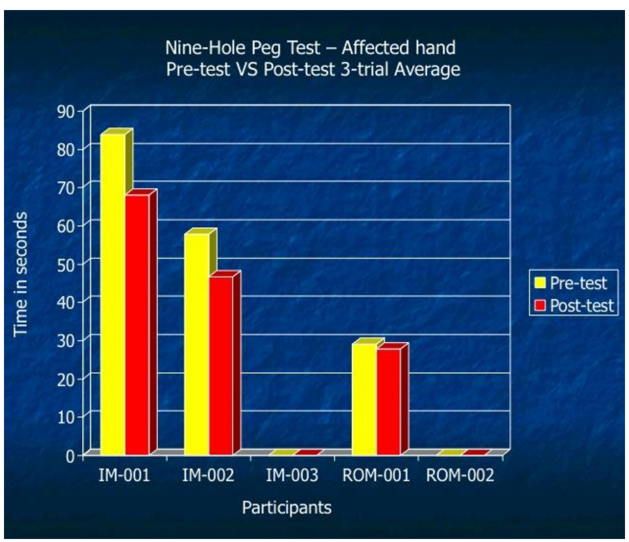
Measurement on IM Change



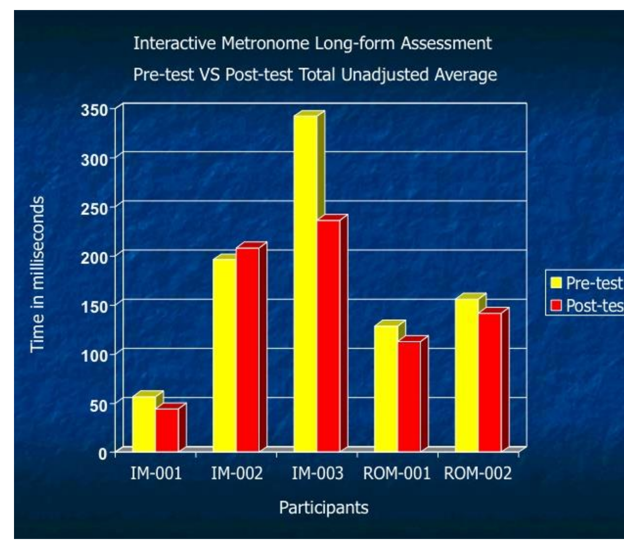
This study looked at normal individuals over the age of 55 and compared pre and post test IM scores and those of the NHPT. Notable improvements ave. 24% and above were achieved.



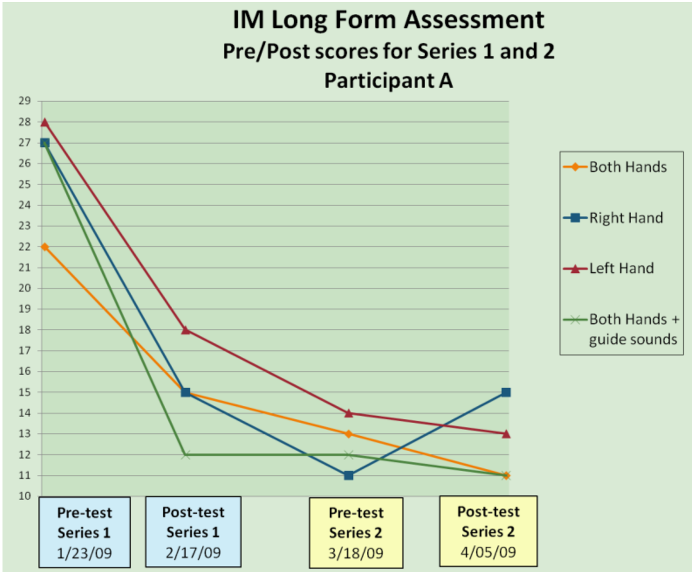
This study compared those clients following standard of care Active ROM exercise program compared to those who received the IM for 8 sessions. Data from this pilot study indicated that participants made significant improvements as measured by the NHPT as well as the IM Long Form.

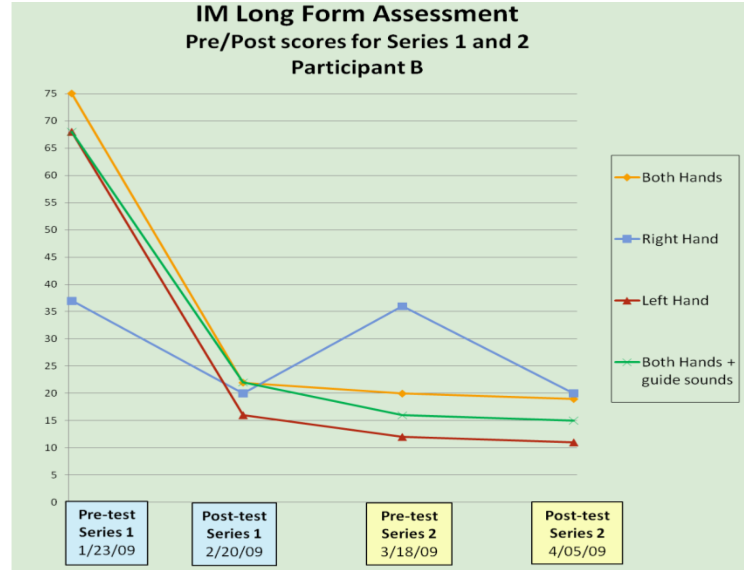


Participants who followed the Active ROM Protocols also showed improvements - this was anticipated as it is an acceptable standard of care and as such out-comes should demonstrate positive change.
However the percentage of change was 24%for the IM participants as compared to 10% following the in home ROM

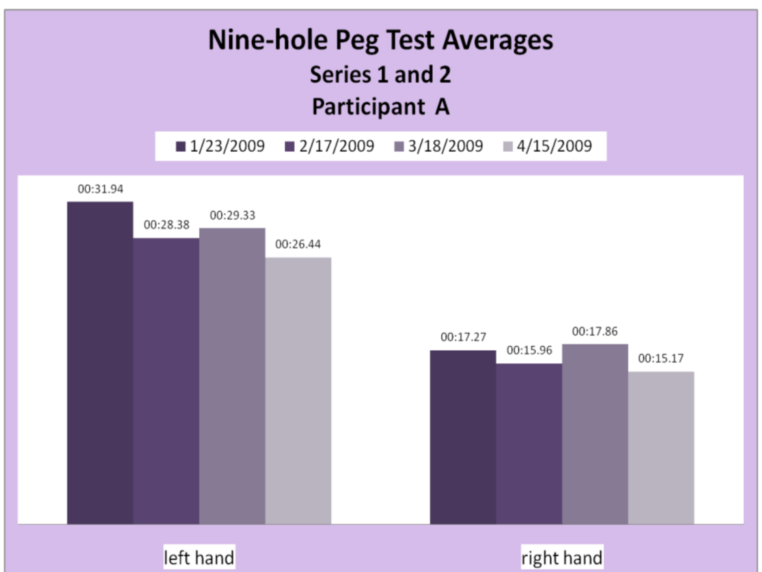


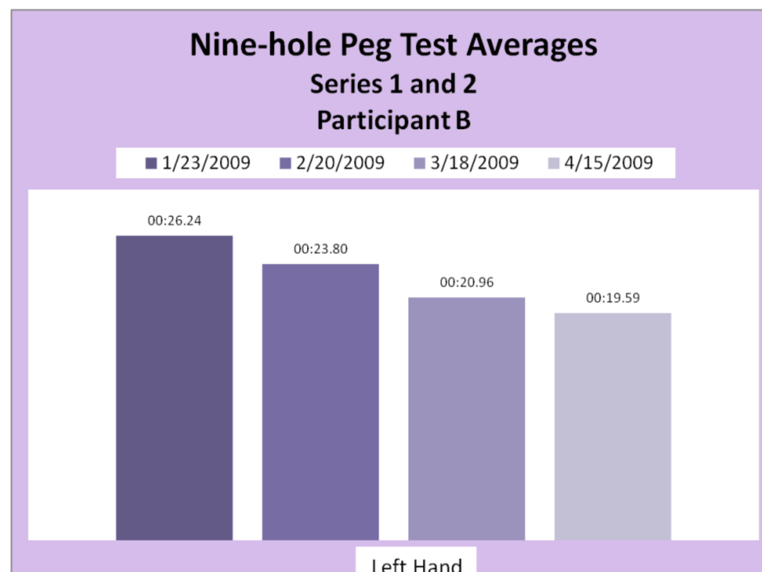
RESULTS of Multiple Pilots





This study looked at 2 CVA cases – Both making notable changes with 30 days longevity retest and 2nd series of IM provided demonstrated performance improvement



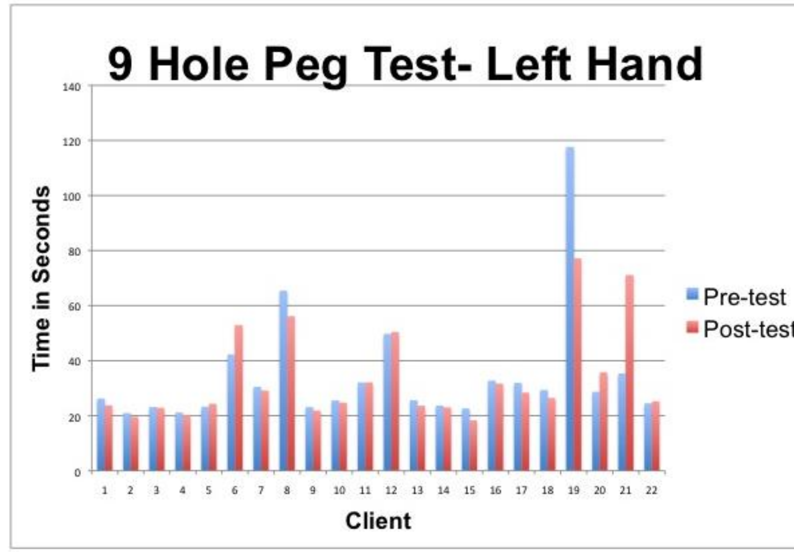


RESULTS of Multiple Pilots

Results: Descriptive Statistics

	Post CVA	Healthy Individuals
Mean % Improvement Adj MS Average	30.4%	53.7%
Mean % Improvement on SRO %	41.1 %	56.9%
Mean % NHPT Cumulative Improvement	16-4 %	26.5%

Positive outcomes in both Post CVA and Healthy Individual groups
No significant differences in percentage of improvement between groups
Indicates IM may be just as effective with individuals who are post-CVA as in healthy aging individuals
Low to no correlation between LFA and NHPT



The sample size for this subtest was 22. These subjects were able to complete both the pre and post tests for the NHPT. Subjects who could not complete both were omitted. The t-value came close to being statistically significant at 0.896. While not statistically significant, this does suggest a correlation between using the IM improved scores on the NHPT.

2

Reading Intervention Using Interactive Metronome in Children With Language and Reading Impairment: A Preliminary Investigation

Synopsis:

This study shows that after only 4 hours of IM training, larger gains were made in most areas of reading achievement over the control group. In a 4 week time period, the IM group did 15 minutes of training before a traditional reading intervention while the control group just did the traditional reading intervention. The improvements over the control group are listed below.

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Reading Intervention Using Interactive Metronome in Children With Language and Reading Impairment: A Preliminary Investigation

Michaela Ritter[1], Karen A. Colson[1], and Jungjun Park[1]

Abstract

This exploratory study examined the effects of Interactive Metronome (IM) when integrated with a traditional language and reading intervention on reading achievement. Forty-nine school-age children with language and reading impairments were assigned randomly to either an experimental group who received the IM treatment or to a control group who did not. Both groups received language and reading intervention, and the experimental group received an additional four hours of IM treatment during a four-week period. Although both groups made gains in reading rate/fluency and comprehension, the extent of the gains was much larger in the IM group. IM training may be useful for promoting the reading rate/fluency and comprehension of children with language and reading impairments.

Keywords

reading fluency, comprehension, language and reading impairment, Interactive Metronome (IM) training, temporal processing, processing speed

Researchers are interested in investigating the different factors that contribute to or limit a child's reading achievement. One such area of considerable investigation is that of reading fluency (Catts, Fey, Zhang, & Tomblin, 2001; Hogan, Catts, & Little, 2005; Hook & Jones, 2002; Kamhi, 2003). Kamhi (2003) defined reading fluency as the ability to read with speed and accuracy as well as with the appropriate expression. Hook and Jones (2002) suggested that fluency not only requires automatic word reading but also the use of appropriate prosody. Accordingly, fluency of reading is dependent on the prosodic features of our language, such as intonation, stress, and phrase patterns, which involve variations in timing (Chafe, 1988). From M. Wolf and Katzir-Cohen's (2001) perspective, the ability to learn to read fluently and ultimately comprehend text depends greatly on the development and integrative function of multiple underlying processes involving perceptual and linguistic components.

Research has documented that children with language impairment (LI) are more likely to experience difficulty in reading achievement, including reading fluency, than typical language learners (Bishop & Adams 1990; Catts, Fey, Tomblin, & Zhang, 2002; Catts, Fey, Zhang, & Tomblin, 1999; Rescorla, 2002). In fact, some findings suggest that children with LI are as much as five to six times more likely to experience difficulties with learning to read than a typically developing child (Catts et al., 1999; Catts et al., 2002). Children with LI struggle with one or more areas of oral language, including morphology, syntax, phonological processing, semantics, and/or pragmatics that mirror similar aspects found in written language (Boudreau & Hedberg, 1999; Cabell, Justice, Zucker, & McGinty, 2009; Rescorla & Lee, 2000). Moreover, there are robust findings in the literature that identify difficulties with phonological awareness as one of the most critical language components for the child with LI in learning to read (Adams, 1990; Castiglioni-Spalton & Ehri, 2003; Catts, 1993; National Early Literacy Panel, 2004). Although it is widely recognized that impairment in phonological awareness is central to the development of reading disorders in many children, a number of researchers contend that this phonological processing deficit does not sufficiently explain the presence of reading disabilities in all children (Catts et al., 2001; Hogan et al.,

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2005; Lonigan, Burgess, & Anthony, 2000; Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001).

One notion of considerable interest in this regard is that many children with developmental language and reading impairments have perceptually based problems involving the speed of information processing, especially in the auditory domain, which is believed to underlie their deficiencies in acquiring and manipulating phonological representations normally (Burns, 2007; Cacace, McFarland, Ouimet, Schrieber, & Marro, 2000; Cestnick & Jerger, 2000; Heath, Hogben, & Clark, 1999; Leonard et al., 2007; Miller et al., 2006). Catts, Gillispie, Leonard, Kail, and Miller (2002) found that school-age children with a reading impairment showed slower processing than controls for motor, phonological, lexical, visual, and grammatical tasks. P. Wolf (2002) suggested that children who have a reading disorder not only have deficits in the language system but also have a dysfunction in "timing." Llinas (1993) indicated that this "timing" problem may result from an underlying temporal processing disturbance in children who have reading impairments.

A major impetus in this ongoing area of investigative inquiry and debate is a series of studies by Tallal and her colleagues that examined the auditory processing abilities of children with specific language impairment (SLI; Tallal & Piercy, 1973a, 1973b) and subsequently those with reading disorders (Tallal, 1980; Tallal, Miller, Jenkins, & Merzenich, 1997; Tallal & Stark, 1982). Their findings that a nonlinguistic auditory temporal processing deficit could be causally related with a phonologically based decoding problem and associated with reading disabilities have spurred numerous investigations focused on determining the nature and scope of the temporal processing difficulties presented by children with LIs and their relationship to the development of literacy skills.

Gaining a theoretical consensus has proven difficult for a number of reasons, including researchers' varying views of what constitutes a rapid temporal processing deficit and its origin for nonlinguistic and linguistic stimuli (De Martino, Espesser, Rey, & Habib, 2001; Farmer & Klein, 1995; Mody, Studdert-Kennedy, & Brady, 1997; Nittrouer, 1999; Rey, De Martino, Espesser, & Habib, 2002; Studdert-Kennedy & Mody, 1995; Wright, Bowen, & Zecker, 2000). Nevertheless, over the last three decades, a substantial body of research has provided evidence that reading impairments in many children, including deficiencies in phonological processing, may be associated with nonlinguistic, rapid temporal auditory perceptual problems (Berninger, Raskind, Richards, Abbott, & Stock, 2008; Cacace et al., 2000; Cestnick & Jerger, 2000; Heath et al., 1999; McCroskey & Kidder, 1980). For example, researchers have documented that many children with reading disabilities exhibit deficits compared with normal controls in temporal order judgment tasks (Berninger et al., 2008; Cacace et al., 2000; Cestnick & Jerger, 2000; Heath et al., 1999). It also has been reported that children with reading disorders perform poorer than those with good reading skills in tonal frequency discrimination (Cacace et al., 2000; Walker, Givens, Cranford, Holbert, & Walker, 2006) and auditory temporal resolution tasks involving gap detection (Hautus, Setchell, Waldie, & Kirk, 2003; McCroskey & Kidder, 1980), which all require rapid processing of fine temporal properties of acoustic stimuli. Collectively, these findings provide support for the idea that many children with reading disabilities have deficits in processing rapid timing changes in acoustic signals. Such deficits may influence the speed and efficiency of their speech perception and phonological decoding (such as using grapheme to phoneme correspondence rules) and ultimately affect their reading fluency and comprehension. In this regard, Burns (2007) recently noted that "there is considerable evidence that auditory processing skills, especially in the domain of rapid auditory processing, underlie language acquisition and reading mastery" (p. 181). Thus, it appears reasonable that for some children with reading disabilities, training to improve rapid auditory temporal processing may promote the speed and accuracy of their text reading and support their reading development.

Research suggests that the human brain measures time continuously and that it is difficult to find any complex behavioral process that does not involve mental timing (Mauk & Buonomano, 2004). This capacity is important to a variety of performance mechanisms, including temporal processing and rhythm perception and production. Investigations on mental timekeeping and temporal processing indicate that humans have multiple timing systems that are associated with different behaviors and neurological substrates and that the fastest timing system is interval or millisecond mental timing (Buhusi & Meck, 2005; Mauk & Buonomano, 2004). According to Mauk and Buonomano (2004), "Temporal processing on this scale is required for simple sensory problems, such as interval, duration, and motion discrimination, as well as complex forms of sensory processing, such as speech recognition" (p. 307). Data from perceptual learning studies show that the neural mechanisms underlying mental timing can be fine-tuned or modified with treatment and that interval learning can generalize across modalities, such as spatial to auditory and auditory to motor (Karmarkar & Buonomano, 2003; Meegan, Aslin, & Jacobs, 2000; Nagarajan, Blake, Wright, Byl, & Merzenich, 1998). Similarly, it has been shown that combining auditory processing treatment with direct instruction in language structure can produce significant improvement in the reading skills of children with dyslexia, despite no direct reading intervention (Temple et al., 2003). Another neuroscience-based intervention for improving rapid interval auditory processing and achievement in other modalities is the use of synchronized metronome tapping (Buhusi & Meck, 2005; Taub, McGrew, & Keith, 2007).

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Interactive Metronome (IM; 2007) is a neuroscience-based intervention for improving rapid temporal auditory processing and achievement in other modalities through the use of a synchronized metronome tapping. IM is a computerized treatment technique that requires individuals to maintain synchrony of a bimanual motor response with auditory tones. During treatment, participants listen to a reoccurring metronome beat via headphones and match tapping/clapping motions using hand and foot triggers to the beat presentation. Participants receive immediate feedback regarding the accuracy of their tracking primarily through an auditory guidance system which uses varying tones to indicate how closely their interactive physical responses correspond to the metronome beat. The synchronized metronome tapping treatment is designed to minimize the latency between the onset of the regularly occurring beat and a participant's expectancy response to that beat (IM, 2007) and thereby promote improved temporal processing. A visual feedback of latency response can be used as well. A number of studies have shown that IM treatment is associated with improvements in motor control and coordination and can have a positive influence on higher level cognitive functioning, including reading (Bartscherer & Dole, 2005; Kuhlman & Schweinhart, 1999; Libkuman & Otani, 2002; Schaffer et al., 2001; Taub et al., 2007). In fact, Taub et al. (2007) found that elementary-age children who were provided IM treatment scored significantly higher on standardized tests of word reading efficiency and fluency than those in a nontreatment control group. These findings are consistent with other data demonstrating a relationship between performance measures for continuous, sequential, motor tapping tasks, oral reading, and temporal processing (Schaffer et al., 2001; Stanford & Barratt, 1996). Therefore, it is possible that adding IM treatment to a traditional language and reading intervention may produce clinical gains on improving rapid auditory processing and reading achievement in children with a language and reading impairment.

It is well established that the process of learning to read fluently with comprehension is not an autonomous process of learning one or two cognitive skills independently; rather, it requires the acquisition and integration of a multitude of component skills involving phonological processing, decoding, vocabulary, syntax, morphology, listening comprehension, and discourse and background knowledge (Anthony & Francis, 2005; Bishop & Snowling, 2004; Bus & Van Uzendoorn, 1999; Troia, 1999; Vellutino, Fletcher, Snowling, & Scanlon, 2004; Verhoeven & van Leeuwe, 2008). Reading fluency is considered by some investigators to be an important predictor of reading comprehension in children. In fact, research indicates that the speed and accuracy of decoding words are critical variables as they actually account for a significant amount of variance for reading comprehension (Fuchs, Fuchs, Hosp, & Jenkins, 2001; Kame'enui & Simmons, 2001). When reading fluency is fully developed, so that word decoding with accuracy and speed becomes relatively automatic, then the reader's attention and other cognitive resources can be directed to comprehending the meaning of the text (National Reading Panel [NRP], 2000; M. Wolf & Katzir-Cohen, 2001). However, when the reader is using most of his or her cognitive resources for decoding, it can be assumed that there are few if any remaining resources that can be allocated to reading comprehension (Fuchs et al., 2001; NRP, 2000).

It is clear that numerous researchers have provided a variety of ways to successfully improve children's reading fluency and foster their reading comprehension (Kuhn & Stahl, 2003; NRP, 2000; Rasinski & Hoffman, 2003; Robertson & Davig, 2002; Roth, Speece, & Cooper, 2002; Rvachew, Ohberg, Grawburg, & Heyding, 2003; Tyler, 2002). There are many readers who become fluent after receiving reading instruction by their regular classroom teacher; still, there are other readers who struggle and require much more intensive and systematic intervention or instruction to become a fluent and successful reader (Kuhn & Schwanenflugel, 2006; Wexler, Vaughn, Edmonds, & Reutebuch, 2008). Thus, it is important to continue to explore additional methods and techniques that may improve the automaticity and fluency of reading in children who have developmental language and reading impairments. The idea that IM treatment can promote the rate and efficiency of information processing and that these skills may generalize to other cognitive abilities, including reading fluency and comprehension, is intriguing and warrants investigation. This is especially true given the evidence that many children with language and reading disabilities have deficits in rapid auditory processing and given the possibility that combining IM treatment with a language and reading intervention may produce a more effective intervention.

Although evidence indicates that IM treatment may be associated with significant improvement in typically developing children's reading fluency (Schaffer et al., 2001; Taub et al., 2007), the potential value of providing IM treatment to promote reading fluency in children who have developmental language and reading impairments has yet to be determined. To date, no study has examined the effects of IM treatment as an adjuvant to a traditional language and reading intervention with this population. Accordingly, we designed exploratory research to gain insight as to whether IM treatment when combined with a traditional language and reading intervention is a viable type of intervention for improving reading fluency in children with a language and reading impairment. We were interested in determining whether IM treatment would have an additive value to traditional language and reading intervention and make a significant difference in the treatment outcome. The Interactive Metronome website states,

> Interactive Metronome (IM) is an engaging, rewarding, and systematic program that improves timing in the brain, thus improving the ability to learn, retain,

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> and apply new information in the academic setting and beyond. IM is used in the schools to improve: Focus & Concentration, Sequencing & Organization, Auditory & Language Processing, Reading & Math Achievement, Handwriting, and Self-Control of Impulsivity and Hyperactivity." (IM, 2012, para. 3)

The present investigation is an exploratory study to examine the potential effects of IM training related to reading achievement.

The purpose of this study is to examine the effects of IM treatment integrated into a traditional language and reading intervention on the reading fluency of children with a language and reading impairment. More specifically, answers to the following questions are sought:

Research Question 1: Is there a difference between pre- and postintervention measures of reading fluency for school-age children with a language and reading impairment who do and do not receive IM treatment integrated with a traditional language and reading intervention?

Research Question 2: Is there a difference between pre- and posttreatment measures of reading comprehension for school-age children with a language and reading impairment who do and do not receive IM treatment integrated with a traditional language and reading intervention?

Method

Participants

Participants were 49 school-age children (e.g., in Grades 2–5) who had been diagnosed with co-occurring language and reading impairments and who were enrolled in a university clinic's summer language and reading program. Participants were randomly assigned to either an experimental group (n = 28) who received IM treatment or to a control group (n = 21) who did not receive the treatment. All participants received a traditional language and reading intervention differing only by the IM treatment.

Although 60 children were originally recruited to participate in this study, 11 participants withdrew from the study prior to completing all treatment due to vacation activities and illness. The IM treatment group (n = 28) consisted of 19 males and 9 females who ranged in age from 7 years 1 month to 11 years 4 months (M = 9 years 2 months, SD = 1 year 3 months). The control group (n = 21) comprised 15 males and 6 females who ranged in age from 7 years 2 month to 11 years 9 months (M = 9 years 6 months, SD = 1 year 3 months). In all, 42 of the participants were Caucasian, 3 were African American, 3 were Hispanic, and 1 was Asian American. As determined by self-report in the case history interview, the participants' families were described as lower to middle class. The parents of the participants were fully informed about the study and were required to sign a parental consent form giving permission for their child to be involved in the research. The investigation protocol was reviewed and approved by the university internal review board.

Inclusion Criteria

A battery of standardized tests was administered to all participants prior to the intervention to establish their language and reading scores. Receptive and expressive language skills were assessed using the *Clinical Evaluation of Language Fundamentals–Fourth Edition* (CELF-4; Semel, Wiig, & Secord, 2003). The four subtests for the Core Language score (*Concepts and Following Directions, Word Structure* [age 5–8] or *Word Classes* [age 9 and up], *Recalling Sentences*, and *Formulated Sentences*) were administered for this purpose. Expressive vocabulary was assessed using the *Expressive Vocabulary Test–Second Edition* (EVT-2; Williams, 2007). The *Gray Oral Reading Test–Fourth Edition* (GORT-4; Wiederholt & Bryan, 2001) was used to obtain reading rate, accuracy, fluency, and comprehension standard scores. The participants met the following selection criteria for inclusion:

- Core Language score at or greater than 1 *SD* below the mean (16th percentile or less) on the CELF-4, and an expressive vocabulary score at or greater than 1 *SD* below the mean (16th percentile or less) on the EVT-2.
- A minimum of 1 *SD* below the mean (16th percentile or less) for reading fluency or reading comprehension scores on the *Gray Oral Reading Test–Fourth Edition* (GORT-4; Wiederholt & Bryan, 2001).
- No suspected intellectual disability or history of neurological disorder (i.e., stroke, traumatic brain injury, or seizure disorder) as determined by parent report.
- No hearing impairment or major physical impairment.
- Monolingual English speaker.

Procedures

Preintervention testing was completed 1 week before treatment was initiated. After both the experimental and control groups had completed the intervention program, all participants were retested on the same measures of reading fluency and comprehension. All language and reading measures with the exception of *Read Naturally* (Read Naturally Inc., 2005) were administered by three trained graduate research assistants in a single session, using standard assessment procedures for the participant's age group. The graduate assistants were pursuing their

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master's degree in communication sciences and disorders and were supervised by a faculty member holding a state license and Certification of Clinical Competence from the American Speech-Language Hearing Association (ASHA). The *Read Naturally Software Edition* (Read Naturally Inc., 2005) was administered and analyzed by a certified reading specialist for all participants. The total assessment time ranged from 60 to 90 min. The examiners for the assessment and test scoring were blind to the participants' assigned groups, and each child was assigned a number that was used in place of his or her name on all test forms. The order of the tests remained constant.

Three reading outcome measures were individually administered, using standard assessment procedures as stated in their perspective manuals. The outcome measurements consisted of the *Dynamic Indicators of Basic Early Literacy Skills–6 Oral Reading Fluency* (DIBELS-6 ORF; Good & Kaminski, 2002), *Read Naturally Test* (Read Naturally Inc., 2005), and GORT-4 (Wiederholt & Bryan, 2001).

The DIBELS-6 ORF is a standardized, individually administered assessment of reading fluency using connected text. The participants read a passage aloud for 1 min. Three 1-min reading samples were obtained, and the median of the three was calculated for correct words read per minute. The participants' current grade level (second through fifth grade) was used as a determinant of the selection of the passage read. The alternate form of the DIBELS-6 ORF was used for the post-testing.

The *Read Naturally* software was also used to evaluate each participant's oral reading fluency. It consisted of a computerized reading assessment that was uploaded to a computer hard drive. The participants' current grade level determined the selection of the passage read. The *Read Naturally* is also timed over three 1-min reading samples, and the median score was used as the fluency measure.

The GORT-4 is a standardized instrument that measures rate, accuracy, fluency, and comprehension of reading. Alternate forms were used in the pre-testing (Form A) and post-testing (Form B) to gain a measurement of each participant's rate, accuracy, fluency, and comprehension of reading. The group's pre- and posttreatment reading measures for the three tests were compared to determine gains in reading fluency and comprehension.

Reliability

All language and reading measures were administered and scored according to the procedures stated in the manual. All examiners received additional training in test administration over a 3-day period prior to the initiation of this study by the first author. All scoring was rechecked by the examiner and then by two graduate assistants working independently. Fifty percent of each assessment session was supervised by one of the supervising faculty, and 20% of those sessions were randomly selected and supervised 100% of the time to further establish reliability of test administration and scoring. Analysis indicated a range of 91% to 100% agreement with an average of 96% agreement for the pre- and posttest scores. All points of disagreement were discussed and resolved and brought to an agreement of 100%.

Intervention

The intervention used in this study for the experimental group was the IM treatment (IM, 2007), which was combined with a traditional language and reading intervention. The control group received the traditional language and reading intervention only. Both the IM treatment and the language intervention were provided by trained graduate clinicians under the supervision of faculty holding a state license, a Certification of Clinical Competence in Speech-Language Pathology from the ASHA and trained by IM Corporation to implement IM treatment. The graduate clinicians completed a total of 7 days of intensive training in implementing the IM intervention, and each aspect of the language intervention protocol with the first author of the study prior to the initiation of the intervention. The reading intervention was conducted by three reading professionals holding a master's degree in education.

IM. The experimental group participated in 15-min IM treatment each day for a total of 4 hr during the 4-week intervention. During the control group's designated snack time, the experimental group participated in the IM treatment. Treatment was provided to each participant in a quiet environment as stated in the IM training manual (IM, 2007). Treatment sessions followed a prescriptive guide that controlled the structure and implementation of each IM session. Specifically, the IM treatment involved a laptop computer, IM software, a hand and foot contact sensor trigger, and two sets of headphones. During the treatment, each participant listened to a computer-generated, reoccurring metronome beat via headphones and matched clapping/tapping motions to the beat presentation while using the hand or foot trigger. A patented guidance system provided immediate real-time auditory feedback for response rhythm and timing. Response accuracy was measured to the nearest milliseconds. The IM computer setting was adjusted so that the pace and complexity level of the treatment was appropriate for each participant's processing abilities.

Each IM treatment session consisted of three to five different tasks that included both hand and foot triggers (e.g., clapping both hands together, tapping one hand to upper thigh, toe taps, alternating toe taps, heel taps, and alternating heel taps using the foot trigger, a combination of the hand and foot movements using both the hand and foot triggers). The participants were instructed to listen to the metronome beats and the guide sounds triggered by their hand and foot movement accuracy. The guide sounds changed in pitch and left/right headphone location according to the accuracy of the participants taps/claps. The IM program displayed the participant's accuracy of response after each task was completed. Verbal feedback was provided to each

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participant during and following each task. To ensure accuracy and reliability, participant training was provided by graduate clinicians who were trained in IM usage procedures, and all sessions were supervised by the first author.

Language and reading intervention. The children in both the IM and control groups received a traditional language and reading intervention 4 days a week over a 4-week period for a total of 48 hr of intervention. The children participated in a 1-hr individual language intervention session, a 1-hr small group language intervention (3–4 participants), and a 1-hr reading intervention session (4–6 participants). Participants were combined in the small group interventions based on their language and reading severity levels.

The language intervention utilized a narrative (story book) platform and focused on vocabulary, narrative retells, and phonological awareness. The narrative platform provided an authentic learning opportunity and encouraged active participation in the intervention (Gillam & Ukrainetz, 2006; Pretti-Frontczak & Bricker, 2004). Thus, each week of intervention, a specific book (e.g., *Cowboy Camp*, Sauer, 2005) was chosen for the narrative-based intervention in accordance with a particular theme. The individual language intervention targeted vocabulary and phonological awareness, and the group language intervention targeted narrative structure. The reading intervention was based on a structured reading program, the Sequential English Education (SEE) curriculum (Pickering, 2001). Each participant received 16 scripted lessons following the SEE curriculum as related to decoding and reading words and sentences based on that individual's current reading level. The appendix provides a description of the intervention.

Treatment fidelity. The 49 participants attended all 16 sessions for a total of 48 hr of language and reading intervention. The experimental group received an additional 15 min of IM treatment while the control group received a snack time. To further ensure that the intervention was implemented consistently and with fidelity, each graduate clinician was responsible for providing the language intervention to one child in the experimental group and one child in the control group. Each trained graduate clinician was supervised for a minimum of 30% of the time by the supervisory faculty. For each supervised session, an evaluation form was completed and discussed with the graduate clinician regarding the consistency, execution, and adherence to the intervention protocol.

Statistical considerations. The effects of IM treatment integrated with a traditional language and reading intervention on each measure of reading fluency and comprehension (i.e., *Read Naturally*, DIBELS-6, and GORT-4) were determined by conducting a series of mixed-model ANOVA with one between-subjects variable (group) and one within-subjects variable (time). We used partial eta square (η_p^2) to determine the strength of significance. Values of .01, .06, and .14 are by convention interpreted as small, medium, and large effect sizes, respectively (Green & Salkind, 2003).

Table 1. The Means, Standard Deviations, Chronological Ages, and Standardized Test Scores on the Receptive and Expressive Language and Vocabulary Tests for the Two Groups

	Control group (n = 21)	IM group (n = 28)
Measures	*M* (*SD*)	*M* (*SD*)
Age (years, months)	9, 6 (1, 3)	9, 2 (1, 3)
CELF-4 Core[a]	76.61 (7.27)	77.07 (6.55)
CELF-4 CFD[b]	6.05 (1.91)	6.04 (1.48)
CELF-4 RS[c]	6.00 (2.03)	5.54 (2.08)
CELF-4 FS[d]	6.14 (2.33)	5.89 (2.50)
EVT-2[e]	74.06 (6.10)	73.05 (8.14)

Note: IM = Interactive Metronome; CELF = *Clinical Evaluation of Language Fundamentals*; EVT = *Expressive Vocabulary Test*.
[a]The Core Language score of the *Clinical Evaluation of Language Fundamentals-Fourth Edition* (*M* = 100, *SD* = 15).
[b]*Concepts and Following Directions* subtest of the CELF-4 (*M* = 10, *SD* = 3).
[c]*Recalling Sentences* subtest of the CELF-4 (*M* = 10, *SD* = 3).
[d]*Formulated Sentences* subtest of the CELF-4 (*M* = 10, *SD* = 3).
[e]*EVT-2 = Expressive Vocabulary Test-Second Edition* (*M* = 100, *SD* = 15).

Results

Pretreatment Reading Measures

To check for randomization bias, potential pretreatment differences between the two groups in regard to their language scores, chronological ages, and reading scores (fluency and comprehension) were examined using a series of t tests. No significant group differences were noted for the three subtests of the CELF-4 at the significance level of .05: *Concepts and Following Directions,* $t(47) = 0.025$, $p = .980$; *Recalling Sentences,* $t(47) = 0.794$, $p = .431$; and *Formulated Sentences,* $t(47) = 0.456$, $p = .650$]. Subsequently, two groups were not significantly different on the CELF-4 Core Language composite score, $t(47) = 0.164$, $p = .871$, and the EVT-2, $t(47) = 0.148$, $p = .883$. A comparison of the group means and standard deviations (*SD*s) for all language measures and chronological age is presented in Table 1.

In addition, no group differences were noted at pretest on any of the reading outcome measures used in this study: *Read Naturally* scores, $t(47) = .525$, $p = .602$; DIBELS-6 ORF scores, $t(47) = 1.31$, $p = .198$; GORT-4 rate scores, $t(47) = .578$, $p = .566$; GORT-4 accuracy scores, $t(47) = .297$, $p = .768$; GORT-4 fluency scores, $t(47) = .941$, $p = .352$; and GORT-4 comprehension score, $t(47) = .695$, $p = .491$. Thus, the randomization procedure appeared to achieve equivalence of the groups at baseline on these specific variables (see Table 2).

Posttreatment Comparisons of Reading Measures

The groups' means and *SD*s for the pre- and posttreatment scores on reading fluency and comprehension measures are shown in Table 2.

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Table 2. Group Means, Standard Deviations, and Mean Gain Scores for the Reading Fluency and Comprehension Measures at Pre- and Post-Treatment

	Control group (n = 21)						IM group (n = 28)					
	Pre-treatment		Post-treatment				Pre-treatment		Post-treatment			
Measures	*M*	*SD*	*M*	*SD*	*Gain score*	*ES*	*M*	*SD*	*M*	*SD*	Gain score	*ES*
Read Naturally[a]	44.57	15.724	46.62	16.023	2.05***	.366	44.93	20.105	52.46	20.851	7.53***	.828
DIBELS-6[a]	45.62	15.184	48.14	15.449	2.52**	.362	43.32	20.318	51.79	21.612	8.29***	.829
GORT-4 rate[b]	4.95	2.47	5.24	2.45	0.29 (*ns*)	.107	4.82	2.70	6.07	2.28	1.25***	.673
GORT-4 accuracy[b]	4.43	2.54	4.86	2.53	0.43 (*ns*)	.168	4.89	2.55	5.18	2.03	0.29 (*ns*)	.042
GORT-4 fluency[b]	4.65	2.43	5.05	1.83	0.40 (*ns*)	.008	4.82	2.42	5.54	2.90	0.72***	.340
GORT-4 comprehension[b,c]	5.14	2.40	5.62	2.21	0.48*	.104	4.93	2.22	6.18	2.21	1.25***	.653

Note: IM = Interactive Metronome; DIBELS = *Dynamic Indicators of Basic Early Literacy Skills*; GORT = *Gray Oral Reading Test*. Gain scores were calculated by subtracting pretreatment group mean from posttreatment group mean score. ES denotes Cohen's effect size as computed by partial eta square (Cohen, 1988).
[a]Scores are expressed as the number of words read correctly per minute.
[b]Scores are expressed as standard scores (M = 10.0, SD = 3.0).
[c]GORT-4 *Reading Comprehension* subtest.
*p < .05. **p < .01. ***p < .001.

First, a two-way (group and time) repeated measures ANOVA comparing the *Read Naturally* scores showed no significant main effect for group: $F(1, 47) = .334$, $p = .566$. There was a significant effect for time, $F(1, 47) = 119.926$, $p < .001$, $\eta_p^2 = .718$, however, and the interaction Time × Group was also significant, $F(1, 47) = 39.32$. $p < .001$, indicating that there were significant differences in performance over time between the two groups. Post hoc univariate ANOVAs revealed that the *Read Naturally* mean fluency scores increased significantly in both groups: the IM group, $F(1, 27) = 129.715$, $p < .001$, and the control group, $F(1, 20) = 17.443$, $p < .001$. However, the effect size of the IM group (η_p^2 = .828) was much larger than that of the control group (η_p^2 = .366). Figure 1(a) shows the pre- to posttreatment changes in each group's *Read Naturally* fluency scores. The IM group showed superior performance post-treatment and the control group did not show the same degree of improvement.

Next, examination of the DIBELS-6 fluency scores with a mixed-model ANOVA revealed a similar result. There was a significant main effect for time, $F(1, 47) = 105.054$, $p < .001$, $\eta_p^2 = .691$, and a significant Group × Time interaction effect, $F(1, 47) = 30.705$, $p < .001$, η_p^2 =.395. There was no main group effect, $F(1, 47) = .015$, $p = .902$, η_p^2 =.0001. Planned follow-up ANOVAs showed a significant treatment effect in both groups: the IM group, $F(1, 27) = 131.157$, $p < .001$, $\eta_p^2 = .829$, and the control group, $F(1, 20) = 18.30$, $p < .001$, $\eta_p^2 = .501$. Again, the IM group outperformed the control group postintervention as evidenced in the larger effect size. As seen in Figure 1(b), the amount of change in the IM group's mean scores was greater than that of the control group.

Next, a two-way mixed ANOVA examined differences in the groups' GORT-4 rate scores. Similar to the DIBELS-6, the results revealed a significant main effect for time, $F(1, 27) = 37.431$, $p < .001$, $\eta_p^2 = .443$, and a Group × Time interaction, $F(1, 47) = 14.758$, $p < .001$, $\eta_p^2 = .239$. Planned post hoc ANOVAs revealed a significant time effect for GORT-4 rate in the IM group, $F(1, 27) = 55.588$, $p < .001$, $\eta_p^2 = .673$, but not in the control group, $F(1, 20) = 1.21$, $p = .137$, $\eta_p^2 = .107$, indicating that IM treatment was associated with score gains on the GORT-4 rate of the experimental group only. Figure 1(c) illustrates the differences in the two groups' posttreatment GORT-4 rate scores.

Examination of the GORT-4 accuracy mean scores indicated no significant main effects for time, $F(1, 47)$ = .4.061, $p = .056$, $\eta_p^2 = .080$; Group × Time interaction, $F(1, 47) = .162$, $p = .689$, $\eta_p^2 = .003$; and group, $F(1, 47) = .883$, $p = .352$, $\eta_p^2 = .018$. As illustrated in Figure 1(d), no noticeable difference between the groups was found on GORT-4 accuracy following intervention. In addition, a mixed-model ANOVA was computed to explore the effect of IM treatment on the GORT-4 fluency composite mean scores. Even though the effect sizes were relatively smaller, significant main effects were found for time, $F(1, 47) = 7.173$, $p = .01$, $\eta_p^2 = .132$, and Group × Time interaction, $F(1, 47) = 4.195$, $p = .046$, $\eta_p^2 = .082$. There was no main effect for group, $F(1, 47) = .163$, $p = .689$. Follow-up post hoc ANOVAs revealed that the GORT-4 fluency scores increased significantly only in the IM group, $F(1, 27) = 13.918$, $p < .001$, $\eta_p^2 = .340$, and there was no significant increase in the control group, $F(1, 20) = .16$, $p = .693$, $\eta_p^2 = .008$. Finally, a 2 (group) × 2

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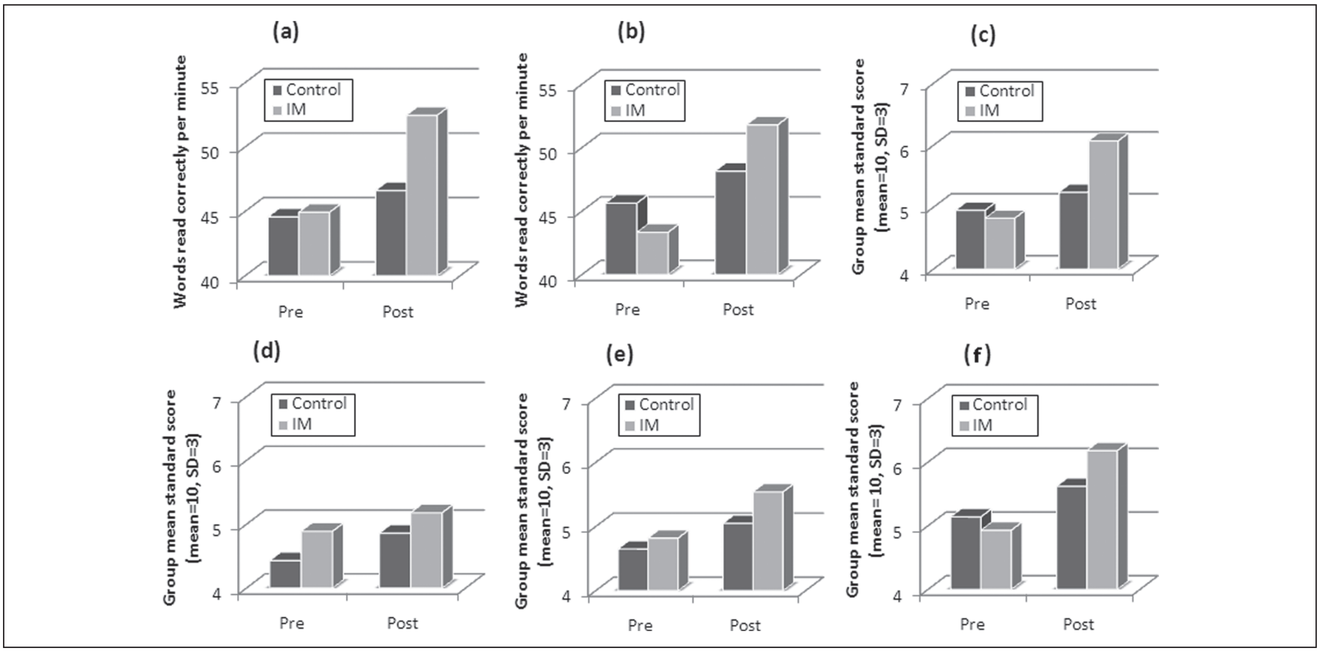

Figure 1. Pre- and postintervention performance on the *Read Naturally*, DIBELS-6 ORF, and the GORT-4 subtests (rate, accuracy, fluency, and comprehension) for the IM and control groups.
Note: DIBELS-6 = *Dynamic Indicators of Basic Early Literacy Skills–6 Oral Reading Fluency*; GORT-4 = *Gray Oral Reading Test–Fourth Edition*; IM = Interactive Metronome.

(time) repeated measures ANOVA on data from the GORT-4 comprehension subtest showed that the difference in performance across time (i.e., pre- and post-treatment) was significant, $F(1, 47) = 37.776$, $p < .001$, and did not interact with subgroups, $F(1, 47) = 7.591$, $p = 0.008$. Follow-up tests revealed a significant time effect in both the IM group, $F(1, 27) = 26.19$, $p < .001$, and the control group, $F(1, 20) = 1.21$, $p = .047$. However, effect size of the IM group ($\eta_p^2 = .653$) was much larger than that of the control group ($\eta_p^2 = .104$). Figure 1(f) illustrates the group data on the GORT-4 comprehension scores of the two groups of children.

Discussion

This exploratory study examined the potential benefits of IM treatment when integrated with a traditional language and reading intervention on the reading fluency and comprehension of school-age children with a language and reading impairment. A major finding of this preliminary investigation was that although both the IM and control groups made significant gains in reading fluency and comprehension, the extent of gain was larger in the IM group.

Reading Fluency Outcome

In reference to our first research question, our results show that both the IM and the control groups made statistically significant gains in reading fluency; however, the IM group made greater gains with larger effect sizes than the control group. The children in the IM group demonstrated statistically significant gains in their ability to fluently read paragraph-level material on all three measures (e.g., *Read Naturally*, DIBEL-6, and GORT-4 fluency). Interestingly, children in the IM group did not show any treatment effect in the accuracy component of the GORT-4. This suggests that the primary source of clinical gains in the IM group's fluency performance, which is composed of rate and accuracy, was that of rate. In other words, the experimental group did not improve their level of reading accuracy but increased their efficiency and rate of reading paragraph-level material. Similar findings were reported by Taub et al. (2007) in their investigation of the effects of IM training on reading achievement. Statistically significant results were found on reading previously known words faster, but no improvement was found in overall word recognition skills.

The children in the control group who received only the traditional language and reading intervention did not show significant improvement on the GORT-4 measures of reading fluency; yet, their reading fluency scores were statistically significant on the measures of *Read Naturally* and DIBELS-6 ORF. One possible explanation is that as the GORT-4 measures use standard scores rather than "number of words correctly read per minute" as found on the *Read Naturally* and DIBELS-6 ORF, the scoring protocol of the

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GORT-4 may not be as sensitive to gains in reading fluency as the other two measures. Nevertheless, there were obvious differences in the pattern of change of those fluency measures that appear to pertain to the effects of the IM treatment. Specifically, both groups showed significant improvement in their *Read Naturally* and DIBELS-6 ORF with large effect sizes reported, but again, the IM group outperformed the control group with a relatively larger effect size for both measures.

Reading Comprehension Outcome

Our second major finding was that both groups improved significantly in their reading comprehension; however, similar to the results found on the fluency subtests, the IM group outperformed the control group with a much larger effect size for the GORT-4 *Comprehension subtest*. This finding supports other research that suggests that as reading fluency increases, comprehension improves due to the availability of additional cognitive resources (Fuchs et al., 2001; Nation & Snowling, 1997). When the reading process becomes more automatic and fluent, the reader's attention and other cognitive resources can be directed toward the task of reading comprehension (NRP, 2000; M. Wolf & Katzir-Cohen, 2001). When interpreting these findings, it should be noted that a single measure of reading comprehension was used in this study.

Plausible Explanations for Findings

Over the past 20 years, there has been considerable evidence that processing speed limitations are contributing factors to reading difficulties experienced by children with language and reading impairments. Research suggests that the nonphonological component of processing speed contributes to the automaticity and/or efficiency of the reading process (Buhusi & Meck, 2005; Catts, Gillispie, et al., 2002; Miller, Kail, Leonard, & Tomblin 2001; Montgomery 2005; Shanahan et al., 2006; P. Wolf, 2002). Relatedly, intervention research linking interval timekeeping with reading achievement (Schaffer et al., 2001; Taub et al., 2007) has demonstrated the potential value of IM training (i.e., a synchronized metronome tapping intervention) to use as a possible option for reading fluency intervention in school-age children. Although few in number, these intervention studies have addressed how a nonacademic treatment (i.e., IM training) could positively affect reading achievement (Schaffer et al., 2001; Taub et al., 2007).

The findings from the current study that only the IM group showed significant improvement in their rate score of the GORT-4 fluency measure and no significant change in their GORT-4 accuracy score indicates that IM treatment may be associated with improvements in speed of processing as suggested by earlier research (Buhusi & Meck, 2005; Shanahan et al., 2006; Taub et al., 2007; P. Wolf, 2002). Thus, processing speed may be the contributing factor for the greater gains in automaticity and efficiency of reading made by the IM group when compared with the control group. This interpretation is consistent with that offered by Taub et al. (2007), suggesting that increases "in the clock speed of the master internal clock" (p. 857) contribute to improvements in reading fluency and efficiency. Taub et al. reported that IM treatment appears to "demonstrate transfer effects on reading fluency/efficiency of existing word recognition skills but not increase the overall level of word recognition skills in a students' repertoire" (p. 857).

Another plausible explanation for the finding that the experimental group had larger gain scores than the controls for reading rate/fluency and comprehension may be attributed to an increase in focus and attention as a result of IM treatment, which is consistent with prior research (Bartscherer & Dole, 2005; Schaffer et al., 2001; Taub et al., 2007). Similarly, Schaffer et al. (2001) found that students with attention deficit hyperactivity disorder (ADHD) who received IM treatment demonstrated improvements in attention, language processing, and reading. Therefore, it is possible that following IM treatment, improvement in the experimental group's focus and attention may have led directly to an increase in their reading rate, which also could account for the increase in reading comprehension. Thus, it is conceivable that following IM treatment, improvement in the experimental group's focus and attention may have led directly to an increase in their reading rate, which also could account for the increase in reading comprehension. Importantly, the results of our study highlight the possible additive effect that IM treatment can have on reading fluency and comprehension when integrated into a traditional language and reading intervention.

Limitations and Future Directions

The first limitation involves the lack of an untreated control group. Both the IM experimental group and the control group received the language and reading intervention and differed only in use of the IM treatment. As statistically significant gains were realized by both groups, it is not possible to conclude that IM treatment was the sole reason for the increase in reading fluency (rate) and comprehension and should be viewed with caution. Nonetheless, we argue that the results are meaningful and suggest that IM treatment does have value for improving reading fluency as suggested by earlier research (Schaffer et al., 2001; Taub et al., 2007) and does in fact facilitate an improvement in reading comprehension (NRP, 2000; M. Wolf & Katzir-Cohen, 2001).

The small clinical sample used for this study restricts the ability to generalize these findings to other populations;

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however, the results are consistent with previous research on IM treatment effects for improving reading fluency in typically developing children (Taub et al., 2007) and children with ADHD (Schaffer et al., 2001). An additional limitation of the study is the lack of a detailed description of each participant's environmental influences as related to his or her motivational level and amount of literacy engagement in the home environment. Further examination of these variables may contribute to a deeper understanding of the reading fluency outcomes.

We did examine the immediate clinical effects of the integrated IM treatment after a 4-week intervention period, but it is possible that IM treatment does not provide long-lasting effects on the reading fluency of this population and this should be addressed in future investigations. The significant change in the experimental group's GORT-4 rate and comprehension score was associated with a small amount of IM treatment (4 hr) relative to the total amount of language and reading intervention (48 hr) provided in the study. Thus, combining even a limited amount of IM treatment with a language and reading intervention proved beneficial. It is possible that extending the length of the IM treatment sessions to 45 to 50 min each day for a total of 15 to 18 hr of treatment (Taub et al., 2007) may have a greater impact on children's reading rate/fluency and comprehension than observed in the current investigation. These considerations are critical and necessary to examine for future studies.

Clinical Implications

As stated on the IM website (IM, 2012), reading educators and speech-language pathologists are using IM training solely or as an adjuvant to a language/reading intervention to improve a child's reading achievement. There is a great need for intervention research that clearly demonstrates the efficacy and effectiveness of IM training for improving reading in different populations. The results of this current investigation can be viewed only as a first step involving IM as a complimentary treatment to improve reading fluency and comprehension in children with language and reading impairments.

From a clinical perspective, the preliminary findings of this study highlight the benefits of IM treatment as an adjuvant to a traditional language and reading intervention in school-age children with language and reading impairments. The results of this study are the first to show that children with language and reading impairments who receive IM treatment as part of their intervention make greater gains in their reading fluency (rate) and comprehension than those who do not. However, because of the above-mentioned limitations used in this study, caution should be used in generalizing these results. To demonstrate further the effectiveness of the IM treatment, future studies with larger participant groups are necessary that focus on the long-term benefits of the treatment and the effects of a more intensive treatment extended over a longer time period.

Appendix

Intervention

Language intervention	Instructional strategies	Specific steps
Targeted vocabulary (individual session): Emphasized the use of active engagement, a variety of contexts, repeated opportunities, multisensory activities, and elaborated exposure (Beck, McKeown, & Kucan, 2002).	Ten Tier 2 vocabulary words were selected from the book each week to be targeted for intervention (Beck et al., 2002). Tier 2 vocabulary is defined as those words that are frequently used in a language and in a variety of contexts (Beck et al., 2002). Scaffolding, word maps, visual mapping, and focused stimulation used as strategies to enhance vocabulary learning.	The steps: Friendly definition provided by clinician Syllables and sounds in words discussed Associations and connections among words made Multiple exposures to the target word used in a variety of oral and written contexts Targeted vocabulary used in a variety of oral and written contexts (e.g., responses to questions, making own sentences, story retell, verbalizing, and writing stories).
Phonological awareness intervention (PAI; individual session): Emphasized phonological awareness at the syllable and phoneme level thus supporting language and reading (Torgesen, Otaiba, & Grek, 2005). After and/or during the phoneme level of instruction, the correspondence of the sound and the symbol were used (Gillon, 2004).	Explicit instruction was provided for PAI and followed a developmental sequence (van Kleeck, 1990). A metalinguistic approach was used combining PAI with sound–symbol correspondence and print concepts as part of this treatment regime (Gillon, 2004; Kaderavak & Justice, 2004). Visual and verbal cues were implemented when the child needed additional support.	The task sequence: Segment and blending syllables in monosyllabic words/polysyllabic words Identifying initial, final, and medial sound in monosyllabic words moving to polysyllabic words Manipulating syllables and sounds in words Finally, sound–symbol correspondence tasks by blending, segmenting, and manipulating sounds in words using letter tiles.

(continued)

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Appendix (continued)

Language intervention	Instructional strategies	Specific steps
Narrative retells (small group session): Emphasized narrative retell intervention to recount a complete episode with all of the story elements (e.g., character, setting, initiating event, feeling, plan, planned attempts to resolve the stated problem, results/consequences, and resolutions). Emphasized morphosyntax: preselected grammatical structures and syntax targeted.	The Story Grammar Marker (SGM; Moreau-Rooney & Fidrych, 2002) was used for the narrative retell intervention. The clinician read the book in its entirety and then immediately modeled the narrative retell using the SGM as the visual support. In the following sessions, the participant retold the narrative with the visual support through scaffolding (e.g., questioning, cloze procedure) then later faded (Ukrainetz, 2006). Visual maps, sequenced pictures, graphic organizers, and scrambled stories were employed to extend narrative production (Roth, 2000). Grammatical errors were recast (Weismer & Robertson, 2006).	The sequence: The clinician read the story in its entirety and then modeled the narrative retell using the SGM. Each story contained targeted morphological and narrative goals for each participant. The clinician then read one story component and asked the participant to paraphrase that part of the story. SGM and other supports were used initially and gradually faded. Continued until all story components were included by the client.

Declaration of Conflicting Interests

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Computer-Based Rhythm and Timing Training in Severe, Stroke-Induced Arm Hemiparesis

Synopsis:

This study of two stroke patients with hemipareis shows remarkable functional gains made using IM years after the patients suffered their strokes.

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Computer-Based Rhythm and Timing Training in Severe, Stroke-Induced Arm Hemiparesis

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Valerie Hermann, Stephen J. Page

KEY WORDS
- motor skills
- paresis
- stroke
- therapy, computer-assisted
- upper extremity

OBJECTIVE. We pilot tested the efficacy of computer-based training implementing rhythm and timing in chronic, severe, stroke-induced hemiparesis.

METHOD. Two chronic stroke patients were administered the upper-extremity section of the Fugl-Meyer Impairment Scale (FM), the Arm Motor Ability Test (AMAT), Stroke Impact Scale (SIS), and Canadian Occupational Performance Measure (COPM). We then administered the computer-based intervention for 60 min, 3 days/wk for 4 wk. One week after intervention, we administered the FM, AMAT, COPM, and SIS.

RESULTS. After intervention, participants exhibited reduced arm impairment (indicated by FM scores of +2.0 and +4.0) and increases in average functional ability (+0.85 and +1.1 points on the AMAT), perceived quality of life (+2.0 and +32.0 points on the SIS), and perception of overall recovery (+10.0 points for each participant on the SIS).

CONCLUSION. This study provides preliminary evidence suggesting efficacy of computer-based rhythm and timing in chronic stroke.

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Stroke remains the leading cause of disability in the United States (Rosamond et al., 2008) and the most common diagnosis seen by occupational therapists (National Board for Certification in Occupational Therapy, 2004). Stroke-induced arm hemiparesis is a problem because of its devastating impact on the ability to perform valued activities of daily living (ADLs). Many promising approaches targeting arm hemiparesis require active, distal movement to be efficacious—an ability not exhibited by most stroke survivors.

Because motor performance is mediated by an internal timing mechanism (Buhusi & Meck, 2005; Lewis & Miall, 2006; Mauk & Buonomano, 2004), researchers have reduced impairments using rhythmic auditory signals (Getchell, 2007). One modality using this approach is the Interactive Metronome (IM; Interactive Metronome, Inc., Sunrise, FL), a computer-based version of a traditional metronome, which purports to target motor planning and sequencing by incorporating rhythm and timing during repetitive movements. Using the IM, several authors (e.g., Bartscherer & Dole, 2005) have shown cognitive, attentional, language, and motor changes in children with attention and motor coordination difficulties, including attention deficit hyperactivity disorder and Landau-Kleffner syndrome.

To date, only one study has examined IM effects on functional arm motor skills (Bartscherer & Dole, 2005), and no studies have examined IM efficacy in stroke-induced hemiparesis. Given the need for treatments for severe arm hemiparesis and the relation between affected arm functional use and neuroplasticity, we hypothesized that IM use during occupation-based activities would reduce impairment and increase ADL performance in adults with chronic stroke. This pilot study examined efficacy of the IM approach in 2 participants exhibiting severe, stable arm hemiparesis after stroke.

Method

Participants

Volunteers were recruited using advertisements placed in rehabilitative clinics in the midwestern United States. A research team member screened volunteers using the following inclusion criteria: (1) severe affected arm impairment indicated by an upper-extremity Fugl-Meyer Scale (FM; Fugl-Meyer, Jaasko, Leyman, Olsson, & Steglind, 1975) score of 10–19; (2) stroke experienced <12 mo before study enrollment; (3) a score ≥25 on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975), (4) age ≥21 and <75; (5) had experienced one stroke; and (6) discharged from all forms of physical rehabilitation.

Exclusion criteria were (1) age <21; (2) excessive pain in the affected hand, arm, or shoulder, as measured by a score ≥5 on a 10-point visual analog scale; (3) excessive spasticity in the affected elbow, wrist, or fingers, defined as a score of ≥3 on the Modified Ashworth Spasticity Scale (MAS; Bohannon & Smith, 1987); (4) currently participating in any experimental rehabilitation or drug studies; (5) received botulinum toxin injection to any portion of the affected arm within the past 4 mo or phenol injections <12 mo before study participation; (6) visual neglect or visual field deficit; and (7) absent bilateral or unilateral hearing.

Using these criteria, 2 volunteers were recruited. Before screening and participation, they signed informed consent forms approved by the local institutional review board. Participant 1 was a 68-yr-old African-American man who experienced an ischemic stroke affecting his right side 23 yr before study enrollment. He was left hand dominant. Participant 1 received inpatient physical and occupational therapy for 1 mo, followed by outpatient physical and occupational therapies for an additional 6 mo. At the time of study enrollment, his medications included diltiazem HCl (240 mg), amlodipine (5 mg), atacand (16 mg), atorvastatin (10 mg/day), metformin (500 mg), and fexafenodine (60 mg). His MAS scores were 1 at all affected upper-extremity joints. He lived with his wife at home, where his only other exercise consisted of riding a bicycle ergometer 2–3 days/wk.

Participant 2 was also an African-American man, age 75, who experienced an ischemic stroke affecting his left, nondominant side 2 yr 2 mo, before study enrollment. His medications included azithromycin (250 mg/day), rosuvastatin (10 mg/day), clopidogrel (75 mg/day), montelukast (10 mg/day), and fluticasone and salmeterol oral inhalation (100/50, twice/day). Participant 2 was a community ambulator with an ankle–foot orthosis and walker; he exhibited mild spasticity in his affected arm, as evidenced by MAS scores of 2 in the affected elbow and 1+ in the affected wrist and fingers. He had received approximately 7 wk of inpatient and outpatient therapies and had done nothing more since time of discharge, either at home or in the community.

Apparatus

The PC-based IM System includes the IM control unit, two hand cuffs, a foot trigger, a hand trigger, and headphones (Figure 1). According to IM specifications, the master control unit produces sounds, registers movement, and counts repetitions. The hand trigger is attached to the cuff with a hook-and-loop strap, and the hand trigger transmits data to the control unit. The foot trigger is a mat with transmitters that sends data to the control unit, and the headphones allow the user to hear the auditory output from the control unit (IM). The foot trigger requires considerable force for activation and precise foot placement to make contact with the sensor. Approximate setup for the IM is 10 min.

Outcome Measures

The primary outcome measure was the upper-extremity section of the FM, which assessed changes in arm impairment. Data arise from a 3-point ordinal scale, ranging from 0 = *cannot perform* to 2 = *can perform fully,* that is applied to each item.

Demonstration of changes in motor impairment alone is not sufficient to warrant clinical implementation of a new rehabilitation intervention. Thus, the Arm Motor Activity Test (AMAT; Kopp et al., 1997) was used to determine whether changes occurred in activity limitation. The AMAT is a 13-item test in which ADLs are rated according to a functional ability scale that examines affected limb use (0 = *does not perform with affected arm;* 5 = *does use arm at a level comparable to*

Figure 1. The Interactive Metronome.

unaffected side) and a Quality of Movement Scale (0 = *no movement initiated;* 5 = *normal movement*).

In addition to the participant's ability to actively perform isolated movements and ADLs, we administered the Canadian Occupational Performance Measure (COPM; Law et al., 2000), an interview used to identify occupational performance problems and to measure satisfaction and importance of tasks according to the patient. After questions are asked, clients identify on a scale ranging from 0 to 10 the importance of the task to them, their perception of their performance with skills, and their satisfaction with their performance. Once the top five tasks are determined, they are used to guide the treatment. The test is usually administered at baseline and discharge to determine change in performance and satisfaction. If the number is positive, then there was change for the better. If the number is negative, the person's perception of the skills have declined.

Finally, to determine whether the previously mentioned changes altered quality of life, we administered the Stroke Impact Scale 3.0 (SIS; Duncan, Bode, Min Lai, & Perera, 2003). The instrument is a 59-item self-report measure with items further broken down into eight domains (Strength, Hand Function, ADL, Mobility, Communication, Emotion, Memory, and Social Participation).

Pretesting and Intervention

This study used a pretest–posttest case study design. Specifically, after consent and screening, each participant was individually administered the FM, AMAT, COPM, and SIS by a research team member who was blinded to the intervention to be administered. It took approximately 90 min to administer all measures to each participant.

One week after pretesting concluded, the intervention phase began. Treatment sessions occurred 3 times/wk for 4 wk. Each treatment session lasted 60 min and consisted of approximately 5 min of preparatory stretching exercises, 30 min of IM use, and a combination of purposeful and occupation-based activities for the final 25 min. Purposeful and occupation-based activities focused on participant-determined tasks established by the COPM. The number and duration of activities varied in each session, depending on participant tolerance. Activities included tying shoes bimanually, opening jars, and signing receipts. Each participant was continuously teamed with Sarah C. Beckelhimer, Ann E. Dalton, or Charissa A. Richter in the same lab environment throughout the duration of the study.

IM protocol specifies six phases of treatment, during which participants engage in activities such as clapping hands or tapping feet while trying to synchronize movement with a reference tone. In Phase 1, participants learn the reference tone; in Phase 2, the guide sounds; in Phase 3, timing skills; in Phase 4, advanced timing skills; in Phase 5, focus skills; and in Phase 6, prolonged focus and timing (Interactive Metronome, 2007). Participants in this study advanced through three to five phases within the short duration of the study. They progressed through the phases of IM on the basis of phase transition guidelines provided by Interactive Metronome, such as understanding of the guide and reference tones or improved task average.

Posttesting

One week after the final treatment session, each participant returned to the room at which pretesting had occurred. The same measures administered at pretesting were again administered by the same rater. The examiner was blinded as to whether the participant had been administered any intervention.

Results

During the course of the intervention, the participants expressed no complaints or limitations. Compliance was 100%; they attended all clinical sessions.

Before intervention, the participants exhibited minimal active movement in their paretic arms, indicated with FM scores of 18 and 13 before intervention (Table 1). This score reflected normal reflexes, ability to partially or fully complete all FM shoulder items, and ability to actively move the affected elbow to varying degrees. After intervention, both participants showed improvement in FM total scores, specifically in grasping, pronation, and supination.

Both participants also demonstrated increased ability to perform laboratory-based ADLs using the affected arm, as measured by the AMAT. Specifically, at posttesting, participants showed increases in average functional ability scores (see Table 1). The most notable changes occurred for test items such as "placing paretic arm in shirt sleeve" and "inserting arms in t-shirt."

We used the SIS to measure participants' perceived quality of life after stroke. Both participants' domain scores increased; Participant 2's domain score increased by 32.0 points (Table 2). Changes in recovery scores were +10.0 points for both participants.

Table 1. Arm Motor Fugl-Meyer (FM) and Arm Motor Ability Test (AMAT) Average Functional Ability Pretest and Posttest Scores

Test and Participant No.	Pretest Score	Posttest Score	Change
Arm Motor FM			
1	18	22	4.0
2	13	15	2.0
AMAT average functional ability			
1	1.05	2.15	1.1
2	0.8	1.65	0.85

Table 2. Stroke Impact Scale Domain and Recovery Pretest and Posttest Scores

	Domain Score			Recovery Score		
Participant	Pretest	Posttest	Change	Pretest	Posttest	Change
1	258	260	2.0	40	50	10.0
2	197	229	32.0	30	40	10.0

Table 3. Canadian Occupational Performance Measure Pretest and Posttest Performance and Satisfaction Scores

Participant	Performance			Satisfaction		
	Pretest	Posttest	Change	Pretest	Posttest	Change
1	2.5	5.5	3.0	3.5	5.5	2.0
2	3.8	7.2	3.4	3.8	8.2	4.4

The COPM assessed participants' perceived performance ability and satisfaction with meaningful occupations. Perceived performance and satisfaction scores increased (Table 3). Participant 1 was able to identify only two COPM objectives. His initial performance scores were 2 for bimanually tying shoes and 3 for reaching objects; those scores increased to 5 and 6 at posttesting. In addition, his satisfaction scores for these tasks were 3 and 4 and increased to 5 and 6 at posttesting.

Participant 2's initial performance scores were 1 for taking off jar lids, 5 for stair mobility, 4 for making the bed, 3 for bimanually tying shoes, and 6 for standing in the shower. He exhibited performance score increases of from 2 to 6 points. His satisfaction with his ability to perform these tasks ranged from 1 to 6 points initially and increased to 7 to 9 points at posttesting.

Discussion

Despite its increasing pervasiveness and disabling impact, few treatments reduce stroke-induced hemiparesis. Moreover, most regimens require some active movement at the affected wrists and fingers—a prerequisite that excludes most stroke patients. In response to those shortfalls, the current study piloted the IM to examine its impact on active affected arm movement and quality of life in stroke patients exhibiting severe hemiparesis.

The participants demonstrated minimal isolated movement in their affected arms at pretesting, and they substantially increased movement after intervention, reflected in their FM scores. FM increases were comparable to isolated movement changes observed in a 2005 case study using the IM (Bartscherer & Dole, 2005), in which a child with motor and attention deficits made significant improvements in visual–motor control and upper-limb strength and dexterity, as measured by a pediatric motor skills test (Bruininks–Oseretsky Test of Motor Proficiency; Bruininks & Bruininks, 2005). Although the Bruininks–Oseretsky Test is used to measure motor skills in pediatric populations, certain items that showed change on that measure are comparable to FM items that showed change in the current study.

Other devices targeting the stroke-affected arm have included the IMT InMotion2 and InMotion3 (Interactive Motion Technologies, Boston, MA), and Motorika Reo Go (Motorika, Birmingham, AL). Although some of them have evidence supporting their promise in severely impaired stroke, all are large-platform systems and incorporate force transducers and visual feedback by means of therapycentric videogames to provide the patient with full to partial upper-extremity assistance. Moreover, the devices do not provide patients with the ability to practice ADLs when they are working with a therapist—a prerequisite for Medicare reimbursement. FM changes in this study were comparable to those shown in previous work involving robotics in severe stroke (Housman, Scott, & Reinkesmeyer, 2009). Unlike the previous studies, however, the current study required little specialized machinery, low expense, and minimal therapist interaction. Thus, our data suggest that IM may be an equally efficacious, lower cost solution to platform-based robotics in treating affected arm impairment in severe stroke.

Both participants demonstrated increased AMAT scores, and Participant 2 showed a 32-point score increase on total domain score (Table 2), demonstrating clinically meaningful change (Duncan et al., 1999). However, those changes did not translate to clinically meaningful change on the SIS for Participant 1 (defined as a ≥10-point change on the domain score). Although SIS scores did not indicate clinically significant change for both participants, subjective reports given by participants during the SIS posttesting session indicated improved perception of function. For example, Participant 1 noted change by saying, "This is the first time I've tied my shoes in 27 years." Participants 1 and 2 also reported increased attentiveness during daily tasks, and Participant 1 noted, "I feel sharper for sure."

Participants 1 and 2 exhibited marked improvement in their overall recovery, as shown by the SIS overall score. Results of this assessment were consistent with an 8-wk study on rhythmic auditory stimulation for chronic stroke by Jeong and Kim (2007). As in the current study, the authors reported that a small sample size may have prevented the results from being significant.

Both participants also demonstrated clinically significant COPM score improvement, which is typically defined as a ≥2 point increase from pretest to posttest (Law et al., 1998). Participants identified initial difficulties in the areas of home management and self-care, similar to a study by Phipps and Richardson (2007), which found that stroke patients receiving outpatient occupational therapy after right-hemisphere stroke were most likely to identify self-care and home management goals on the COPM. After intervention, both participants reported increased performance in and satisfaction with daily tasks. Changes observed were comparable to changes in the Phipps and Richardson study and those in a case study by Hill Hermann et al. (2008).

Study Limitations

The change in COPM scores represents a significant increase in participants' perceived performance and satisfaction with performance for meaningful activities. Holliday, Ballinger, and Playford (2007) noted that use of client-driven goals in neurological rehabilitation led to increased understanding and greater commitment to the treatment protocol. Because participants set their own objectives for treatment, it is possible that they became more invested in their recovery as a part of this study. The primary study limitation was a small sample size, although this was understandable, given that the goal was to examine IM feasibility in the stroke population.

Conclusion

Given our promising findings, future research not only should attempt to replicate the effects herein described with a larger sample but also should use qualitative measures to better understand whether Holliday and colleagues (2007) were accurate in their assertion. Given the magnitude of treatment effects observed and the variety of domains in which motor changes were observed, it is unlikely that treatment effects were simply caused by the attention that participants received from study participation. Nonetheless, controlled methods in future work would allow for adequate monitoring of this effect. ▲

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Effects of motor sequence training on attentional performance in ADHD children

Synopsis:

This study addresses the lack of motor coordination in ADHD children and suggests that going through IM training would have a significant effect on improving focus in ADHD children.

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Effects of motor sequence training on attentional performance in ADHD children

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Abstract

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

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

Introduction

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

Attention-deficit/hyperactivity disorder

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

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

Motor sequencing training

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

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

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

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

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

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

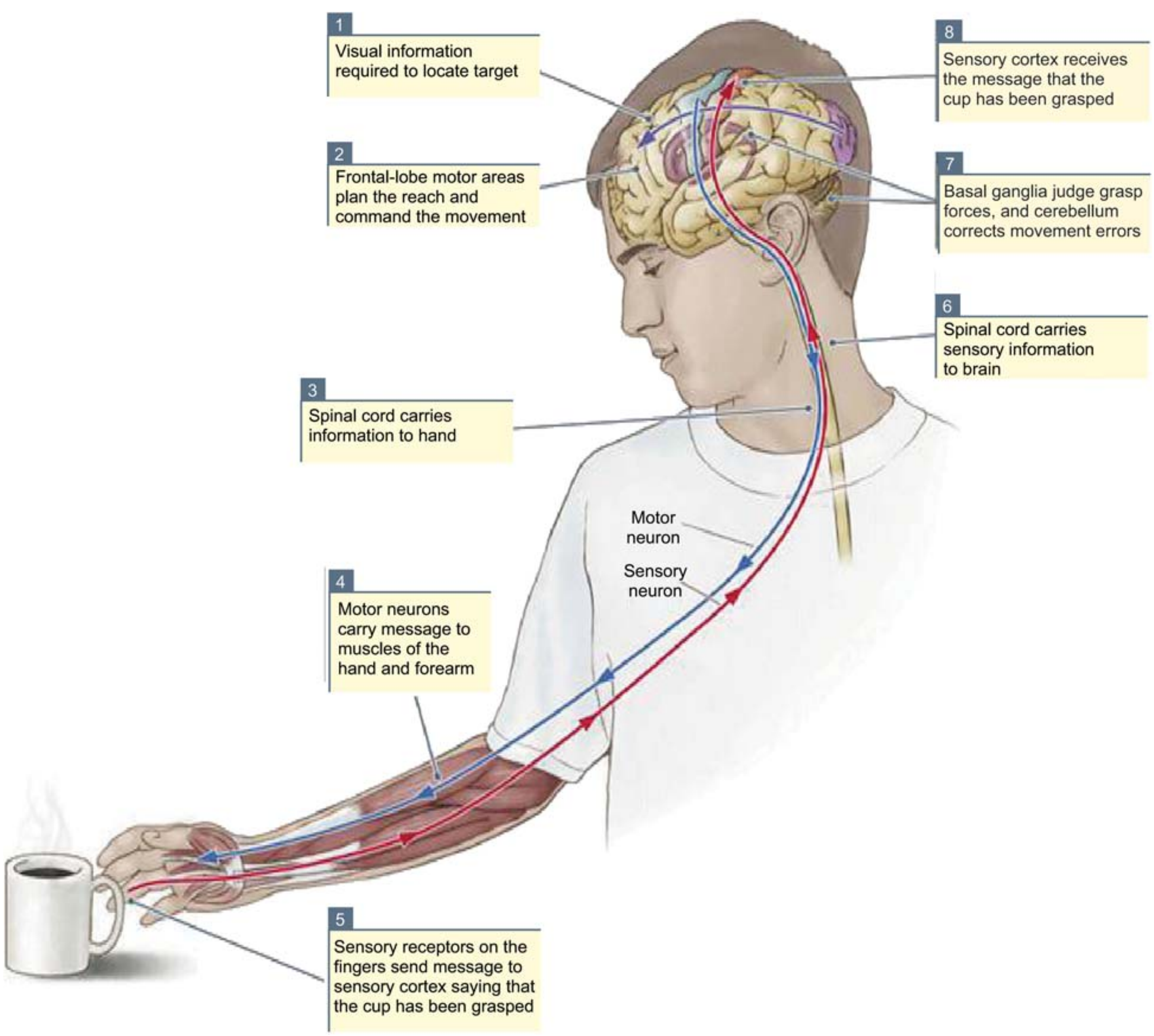

Figure 1 The system of motor planning with feedback.

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

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

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

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

Signal detection theory

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

Table 1 Common symptoms of cerebellar dysfunction.

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

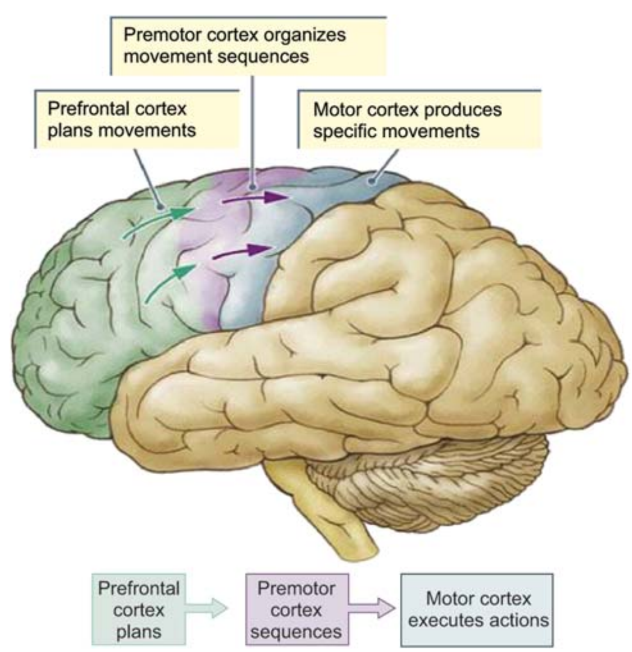

Figure 2 Cortical basis for motor sequences and planning.

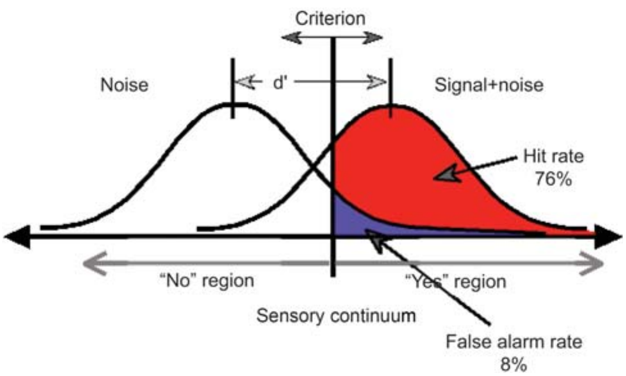

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Figure 3 Signal detection theory.

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

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

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

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

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

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

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

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

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

Table 2A Four possible outcomes of signal detection.

Q2:
Please check that the layout of Table 2 is acceptable

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

2B

	"Yes"	"No"
SN	0.76	0.24
	0.08	0.92

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

Methods

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

Procedure

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

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

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

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

Table 3 Motor sequencing training signal detection study participants.

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

Results

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

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

Discussion

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

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

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

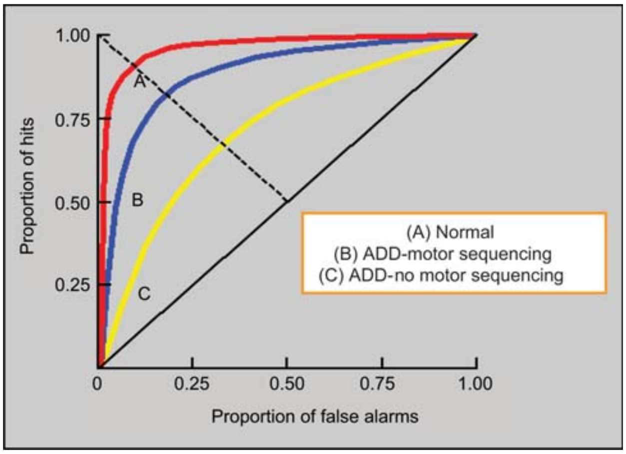

Figure 4 ROC analysis of motor sequencing feedback program subjects.

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

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

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

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

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

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

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

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

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Improved motor-timing: effects of synchronized metronome training on golf shot accuracy

Synopsis:

This European study is an independent recreation of earlier IM research studying golfers. This new study showed the same results: working with IM's timing exercises improves golfers' control of their swing and improves shot accuracy.

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Research article

Improved motor-timing: effects of synchronized metronome training on golf shot accuracy

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Abstract
This study investigates the effect of synchronized metronome training (SMT) on motor timing and how this training might affect golf shot accuracy. Twenty-six experienced male golfers participated (mean age 27 years; mean golf handicap 12.6) in this study. Pre- and post-test investigations of golf shots made by three different clubs were conducted by use of a golf simulator. The golfers were randomized into two groups: a SMT group and a Control group. After the pre-test, the golfers in the SMT group completed a 4-week SMT program designed to improve their motor timing, the golfers in the Control group were merely training their golf-swings during the same time period. No differences between the two groups were found from the pre-test outcomes, either for motor timing scores or for golf shot accuracy. However, the post-test results after the 4-weeks SMT showed evident motor timing improvements. Additionally, significant improvements for golf shot accuracy were found for the SMT group and with less variability in their performance. No such improvements were found for the golfers in the Control group. As with previous studies that used a SMT program, this study's results provide further evidence that motor timing can be improved by SMT and that such timing improvement also improves golf accuracy.

Key words: Golf accuracy, motor timing, golf shot variability, metronome training.

Introduction

A successful golf stroke is obviously a very complex motor action, that requires precise coordination and control of numerous of muscles and sensors guided by the underlying timing centres in the brain. Timing includes observing, controlling, and differentiating the rhythm of a specific motor action depending on the situational demands (Martin, 1988). Moreover, timing is described to be an important factor in learning, development, and performance of any motor skills, and golf players and instructors (e.g., Pelz and Frank, 1999) have a long time believe that timing is a key attribute in performing the optimal golf shot. Thus, given the focus of importance of timing in the golf literature, and by golfers, it is surprising to find so few empirical-based studies investigating the timing properties of the golf swing and how timing training may affect the actual golf accuracy.

Several studies have drawn the conclusion that timing is critical in the generation of coordinated motor actions (Ivry, 1996; Mauk and Ruiz, 1992; Meegan et al., 2000; Medina et al., 2005) such as the golf swing. Motor planning requires a combination of attention, sensory integration, synchronisation, and timing (Baht and Sanes, 1998), and because movements involve changes in muscle length over time (Mauk and Buomonano, 2004), motor control and timing are inextricably related. When examining the commercial golf literature (e.g., GolfDigest and Golf Magazine) there are numerous testimonies regarding the importance of timing and as many definitions of what a well-timed golf shot involves. However, findings by Neal et al. (2008) suggest that there is no correlation between golfers' own classification of a well-timed shot and the temporal properties of their golf swing. Thus, this indicates that timing is a complex concept, not only in terms of definition, but also for the individual golfer to embrace and comprehend.

Libkuman et al. (2002) have reported that training by means of timing and rhythmicity leads to improvement in golf shot accuracy. For instance, they found that golfers after receiving just 10 hours of timing training over a 4-week period significantly improved their golf shot accuracy. These results indicate that training per se may not simply have to be golf-specific to affect and enhance our underlying control of the planned and ongoing sequential, integrated actions necessary to perform an optimal golf swing. In line with this view, Jagacinski et al. (1997) have reported evidence that the age-related decline found in golf performance may be explained by the differences found in the timing abilities between young and older adult golfers.

Using observations made of the neural basis and dynamics of rhythmic timing, researchers have noted that auditory rhythms rapidly entrain motor responses into stable steady synchronization states (Thaut, 2003). Accordingly, Meegan et al. (2000) found that training on a perceptual task, using enhanced representation of a particular temporal interval induced by auditory training significantly was transferred to a motor task. This implies that motor learning can occur even without any motor activity. Thus, one interpretation of these findings is that it may be possible to affect and/or improve the underlying, unconscious timing control of actions without any sport-specific training, a type of training that may improve motor output integrated in a sport performance.

Most complex movement skills involve synchrony between physical and cognitive activation and functioning. For instance, to optimize the outcomes of different sport activities (e.g., when playing football or performing a golf swing), dynamic processing and integration between attention/concentration, motor planning, sensory-motor coordination, timing, mental organization, and sequencing are required. Recent findings from synchronized metronome based intervention have reported bene-

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fits across many diverse domains of human performance as well as in rehabilitation of different clinical conditions. For instance, such improvements have been found for reading achievement and academic performance in school children (Taube, et al., 2007), and by means of improved attention, motor control, and behaviour regulation in children with ADHD (Shaffer, et al., 2001). Synchronized metronome training (SMT) and/or similar timing training methods may also benefit diverse sport performance (Libkuman et al., 2002; Zachopoulou et al., 2000). However, evidence-based studies of timing training effects on different sport performance are still very limited. Consequently, such documented observations are in great need of further scientific evaluations.

Thus, the purpose of this study was two-folded; first, to investigate whether 4-weeks of timing and rhythmicity training by means of SMT improves motor timing and second; to investigate whether such effects of SMT influence golf shot accuracy of experienced golfers.

Methods

The preset inclusion criteria for this study were healthy male golfers between 20-40 years of age, and with a golf handicap (hcp) between 0-20. For all included golfers, the start off of this study (in January) was approximately 3 months after the end of the local golf season.

Participants

A total of twenty-six experienced male golfers participated in this study. Their age and handicap (hcp) ranged between 20 and 37.1 years (mean 27.7), and 4.4 to 19.8 hcp (mean 12.6) respectively. After completing the pre-test, the golfers were randomly assigned to either an SMT or a Control group. The two groups did not differ significantly on any background or golf pre-test variables except for years of golf experience (t (24) = -2.877, $p < 0.05$). (See Table 1 for background description).

Table 1. Participants' mean age, golf handicap and years of experience (± SD).

Group	N	Age (yrs)	Handicap	Experience
SMT	13	27.5 (4.6)	12.7 (5.0)	10.9 (4.8)
Control	13	27.7 (5.3)	12.3 (4.8)	7.3 (4.1)

Apparatus

Pre- and post-test golf precision measures were established in a P3ProSwing Golf Simulator located in a 5 m × 5 m × 3.5 m golf lab at Umeå University (Figure 1). The participants typically execute a full swing and hit a real golf ball that will travel approximately 3 m before hitting a screen. The screen displays the fairway, on which the ball is positioned, as well as the green and the hole with a pin and a flag. A visual ball path trajectory line of the golf ball's flight to the final position is instantly projected on the screen as the player makes his shot.

The ball is shot from a 22.9 cm x 35.6 cm sensing platform with 1.5 cm high artificial grass on top. The platform contains 65 optical sensors that capture information about the speed and direction of the club head at ball impact. The simulator estimates the distance and direction for each shot. According to the manufacturer (P3ProSwing, Sports Vision Technologies, California, USA), the simulator accurately monitors ball flight with 99% precision. Before this study, a number of golf shots performed in the P3ProSwing golf simulator were simultaneously measured by an Optoelectronic registration system (ProReflex, Qualisys Inc., Gothenburg, Sweden) by means of the club head velocity and angle at ball impact and compared with the P3ProSwing data. Outcomes from five different clubs (9-Iron, 4-Iron, Pitching Wedge, Driver and Putter) and in total 30 golf shots were analysed and compared. There was a high significant correlation between the two outcomes measures (overall r = 0.97). The mean velocity differences (km/h) between the two measurements were small, although consistently somewhat slower (both over repeated trials and clubs) for P3ProSwing (mean vel diff = -4.4, -4.2, -3.9, -7.4 and -0.4 km/h, respectively) in comparison to ProReflex outcomes. Similar correlations (overall r = 0.82) and differences were found for the club angle at ball impact (mean diff = 0.3, 0.23, 1.39, 0.89, 1.45 degree) for respective clubs between the two systems. Thus, we considered the outcome measures from the P3Pro simulator to be both valid and consistent.

Figure 1. Photo of the Golf simulator set-up.

For each golf shot, accuracy was measured using the distance (in meters) between the golf ball's final resting place and the pin (Absolute Error). Accuracy was also measured in terms of direction and distance accuracy as well as performance variability (Figure 2). In addition, the club head speed (tangential velocity) at ball impact was analysed. All scores were averaged over 20 trials for each club and each participant.

The Interactive Metronome (IM) ® system assessed all participants' (SMT and Control group) timing and rhythmic skills at pre- and post-test and as training intervention for the SMT group. The IM is a computer program for Windows based on the traditional music metronome that attempts to improve and maintain timing and rhythmicity. It is set up with standard stereo headphones and a set of contact-sensing triggers, including a hand glove and a flat plastic footpad. The participants are required to perform uni- and bilateral, rhythmic hand/arm and leg/foot movements in conjunction with a computer-generated reference beat, heard through headphones (Figure 3).

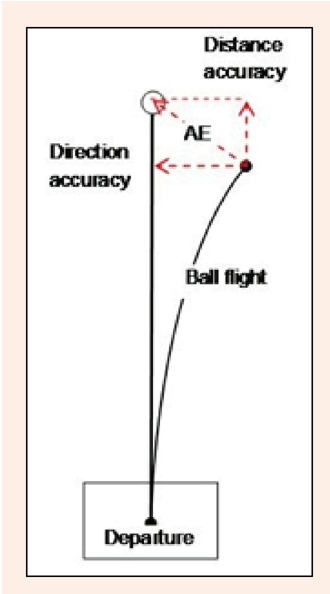

Figure 2. Schematic illustration of Golf performance accuracy measuring, illustrating distance and direction accuracy and the absolute error (AE).

The IM system generates scores on three dependent measures; namely the mean millisecond discrepancy between the participant's responses and the reference beat (timing skills), the variability average that is a measure of how close each hit is timed to the previous hit (rhythmic skills), and finally the highest number of times in-a-row that the participant is able to stay within ±15 ms of the reference beat (reflecting degree of stability in performance). A high timing score indicates a larger millisecond discrepancy between the metronome beat and the participant's movements, a score that indicates less accurate timing. Thus, lower timing scores signify better timing.

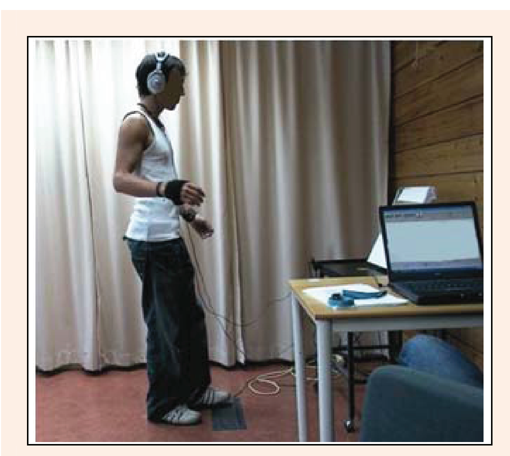

Figure 3. Photo of the IM training set-up.

Procedures

First, at the pre-test occasion the participants received an explanation of the experiment protocol and provided informed consent before testing, thus, in accordance with the ethical standards specified in the Helsinki Declaration. They received 500 SEK (70 USD) for taking part in the study. Additionally, to increase the ecological validity, they were competing for a 1000 SEK (140 USD) bonus prize, information every participant received at the first pre-test occasion. All participants used their own clubs.

At the time of the golf pre-test, the participants began by setting the distance from the ball (fairway) to the pin. It was emphasized that they should choose a distance from the pin that was, with some margin, within the reach of their shot with each club (4-Iron, 7-Iron and Pitching Wedge, respectively). They were informed that the same distances, with the same clubs, and under the same conditions would apply for the post-test. Before the pre-test measurement started, they could take up to five practice shots with each club to familiarize themselves to the new surface and the artificial environment. At the start of the measurement, the participants were instructed to aim for the pin and to proceed at their own pace. All golfers performed 20 test shots with each club (60 in total) in a counterbalanced randomized block design. The same procedure was used during post-test.

The purpose of the IM pre- and post-test test was to assess the participant's timing and rhythmic skills. The test is a standardized assessment developed by the instrument manufacturer, consisting of 14 different tasks, involving uni- and bi-manual hand and feet actions (Interactive Metronome, 2008). In addition, the optional Attend Over Time (AOT) test, which challenges the participant to clap both hands in synchrony with the reference beat for 10 consecutive minutes, were distributed as part of pre- and post-testing. The AOT test assesses the participants' ability to attend selectively to a stimulus without being burdened by internal thoughts or external distractions for extended periods. At the start of the test, the experimenter attached the handsensor to the participant's hand, and placed the headphones properly on the head. Before each of the tasks included in the test the participants were shown a video modelling the appropriate movements. The IM pre-and post-test took about 20 minutes to complete. The tempo of the metronome was set at 54 beats per minute (bpm) for all tasks during both tests.

Intervention

The SMT group received 12 training sessions of IM training, distributed on three 45-50 min sessions a week over a 4-week period after the post-test. The IM training was accomplished individually, and a certified IM provider was present for all sessions, monitoring the participants' activities, modelling proper actions and correcting any technical problems. During training sessions, the IM system instantaneously transposes the timing information into discriminative, temporally based guide sounds presented in the participant's headphones, continually indicating whether the participant was on target, early, or late. Guide sounds were not present during pre- and post-test. An early contact (i.e., a contact that precedes the beat) generates a low pitch tone in the user's left ear. A late contact (i.e., a contact that follows the beat) generates a higher pitch tone in the right ear. A contact that matches the beat within ±15 ms generates a higher pitched tone in the centre of the headphones and is simultaneously perceived in both ears. These instantaneous guide sounds enable the participant to correct deliberately their timing errors as they occur (for further details of the IM devise, see Libkuman et al., 2002; Taube et al., 2007). The participants would typically perform 4-10 successive tasks involving use of hands and feet in uni- and bi-lateral manners in synchrony with the metronome reference beat that was set at 54 bpm for all tasks during the first seven sessions. From session number eight several new tasks and reference beat tempos (45, 66, and 78 bmp) were introduced: clapping hands while standing on a balance-board, hitting wall-mounted sensors with hands crossing body midline, clapping hands behind back, and tapping footpad crossing body midline. At the completion of training, participants typically have engaged in approximately 27,000 motor repetitions. After each training session, the participants were shown their scores, meant to work as a motivating feedback for future performance enhancement. The purpose of the training was twofold: to improve the participants' motor timing and rhythmic skill and to improve their ability to attend selectively to a stimulus for extended periods.

Due to the off-golf-season, the participants in the Control group were allowed to maintain some aspect of golf activity by performing golf swings in a commercial swing training device (Explanar Trainer®). These golfers performed in total eight 20 minute sessions with the Explanar Trainer ® distributed on two sessions a week, during a four week period between pre- and post-test. The purpose of this training was twofold; first to keep the golfers motivated to participate in the study, second; to be able to control the amount of golf-activity amongst the participants in the control group. All golfers, independent of group belonging, agreed not to take part of any other golf activity during the period between the pre- and post-test.

Data and statistical analysis

From the pre- and post-test outcome data of timing and rhythmic skills (IM tasks) for each golfer, we analyzed the task average (deviation from reference beat) and the variability average, which is the measure of how close each hit is timed to the previous hit (reflecting the degree of rhythmic skill). Additionally, the highest number of times in-a-row (IARs) that the golfer was able to stay within ±15 ms of the reference beat, and the attention over time (AOT) scores were analyzed to map any possible changes in attention skills. To further investigate possible pre- to post-test improvements from the IM tasks, statistical differences were analysed by performing a mixed ANOVA with group (Control, SMT) as between-subject factors and test (pre-, post-test) as within-subject factors, using repeated measurement on dependent measures. For analysing possible differences between groups, tests, and possible interactions regarding the pre- and post-test outcome data from the golf shots (made in the golf simulator), all accuracy records (Absolute Error, Distance and Direction Error, and Variability in performance) were further analysed by separate mixed ANOVAs with use of repeated measures. Additionally, as the participants set the distance from the ball (fairway) to the pin individually, we divided the golfers into two sub-groups; low (< 10.9) and high (> 10.9) hcp golfers (resulting in 6 high hcp- and 7 low hcp golfers in respective group) to analyse possible effects of golf handicap on self selected distance between ball and pin. *Scheffe's* post hoc test was used on all significant effects, and the pre set *alpha* level was 0.05.

Results

For Task Average, a 2 (group: SMT and Control) × 2 (test: pre- and post-test) ANOVA revealed no main effect for group; $F(1, 24) = 3.1$, $p = 0.09$. However, a significant effect of test; $F(1, 24) = 37.2$, $p < 0.0001$, as well as a significant interaction between group and test; $F(1, 24) = 25.3$, $p < 0.0001$, was found. The post-hoc comparisons showed that only the SMT group differed significantly ($p < 0.001$) between pre-and post-test scores (Figure 4).

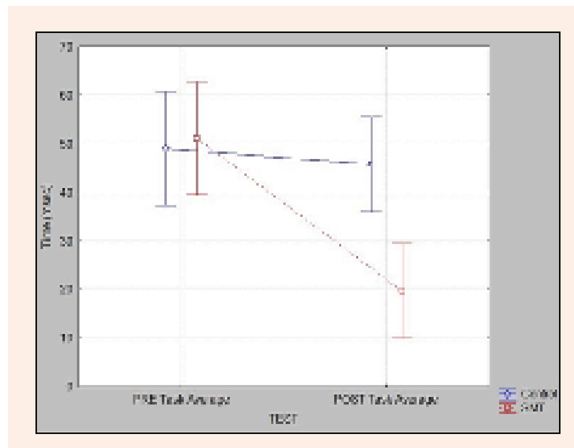

Figure 4. Timing deviation (task average) from reference beat as a function of group and test.

For Task Variability, the ANOVA revealed no main effect for group; $F(1, 24) = 3.06$, $p = 0.09$, however, a significant effect of test; $F(1, 24) = 91.39$, $p < 0.0001$, as well as a significant interaction between group and test; $F(1, 24) = 29.85$, $p < 0.0001$, was found. In agreement with the findings from Task Average, the post-hoc comparisons showed that only the SMT group differed significantly ($p < 0.01$) between pre-and post-test scores (Figure 5).

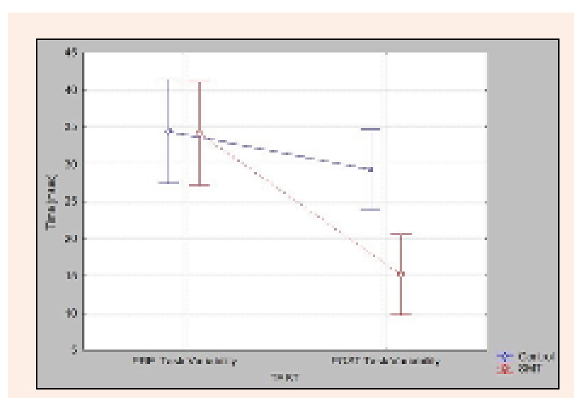

Figure 5. Task variability of timing (average) as a function of group and test.

For AOT, the ANOVA revealed a significant main effect of group; F (1, 24) = 6.54, $p < 0.05$, as well as of test; F (1, 24) = 13.1, p = 0.01. Additionally, a significant interaction between group and test; F (1, 24) = 35.60, $p < 0.001$, was found. The post-hoc comparisons showed that the SMT group significantly differed ($p < 0.001$) between pre-and post-test scores for AOT; in addition, a significant difference ($p < 0.05$) between the SMT and the Control group for the post-test scores was found (Figure 6).

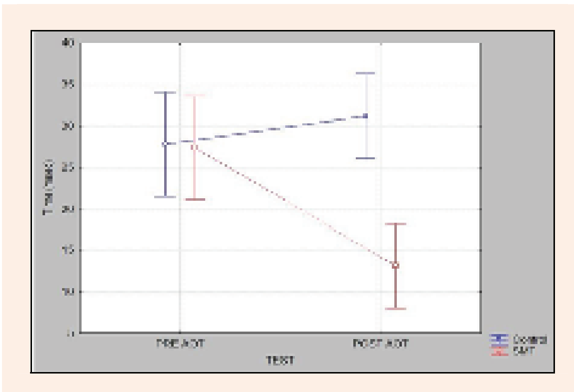

Figure 6. Timing deviation from the reference beat (AOT test), as a function of group and test.

For IAR, the ANOVA revealed a significant main effect of test; F (1, 24) = 34.14, $p < 0.001$, and group; F (1, 24) = 9.78, $p < 0.001$. Furthermore, a significant interaction between group and test; F (1, 24) = 19.81, $p < 0.001$, was found. The post-hoc comparisons revealed that the SMT group significantly differed ($p < 0.001$) between pre- and post-test scores for number of IARs, in addition, a significant difference ($p < 0.01$) between the SMT and the Control group for the post-test scores was found (Figure 7).

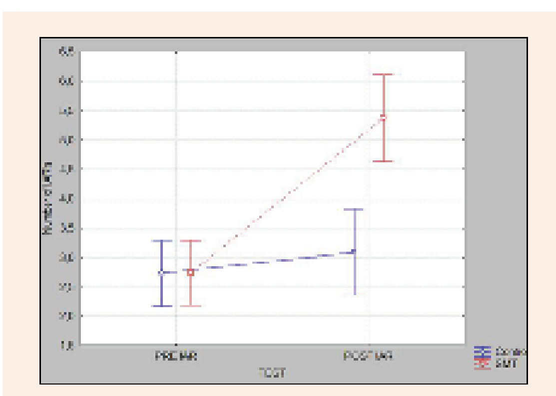

Figure 7. Highest number of time-in-a-row within ±15 ms of the reference beat (IAR's), as a function of group and test.

Golf accuracy

As each participant set their own distance from the ball (fairway) to the pin, based on their individual judgement on what was the reach of the shot with each club (4-Iron, 7- Iron and Pitching Wedge, respectively), a 2 (group: SMT and Control) x 2 (Handicap: High and Low) x 3 (Clubs) MANOVA, with group and handicap as between factors and clubs as a within factor and with repeated measures over the last factor, was initially conducted. Thus, to investigate the existence of possible group differences in relation to handicap level and the distance chosen between fairway and the pin. No main effect of group F (1, 22) = 0.52, p = 0.48, or handicap; F (1, 22) = 2.28, p = 0.15, was found. However, as expected a significant main effect of clubs; F (2, 44) = 615.5, p = < 0.001, was evident. Independently of group and handicap, the mean distance chosen for respective clubs was 175 m for the 4-Iron; 152 m for the 7-Iron; and 115 m for the Pitching Wedge. No significant Group x Handicap (p = 0.39); Group x Clubs (p = 0.48), or Group x Handicap x Clubs (p = 0.35), interactions were found.

Accuracy (Absolute Error): To control for possible training effects associated to repeated trials (golf shots) during the pre- and post-test sessions, data analysis was conducted by splitting respective test-sessions into two blocks. Each block (block 1: trial 1-30 and block 2: trial 31-60) includes the composite mean absolute error for 10 shots with each of the three clubs. The outcome illustrated by Figure 8 does not depict any learning effects of repeated golf trials, either for groups or tests. Thus, no overall training effects between the first 30 trials in comparison to the last 30 trials of golf shots for respective group or test were found (Figure 8).

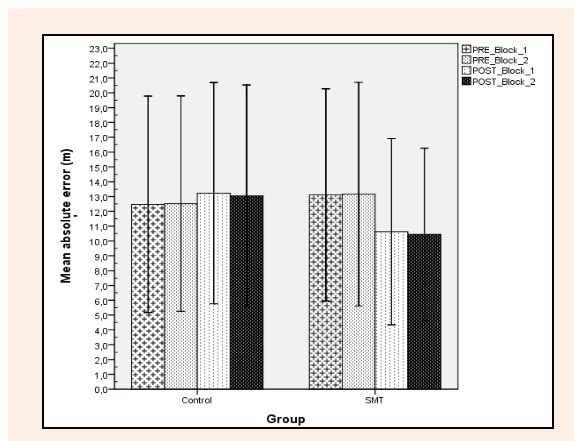

Figure 8. Absolute error as a function of groups, tests, and the two blocks (Block 1: trial 1-30; Block 2: trial 31-60).

A 2 (group: SMT and Control) × 2 (test: pre- and post-test) x 3 (club: 4-Iron, 7-Iron and Pitching Wedge) mixed-design ANOVA revealed no significant main effect of group; F (1, 24) = 0.99, p = 0.33. However, a main effect of test; F (1, 24) = 4.35, $p < 0.05$, as well as a main effect of clubs; F (2, 23) = 34.68, $p < 0.0001$, was found. The post-hoc test revealed that the absolute error by the Pitching Wedge (9.7 m) was found to be significantly shorter ($p < 0.01$) than the absolute error by the 7-Iron (13.2 m) and the 4-Iron (14.5 m), respectively. Furthermore, a significant Group × Test interaction was found; F (1, 24) = 12.03, $p < 0.01$ (Figure 9).

The post-hoc comparisons showed a significant ($p < 0.01$) difference between the pre- to post-test for the SMT group by means of an overall increasing accuracy (decreasing distance to the pin) at the post-test in comparison to the pre-rest. Such improvement was not found for the Control group. In addition, the improvement

Table 2. Pre- and Post-test mean accuracy (absolute error) in meters, as a function of group and club (± SD).

	Club							
	PW		7 Iron		4 Iron		Overall	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
SMT	10.1 (3.6)	7.7 (1.7) *	14.4 (3.8)	11.4 (1.8) †	15.0 (4.4)	12.5 (2.8)	13.1 (3.1)	10.5 (1.5) *
Control	9.0 (2.9)	10.0 (3.0)	13.6 (3.6)	13.6 (4.5)	14.9 (3.8)	16.0 (4.7)	12.5 (2.9)	13.1 (3.3)

* and † denote $p < 0.05$ and $p < 0.01$ respectively compared with pre.

showed by the SMT group by means of a decreasing distance to the pin was found to be consistent over all clubs (Table 2). No other significant interactions were found.

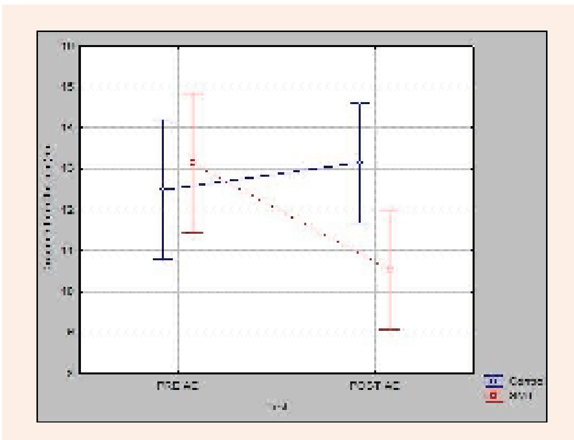

Figure 9. The overall distance from the pin (AE) as a function of group and test.

As the number of years of experience differed between the two groups, a mixed-design ANCOVA was further conducted (on AE) using experience (number of years) as a covariate. The ANCOVA revealed no main effects of group; $F(1, 23) = 0.54$, $p = 0.47$, or test; $F(1, 23) = 0.056$, $p = 0.81$. However, the Group x Test interaction was still found to be significant; $F(1, 23) = 8.29$, $p < 0.01$. Thus, this finding confirmed the result from the previous analysis. Consequently, golf experience does not explain the outcome differences between the SMT- and Control group found at the post-test.

Accuracy in distance and direction: In terms of Distance, a 2 (group: SMT and Control) × 2 (test: pre- and post-test) ANOVA revealed no significant main effect of group; $F(1, 24) = 0.003$, $p = 0.96$. However, a main effect of test; $F(1, 24) = 4.96$, $p < 0.05$, but no Group × Test interaction; $F(1, 24) = 2.65$, $p = 0.11$, was found. The post-hoc comparisons revealed that the improvement between pre- and post-test was only evident ($p < 0.05$) for the SMT group (Table 3).

For the Direction measure, the ANOVA revealed no significant main effects of group; $F(1, 24) = 1.23$, $p = 0.28$, or test; $F(1, 24) = 0.96$, $p = 0.34$. However, a significant Group × Test interaction was evident; $F(1, 24) = 6.35$, $p < 0.05$. In agreement with the outcome from the distance, the post-hoc comparisons revealed that the direction improvement between pre-post-tests was only evident ($p < 0.05$) for the SMT group (Table 3).

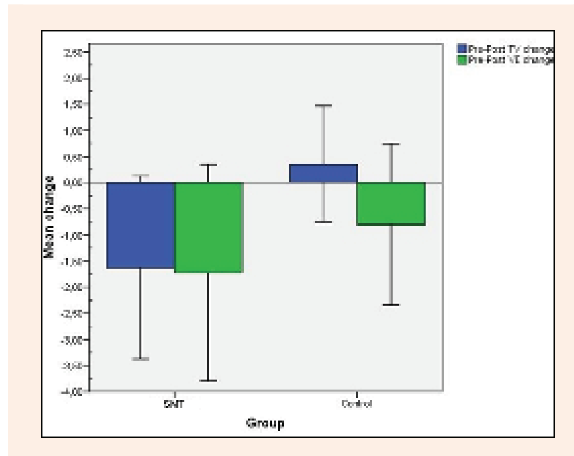

Figure 10. Mean Variable Error (VE) and Target Variability (TV) change from pre- to post-test, as a function of group (positive numbers denotes a decline in performance).

Variability in accuracy: As variability is a major challenge for the golfer, Total Variability (TV) and Variable Error (VE) were analysed. TV (root-mean-square error) is a measure of the participant's total spread about the target, representing an overall measure of how successful the subject was in achieving the target. VE denotes the variability of the participant's deviation from his own mean, representing the variability or inconsistency in the golf shots. A 2 (group: SMT and Control) × 2 (test: pre- and post-test) mixed design ANOVA on the TV measure revealed no main effect of group; $F(1, 24) = 0.461$, $p = 0.50$, but a main effect of test; $F(1, 24) = 4.92$, $p < 0.05$, was found. Furthermore, a Group × Test interaction was evident; $F(1, 24) = 11.75$, $p < 0.01$. The post-hoc comparisons revealed that the SMT group significantly differed ($p < 0.01$) between pre-and post-test scores for TV by means of an overall decreasing variability at the post-test in comparison to the pre-test. Such improvement was not found for the Control group (Figure 10). For the VE measure, the ANOVA revealed no main effect of group; $F(1, 24) = 0.002$, $p = 0.96$, but a main effect of test; $F(1, 24) = 12.43$, $p < 0.01$, was found. In agreement with the outcome from TV, the post-hoc comparisons

Table 3. Pre- and Post-test mean overall distance from the pin (in meters) as s function of distance, direction and group (± SD).

	Overall distance		Overall direction	
	Pre	Post	Pre	Post
SMT	6.23 (1.85)	5.18 (1.03)	10.25 (2.90)	8.65 (1.68)
Control	5.81 (1.71)	5.67 (2.04)	10.08 (2.53)	10.79 (2.87)

showed a significant ($p < 0.05$) difference between the pre- to post-test for the SMT group only, by means of an overall decreasing variability at the post-test in comparison to the pre-rest. However, no Group × Test interaction was found: $F(1, 24) = 1.67$, $p = 0.21$ (Figure 10).

Individual golf accuracy improvement: In the SMT group, ten of 13 participants (76.9%) improved their golf accuracy from pre- to post-test (mean absolute error improvement = 3.57 m). In comparison, only 4 of 13 (30.8%) participants in the Control group showed improvement from pre- to post-test (mean improvement = 1.14 m). When investigating the proportion of golfers improving from pre- to post-test as a function of group, a χ^2-test showed a significant difference in the proportion of successful golfers within the SMT and the Control group (χ^2 (Yate's Control for Continuity) = 3.87, df = 1, $p < 0.05$).

Club head speed variability: As consistency is a crucial factor in golfing, we conducted a paired samples t-test on the composite score of all clubs to analyze any possible pre- to post-test changes in club head speed variability. This test indicated a significant ($t(38) = 3.83$, $p < 0.001$) decrease in club head speed variability from pre- to post-test for the SMT group (mean diff. = -1.83, SD= 2.98 $km \cdot h^{-1}$). No significant change ($t(38) = 1.07$, $p = 0.13$) was evident for the Control group (mean diff. = -0.72, SD= 2.29 $km \cdot h^{-1}$).

Discussion

Timing and rhythmicity training programs have been used in a variety of rehabilitation settings with documented success. Based on that success, the concept of timing training has also gained popularity in applied fitness settings to enhance sport performance. However, few studies have looked at the efficacy of timing training and its effect on sport performance. The present study was designed to determine the efficacy of Synchronized Metronome Training (SMT) on motor timing and to determine its possible effect of improved motor timing on golf shot accuracy using a pre-test/post-test design in groups of experienced male golfers.

As with Libkuman et al., (2002), this study provides further evidence that improved timing and rhythmicity has positive effects on the outcomes of golf performance, investigated by means of accuracy. First, as with previous SMT studies including various groups of populations, it was found that SMT produced significant improvements in the timing and rhythmicity for the experienced golfers investigated in this study as measured repeatedly by the IM measurement system. As expected, the golfers in the SMT group, when compared to the golfers in the Control group, demonstrated significant improvements in measured timing and rhythmicity scores, from pre- to post-test. Second, and more importantly, the analysis made of the golf accuracy revealed significant overall improvements as well as decreasing variability for the golfers in the SMT group from pre- to post-test, outcomes not found for the golfers in the Control group.

One explanation in line with Libkuman et al., (2002) is that SMT increased accuracy because the temporal properties of the golf swing were improved. As the metronome-based training is primed to enhance motor timing, this may seem like a plausible explanation. However, also other explanations have to be considered on the subject of the link between improved motor timing and its positive effect on the golf shot accuracy. Some current, related findings might bring further insight to such relationship.

For example, Meegan et al., (2000) found that training on a perceptual task can significantly be transferred to a motor task; that is, that motor learning can occur even without any motor training. This is in line with Prinz's (1990) claim that training of precise timing in motor performance is linked to the corresponding training and improvement of auditory temporal resolution. From a generalized motor program (GMP) perspective, it is compelling to search for answers in the impulse-timing hypothesis. This hypothesis explains how the motor program provides pulses of motor neuron activity to the muscles to be activated. In principal, it is hypothesized that the GMP controls bursts of force spread over time, defining the time of onset and offset of the relevant muscles involved in the actual movement (Schmidt and Lee, 2005). In concurrence with this notion, Thier et al., (2002) have found that for saccadic eye movements, involving agonist muscles to initiate and antagonist muscles to decelerate movement, the activity of cerebellar purkinje cells precisely encodes the onset and offset of a saccade. Much research has investigated the timing features/properties of the human being in relation to coordinated motor responses, and many have suggested that enhanced motor timing skills are due to fine-tuning of the precision in the neuronal activity, a higher frequency of neural oscillation (e.g., Rammsayer and Brandler, 2006), or via an increase in the *clock speed* of the master internal clock (Taube et al., 2007). The IM is thought to work by augmenting internal processing speed within the neuroaxis and increasing "cognitive efficiency" in the information-processing bottleneck (Gorman, 2003). In line with this notion Diamond (2003) suggests that SMT may increase the efficiency and organization of the central nervous system circuitry, making the brain's signal processing become more efficient and more consistent. Myskja (2005) states that when movements become more rhythmically stable along the time-axis this rhythmic coordination will generate a more optimal movement in space, as time and space are connected. As a result, movements will become more effective and advantageous; this may explain the golfer's outcome improvements found as a result of SMT. The decreased club head speed variability found at the post-test for the SMT group can also be understood in according to Myskja (2005). Thus, indicates a more stable and synchronized intra- and inter-limb coordination throughout the golf swing.

An alternative explanation is that SMT does improve the golfer's ability to concentrate and stay focused. There are two results pointing towards changes in the participant's attention and focus. First, the SMT significantly increased the mean number of IARs (hits in a row within ± 15ms of the reference beat) the participants could achieve. We interpret this as an improvement of the participant's ability to attend to the task at hand. Secondly, the significant decrease in the deviation from the reference beat during the AOT test (10 consecutive minutes of matching the reference beat) strengthens the notion that SMT improves the participant's ability to attend selectively to a stimulus without interruption by internal thoughts or external distractions for extended periods. Similarly, Diamond (2003) suggests that the use of guide sounds in SMT may help "choice discrimination" and thus increase the ability to exclude irrelevant information. The SMT is a demanding task over time and requires a high level of concentration to ensure improvements of the timing performance. Our interpretation is that SMT facilitates directed attention. In addition, the online motor correction based on feedback may contribute to optimization of timing and organized actions. Thus, SMT seems to affect the person's abilities to inhibit irrelevant stimuli and distracters.

Limitations and future research

It is not clear from the findings from the SMT whether number of repetitions, length of training sessions, alternative timing exercises, and a different reference beat tempo (longer/shorter) might affect the results differently. Furthermore, there is also a need for further investigations of what type of sensory feedback (by means of the instantaneous provided feedback – auditory and/or visual - that enables the participant to deliberately correct their timing errors as they occur) may optimize and/or affect the outcome of IM training. In addition, the possible long-term effects of SMT are unknown and in need of evaluation.

Thus, future research will be necessary to further delineate the phenomenon and to develop a theory that can explain how the property of timing influences the complex motor activity in golf performance. Thus, we plan subsequent investigations of the kinematics properties and dynamics of the golf swing performance and how timing training by means of SMT may affect the kinematics. However, such investigation was beyond the scope of the present study.

Conclusion

The present study showed a significant effect of SMT by means of improvements in motor timing and synchronizations. Additionally, significantly improved scores on selected golf shot accuracy variables and with clearly decreased variability after just 4-weeks of training were evident. As the present study shows, sensory motor control and golf shot accuracy outcomes were positively affected by SMT. This suggests that enhanced and optimal golf shot accuracy does require precise, timed, and synchronized sensory motor control.

The finding that improvements of golf shot accuracy are positively affected by improved motor timing and that such improvement occurs after just a 4-weeks intervention without any sport specific training has interesting implications for other sports as well. For example, other athletes could benefit from such a complementary training method. Additionally, the SMT method may also be useful during periods of limited and/or impaired sensory motor functions.

Acknowledgements

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Key points

- This study investigates the effect of synchronized metronome training (SMT) on motor timing and how this training might affect golf shot accuracy.
- A randomized control group design was used.
- The 4 week SMT intervention showed significant improvements in motor timing, golf shot accuracy, and lead to less variability.
- We conclude that this study's results provide further evidence that motor timing can be improved by SMT training and that such timing improvement also improves golf accuracy.

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A Preliminary Study of the Effects of Interactive Metronome Training on the Language Skills of an Adolescent Female With a Language Learning Disorder

Synopsis:

This published study demonstrated the effect of IM training on expressive and receptive language skills in an adolescent female with a language learning disorder (LLD). The authors suggest that IM training may be a useful tool in the treatment of communication disorders for a wide range of clinical conditions.

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CICSD

A Preliminary Study of the Effects of Interactive Metronome Training on the Language Skills of an Adolescent Female With a Language Learning Disorder

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The interactive metronome (IM) is an innovative, patented, microcomputer-based version of the traditional music metronome (Jacokes, 2003, 2004). IM hardware includes a computer, headphones, and two contact sensing triggers (one for the hand and one for the foot). IM software generates a steady beat through the headphones, and the user produces continuous rhythmic movements of the hands and/or feet in response to the auditory stimuli. Sensors register these movements and the software analyzes them according to their speed and accuracy. Interactive visual and auditory feedback are then provided to the user to allow for adjustments in rhythm and timing until movements are synchronized with the auditory stimuli. Rhythmic movements may include clapping of both hands, clapping one hand at a time against the side of the body, alternating toe and heel tapping of a

ABSTRACT: The interactive metronome (IM) uses innovative technology to provide a movement-based repetition program that may improve a person's cognitive and motor performance. Essentially, the IM is a patented, microcomputer-based version of the traditional music metronome in which the user listens to a steady beat through headphones and makes synchronized rhythmic movements in response to the beat. The assumption is that IM training provides drill in rhythm and timing, which in turn may influence neural pathways. To date, IM training has been found to have beneficial effects on motor, cognitive, and academic performance (P. Bartscherer & R. Dole, 2005; T. M. Libkuman, H. Otanim, & N. Steger, 2002; R. J. Shaffer et al., 2001). However, there are no studies reported in the literature of the application of IM training to the field of speech-language pathology. As delayed response time is one characteristic of many learning disabilities (S. J. Diamond, 2003), IM training may facilitate improvement of underlying motor and cognitive processing capacities that are foundational in an individual's ability to attend and learn.

The present study investigated the effects of IM training on an adolescent female with a language learning disorder (LLD). Results showed that the participant demonstrated improvement in all language areas assessed on the Expressive One-Word Picture Vocabulary Test (R. Brownell, 2000) and the Oral and Written Language Scales (E. Carrow-Woolfolk, 2006) from pre- to posttest. These preliminary results suggest that IM training may have potential application to a wide range of clinical conditions in the field of speech-language pathology.

KEY WORDS: interactive metronome, intervention strategies, language learning disorder

foot, and alternating toe tapping and hand clapping. The IM training program consists of 15 sessions. Each session has predetermined objectives and specific instructions on how to perform the required movements. Variations of movements can be developed to accommodate the user. IM treatment requires administration by a certified trainer. Certification can be accomplished through the Internet within a day's time.

According to Koomar et al. (2001), the underlying theory behind IM training is that motor planning processes of organizing and sequencing are based on an internal sense of rhythm. Rhythm provides the foundation of timing upon which one organizes and sequences the thoughts and movements of daily life. An individual may have the ability to organize and sequence, but without an accurate internal sense of timing, there is no foundation on which to functionally organize and sequence. Drill in rhythm and timing provides for more efficient neuronal organization that in turn facilitates improvement for underlying central nervous system motor and cognitive processing capacities such as motor planning, motor sequencing, concentration, thinking, and interacting. These capacities are foundational in an individual's ability to attend and learn. As such, IM training may have implications for motor skill development, cognitive and language abilities, and academic achievement.

IM training has been found to be beneficial with motor, cognitive, and academic performance. Libkuman, Otanim, and Steger (2002) studied the effects of IM treatment on the motor performance of golfers. This study involved 6 women and 34 men, 25–61 years of age, with basic level golf skills. Due to the wide range in age among participants, age was used as a covariate. The 40 participants were randomly assigned to either a control group or an experimental group. The experimental group received approximately 10 hr of IM training in twelve 50-min sessions over the course of 5 weeks. The control group read golf instruction literature. Participants were asked not to practice swings with golf clubs outside the experiment setting. The dependent variable was the accuracy of golf swings as defined by the number of feet that each ball landed from a target. Pretest measures were taken of each participant's accuracy. Upon completion of the 5-week period, both groups were posttested. A full-swing golf simulator was used in an indoor booth to estimate the distance and direction of each shot from the hole for pre- and posttesting. Participants played the same hole using the same balls, driving mats, rubber tees, and their drivers along with their five, seven, and nine irons. Fifteen shots were taken with each iron for a total of 60 shots for both pre- and postmeasures. Statistical analyses indicated that there was no significant difference in accuracy between groups at pretest. However, the experimental group demonstrated statistically significant improvement from pretest to posttest in accuracy of golf shots. By comparison, no significant improvement in accuracy of golf shots was found for the control group. Therefore, the IM training program was found to have a positive effect on golf swing accuracy.

In addition to motor performance, IM training appears to enhance cognitive abilities. Shaffer et al. (2001) found IM training to have positive effects on the motor and cognitive skills of boys with attention deficit hyperactivity disorder (ADHD). Fifty-six boys between 6 and 12 years of age with a diagnosis of ADHD were randomly selected as study participants. Three groups were formed based on age, medication dosage, and severity of ADHD. Group 1 received fifteen 1-hr sessions of IM training; Group 2 received no treatment; and Group 3 received training on selected nonviolent video games requiring eye–hand coordination, advanced mental planning, and multiple task sequencing. All groups were pre- and posttested using several assessment instruments. The Test of Variables of Attention (TOVA; Greenberg & Dupuy, 1993), Conners' Rating Scales—Revised (CRS–R; Conners, 1990), Wechsler Intelligence Test for Children—3rd Edition (Wechsler, 1992), and Achenbach Child Behavior Checklist (ACBC; Achenbach & Edelbrock, 1991) were used to assess the participants' attention and concentration. The CRS–R, the ACBC, and Bruininks-Oseretsky Test of Motor Proficiency (B-O; Bruininks, 1978) were used to assess each participant's senses, movement, and socioemotional functioning. Finally, the Wide Range Achievement Test—3rd Edition (WRAT–3; Stone, Jastak, & Wilkinson, 1995) and Language Processing Test—3rd Edition (LPT–3; Wilkinson, 1993) were used to assess the participants' academic and cognitive skills. Results revealed significant improvement between pre- and posttest scores for Groups 1 and 3, but no significant improvement from pre- to posttest for Group 2. In addition, Group 1, which received IM treatment, scored significantly better than Group 3, which received video game treatment. Results of this study suggest that IM treatment improves the motor control and cognitive abilities of boys with ADHD.

Bartscherer and Dole (2005) investigated IM training through a case study on a boy with attention and motor coordination difficulties. The participant was a 9-year-old African American male with difficulties in attention and a developmental delay of unspecified origin. He attended a private school that focused on experiential learning; he had not received any special education or therapeutic services. In addition, due to the parents' fear of labeling their son, the boy had not been officially evaluated for learning difficulties, attention problems, or other developmental delays. However, according to the *Diagnostic and Statistical Manual of Mental Disorders—4th Edition* (American Psychiatric Association, 1994), he exhibited several behavioral characteristics that are consistent with a diagnosis of ADHD and developmental coordination disorder.

After seeing reports in the news media, the boy's mother had him undergo a 7-week IM training program. Accuracy in timing on IM tasks was assessed before, during, and after treatment. The B-O Test (Bruininks, 1978) was used to assess the boy's gross and fine motor skills before and after treatment. The boy's pretest motor skills revealed a performance that was markedly below that of his same-age peers. The boy demonstrated significant improvement on timing accuracy on the B-O posttest (Bruininks, 1978). In addition, before treatment, the boy's mother expressed that the boy had trouble with concentration, coordination, organization, and fine motor movements (e.g., cutting out shapes with scissors). After IM treatment, his mother provided anecdotal reports of positive changes in these behaviors at home. In addition, the boy's mother reported improvements in his math and handwriting skills.

Lazarus (2006) investigated the effects of timing and rhythm as a result of IM treatment on various components of reading in high school students. A total of 280 physical education/health students were recruited from Florida's largest, most multicultural high school. All participants were pretested using various reading subtests (i.e., Letter Word Identification, Reading Fluency, Passage Comprehension, and an overall Broad Score of all subtests) of the Woodcock-Johnson III Tests of Achievement (WJ III; Woodcock, McGrew, & Mather, 2001), then randomly placed in a control group receiving no treatment or an experimental group receiving twelve 45–60-min IM treatment sessions. Both groups were then posttested with the WJ III. Statistical analyses revealed that scores for all three subtests improved from pre- to posttreatment for both groups. However, the IM treatment group had a statistically significant higher Reading Fluency score and overall Broad Score. In addition, students in the IM group reported in posttreatment interviews that they felt more attentive and focused on tasks following IM training in timing and rhythm. Improvements were hypothesized to be due to more efficient cognitive processing strictly from the IM training because treatment was not academically oriented, did not require new learning, and only lasted 3 weeks in duration.

From the small body of research that currently exists, preliminary data appear to indicate that IM training is an effective tool for improving a person's motor, cognitive, and academic performance (Bartscherer & Dole, 2005; Lazarus, 2006; Libkuman et al., 2002; Shaffer et al., 2001). Current evidence suggests that IM training provides beneficial improvements in timing and rhythm related to motor planning and sequencing and cognitive processing. There is a well-established relationship between the processes underlying cognition and language processing and use. As such, one might expect to see gains in language skills for some persons who undergo IM training. To date, however, no studies involving IM training in the field of speech-language pathology have been reported in the literature. The purpose of the present study was to conduct a preliminary investigation into the effects of IM training on an adolescent female with a language learning disorder (LLD). It is anticipated that the present study will establish a starting point for future investigation of the IM's use with persons exhibiting various communication deficits.

METHOD

Participant

Developmental and communication history. Renee[1] is a 13-year-old female of Bulgarian descent. A complete case history is lacking due to the fact that she was born outside the United States and spent her first 4 years of life in orphanages. Renee was adopted by American parents at the age of 4½ and as a result emigrated to the United States. Details concerning her early developmental history are unknown. Her adoptive parents reported that the orphanage was clean, but all of the children slept in the same room in individual twin-size beds. Renee's birth mother was 23 when she gave birth to Renee. Renee's birthweight was 3 lbs., 5 oz. A videotape of Renee at 3 years of age revealed that she did not know her own name or age. She weighed 32 lbs. upon adoption, could not run or skip, and demonstrated poor gross motor development. She spoke only two to three Bulgarian words upon adoption but was speaking in simple English sentences by 5½ years of age. Despite the fact that Renee had virtually no expressive Bulgarian language, it is still considered her native language due to her exposure to it for the first 4½ years of her life.

Renee's language deficits were originally thought to be due to her immersion in a new culture and language. Once in kindergarten, Renee's deficits were more apparent and she began receiving speech-language services until the sixth grade, when services were discontinued in 2005. In November 2005, Renee's parents had an outside evaluation conducted by a neuropsychologist due to the fact that Renee still displayed major language issues despite the fact that she had been immersed in English for more than 7 years. The Clinical Evaluation of Language Fundamentals—4th Edition (CELF–4; Wiig, 2004), LPT–3 (Wilkinson, 1993), and Test of Narrative Language (TNL; Gilliam & Pearson, 2004) were used to assess Renee's language abilities. Renee received a receptive language standard score of 79 (8th percentile), an expressive language standard score of 59 (<1st percentile), and an overall standard score of 62 (1st percentile) on the CELF–4. In addition, Renee received a standard score of 87 (20th percentile) on the LPT3 and a standard score of 12 (5th percentile) on the TNL. Results suggested that Renee's expressive language skills were much weaker than her receptive language skills, although her receptive skills were also suspect. As a result of the assessment, Renee was diagnosed with an LLD and was referred to speech-language pathology services. Renee received language intervention from a speech-language pathologist (SLP) in private practice. It was at this clinic that Renee received IM training.

Educational history. At the time of the study, Renee was a seventh grader at a middle school in the Pacific Northwest. Her adoptive parents reported that Renee still had problems with oral and written expressive language. Her parents also reported Renee's extreme frustration with her language difficulties. Academically, Renee received several special accommodations (e.g., additional time for tests and assignments, altered or shortened assignments, modified grading scale, open book exams, shortened verbal instruction) in the regular classroom and also received special education services in the areas of reading, writing, and math. Her individual education plan (IEP) targeted word retrieval, syntax (with pronouns specifically), reading, writing, and math.

[1]For the purpose of confidentiality, the participant will be referred to as Renee throughout the remainder of the article.

Social history. Renee's American parents also adopted another girl from the same orphanage in Bulgaria. Although Renee's nonbiological sister is of the same age and descent and came from the same environment at the Bulgarian orphanage, she is not delayed in her English language development.

Renee has difficulty establishing friendships because she is often teased by peers. Her parents reported that her immaturity and receptive and expressive language difficulties have caused social isolation. Renee enjoys playing the piano, running, listening to music, engaging in church activities, and being with the few friends she has. Renee resides with her adoptive parents and her nonbiological sister. Her adoptive family speaks English only.

Procedure

Research design. This study used a single-subject pretest–posttest design. Measures of language ability were taken before the introduction of IM training. Once the pretest measures were taken, the treatment was introduced. Upon completion of the treatment, the same measures that were taken before treatment were administered as a posttest. Comparisons were then made between the pretreatment and posttreatment measures. This design is relatively weak but was used as a starting point of inquiry that hopefully will lead to more well-controlled studies.

Pretest and posttest. In order to determine the possible effects of IM training on Renee's language abilities, the Expressive One-Word Picture Vocabulary Test (EOWPVT; Brownell, 2000) and the Oral and Written Language Scales (OWLS; Carrow-Woolfolk, 2006) were administered both before and after the IM treatment. The EOWPVT and OWLS were chosen as basic measures of Renee's receptive and expressive language abilities, and each instrument was administered twice. The first administration of these instruments provided a baseline of Renee's language skills before commencement of IM training. The second administration occurred after IM training and served as comparison data to the pretreatment measures. This comparison allowed the researchers to determine to some degree the effects of treatment in timing and rhythm on Renee's language skills. Both the pretest and posttest measures were administered in a quiet room that was free of distractions by the first author, who was a speech-language pathology graduate student at the time of the experiment.

Treatment

Renee's speech-language services were temporarily suspended during the experiment in order to prevent confounding of the results by ongoing language intervention. IM treatment was administered by a certified IM trainer. Renee participated in the 15-session plan provided by the IM software. Renee received treatment four times a week for nearly a month until all 15 sessions were completed. Each session took approximately 50 min to complete.

The IM software maps out each session in duration in minutes and total repetitions of body movements per session. Each session is then analyzed further according to the specific exercises and their individual durations, total repetitions, and levels of difficulty. The broad goal of Renee's IM treatment was to improve her receptive and expressive language abilities through exercises in motor and cognitive rhythm and timing. The IM software guides the certified trainer to the appropriate settings for each session (e.g., difficulty level and beat tempo).

Depending on the specific exercise, Renee was asked to engage in various motor activities (e.g., clapping her hands, jumping, etc.) in synchrony with the audible beeps that she was hearing through headphones. The beeps were presented using various rhythmic patterns that Renee had to emulate through her motor responses. As Renee engaged in the training, the IM software kept measurements of her timing accuracy. Although these measurements could be used clinically to gauge Renee's improvement in timing accuracy, the data were not used because the language pretest and posttest data were the measurements of interest. Throughout the IM training program, Renee received positive reinforcement by the certified trainer in the form of verbal praise.

RESULTS

Renee's standard scores on the EOWPVT and OWLS revealed dramatic improvement from pretest to posttest.[2] Before initiation of the IM treatment protocol, Renee received a raw score on the EOWPVT of 106, which converted to a standard score of 93 and a percentile rank of 66 (age equivalent = 11;4 [years;months]). One month later, after completion of the IM treatment, Renee's raw score on the EOWPVT was 138, which converted to a standard score of 124 and a percentile rank of 95 (age equivalent >19). Renee received a pretest raw score of 70 on the OWLS, which converted to a standard score of 86 and a percentile rank of 18 (age equivalent = 9;6). The posttest raw score 1 month later was 81 (standard score = 99; percentile rank = 47; age equivalent = 12;9). Renee's performance on the EOWPVT and the OWLS revealed an increase of 29 percentile points on each test. Renee demonstrated improvement in all language areas assessed.

Upon termination of the month-long experiment, it was noted that Renee had completed more tasks on the posttest than she had on the pretest. Anecdotally, Renee reported that her mind felt "cleaner" and "lighter." Renee's mother also reported a decrease in the amount of time that Renee needed to process language, as well as an increase in her ability to cope with frustrating situations on a day-to-day basis.

[2]Although Renee produced few Bulgarian words upon adoption, her exposure to the Bulgarian language for $4^{1}/_{2}$ years indicates that English is her second language. Consequently, results of these language measures must be interpreted with caution as they were not normed on children of foreign birth who speak English as a second language. Therefore, test results may be an underestimate of Renee's true scores. It is important to focus on the comparison and improvement from pre- to posttest rather than on the scores per se.

DISCUSSION

The present study investigated the effects of IM training on an adolescent female with an LLD. Results revealed dramatic gains in language skills as noted by pre- to posttest comparisons of standard scores on the EOWPVT (Brownell, 2000) and the OWLS (Carrow-Woolfolk, 2006). The positive effect of IM training on language skills appears to lend further credence to its facilitative effect on motor, cognitive, and academic performance (Bartscherer & Dole, 2005; Lazarus, 2006; Libkuman et al., 2002; Shaffer et al., 2001). According to Koomar et al. (2001), drill in rhythm and timing provides for more efficient neuronal organization, which in turn facilitates improvement for underlying central nervous system motor and cognitive processing capacities. Further study into whether IM training actually facilitates neuronal organization and/or reorganization is warranted.

The facilitative effect of IM training on language performance is not surprising in light of the body of research that exists on similar intervention techniques that also exploit timing and/or rhythm. Perhaps the oldest of these techniques is delayed auditory feedback. Its disruptive effect on the timing of normal speech production (Stuart, Kalinowski, Rastatter, & Lynch, 2002; Van Borsel, Sunaert, & Engelen, 2005; Zanini, Clarici, Fabbro, & Bava, 1999) and facilitative effect on disfluent speech (Harrington, 1988; Kalinowski, Armson, Roland-Mieszkowski, Stuart, & Gracco, 1993; Kalinowski & Stuart, 1996; Macleod, Kalinowski, Stuart, & Armson, 1995; Martin & Haroldson, 1979; Novak, 1978; Radford, Tanguma, Gonzalez, Nericcio, & Newman, 2005; Soderberg, 1968; Stager, Denman, & Ludlow, 1997; Stark & Pierce, 1970; Stuart, Kalinowski, & Rastatter, 1997; Timmons, 1983; Van Borsel, Reunes, & Van den Bergh, 2003; Webster, Schumacher, & Lubker, 1970) have been well established. Delayed auditory feedback has also been demonstrated to slow the rate of speech and thereby improve intelligibility for persons who exhibit accelerated speech as a characteristic of some forms of dysarthria (Adams, 1994; Downie, Low, & Lindsay, 1981; Hanson & Metter, 1981, 1983; Yorkston, Beukelman, & Bell, 1988).

An intervention technique that is somewhat similar to IM is melodic intonation therapy (MIT; Helm-Estabrooks & Albert, 2004; Helm-Estabrooks, Nicholas, & Morgan, 1989). MIT uses the rhythmic intoning of propositional utterances for the purpose of improving expressive speech and language. It has been found to have a facilitative effect on the speech skills of persons with aphasia (Albert, Sparks, & Helm, 1973; Belin et al., 1996; Naeser & Helm-Estabrooks, 1985; Popovici, 1995; Popovici & Mihailescu, 1992; Sparks, Helm, & Albert, 1974; Sparks & Holland, 1976) and apraxia of speech (Helfrich-Miller, 1994). IM training may have similar effects on neural organization as MIT.

The music metronome (as an informal tool) has been used effectively in the past as a technique for improving speech abilities in persons with fluency disorders (Hanna & Morris, 1977; Silverman, 1971) and in persons with dysarthria or apraxia of speech (Dworkin, 1991; Dworkin, Abkarian, & Johns, 1988; Pilon, McIntosh, & Thaut, 1998). In these cases, the metronome was typically used to reduce the rate of speech, thereby improving fluency and/or intelligibility. Whether the use of a metronome in these cases facilitated speech production by tapping into underlying neural organization is unclear.

Although it is not fully understood what neural underpinnings are involved in the use of the IM, it does appear at least tentatively that training in rhythm and timing has positive effects on language skills. Results of the present study suggest that it is possible that motor planning and cognitive processing difficulties found in those with deficits in learning disabilities, ADHD, central auditory processing disorders, autism, Down syndrome, cerebral palsy, traumatic brain injury, and apraxia of speech (to name a few) may be ameliorated to some degree by training in timing and rhythm. IM treatment may be an effective complement to existing interventions that are currently being used by therapists to address these disorders.

Limitations and Future Research

As the current study was a preliminary investigation into IM treatment in speech-language pathology, a simple case study format with a pretest, treatment, and posttest was used. This research design is relatively weak and has its limitations. As a single-subject study without controls, both internal and external validity may be compromised. Variables such as maturation and history may have accounted for some of the gains seen between pre- and posttesting. Similarly, with the relatively short duration of the experiment (approximately 1 month), there may have been a practice effect of the pretest on performance on the posttest. Finally, no attempt was made to see if the gains in language performance that were seen between pre- and posttesting carried over for any extended period of time. With these limitations in mind, one should be cautious in interpreting the results. However, due to the dramatic improvement in posttest scores over pretest scores seen in this experiment, one may reasonably assume that IM training had some influence on the outcome. Further study into the effect of IM training on language performance using stronger research designs with controls is warranted. Additional systematic studies are needed to explore the IM's potential usefulness across age groups and types of disorders involving difficulties in timing, rhythm, and motor planning and sequencing. Continued scientific inquiry into the effects of IM training may make it possible to determine its efficacy as an intervention approach.

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Improvements in Interval Time Tracking and Effects on Reading Achievement

Synopsis:

A study published in the journal Psychology in Schools showed that children completing a training program with Interactive Metronome achieved accelerated reading outcomes. A gain of 7 - 20% in reading achievement was shown in the 49 children whose reading and pre-reading skills were pre and post-tested.

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IMPROVEMENTS IN INTERVAL TIME TRACKING AND EFFECTS ON READING ACHIEVEMENT

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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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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 $\times$ 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

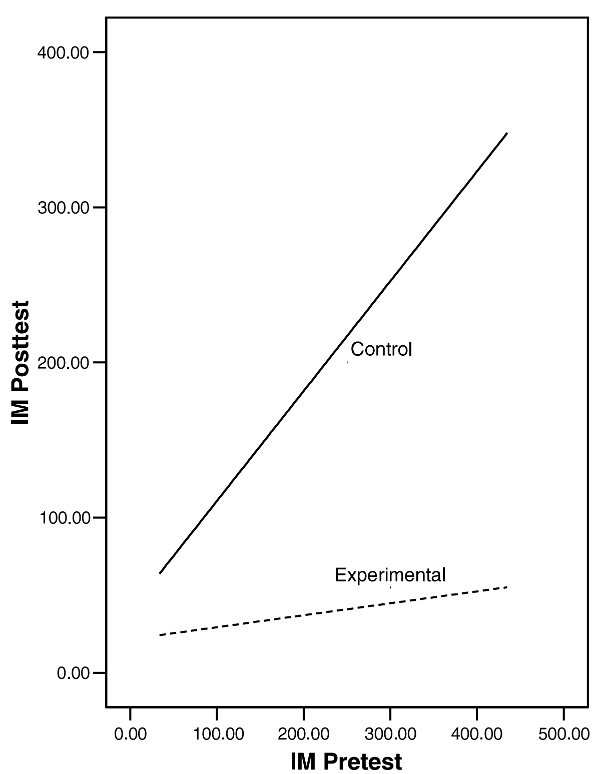

FIGURE 1. Interaction between IM pretest and IM training. The regression lines show that IM training was most effective in improving the timing and rhymicity of children with initial poor performance (low scores represent better performance).

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

[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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The Effect of Interactive Metronome Training on Children's SCAN-C Scores

Synopsis:

This pilot study by Joel Etra, PhD, SLP measured the effects of IM on children diagnosed with Central Auditory Processing Disorder. It showed that IM statistically significantly improved 4 areas of auditory processing in all the children tested. The largest increases occurred in dichotic listening, a measure of selective attention.

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The Effect of Interactive Metronome Training on Children's SCAN-C Scores

by
Joel L. Etra

An Applied Dissertation Submitted to the
Fischler School of Education and Human Services
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Speech-Language Pathology

Nova Southeastern University
2006

Approval Page

This applied dissertation was submitted by Joel L. Etra under the direction of the persons listed below. It was submitted to the Fischler School of Education and Human Services and approved in partial fulfillment of the requirements of the degree of Doctor of Speech-Language Pathology at Nova Southeastern University.

Barbara Packer, EdD Committee Chair	Date
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Abstract

The Effect of Interactive Metronome Training on Children's SCAN-C Scores. Etra, Joel L., 2006: Applied Dissertation, Nova Southeastern University, Fischler School of Education and Human Services. Auditory Perception/Auditory Training/ Auditory Tests/Audiology

In this study, the effect of Interactive Metronome, a treatment for attention deficit that requires the subject to match a computer generated rhythm, on auditory processing in male and female children ages nine to fourteen was investigated. Eight children were administered the SCAN-C and then were given the 15-hour Interactive Metronome training and administered the SCAN-C again.

SCAN-C raw scores showed a significant increase ($p = .002$). SCAN-C subtests of dichotic listening showed greater improvements than the other subtests. It is suggested that Interactive Metronome may affect auditory processing disorders by influencing neurological organization. It was concluded that Interactive Metronome could be an effective treatment for disorders of auditory processing. Potential difficulties in the provision of Interactive Metronome were discussed. Additional research was suggested with larger and more diverse samples as well as different trainers. More research into the design of the Interactive Metronome training schedule was also suggested.

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Chapter 1: Introduction

Statement of the Problem

Children with auditory processing disorders (APD) may have difficulty following directions, perform poorly in academics, and have difficulty with selective listening (Tillery, Katz, & Keller, 2000). Smoski, Brunt, and Tamahill (1992) noted that children with APD are often considered to be poor listeners and inattentive. It is easy to see how children with such difficulties would present a significant challenge in the classroom.

Speech-language pathologists (SLPs) treat disorders of auditory processing in a variety of settings including schools, private practice, hospitals, and medical clinics. A number of direct and indirect therapies are commonly used to reduce the effect of APD. Treatments such as traditional language therapy and environmental modification have little empirical support for their effectiveness. Additional cost-effective treatment choices would be welcomed by many SLPs. To be truly attractive, such treatment options should be inexpensive to acquire and to administer. In addition, extensive training of the clinician should not be a prerequisite. The progress made in an ideal program should be easily measured. The clinician should also be able to use the program with a variety of ages.

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Purpose

The purpose of this applied dissertation study was to research the effectiveness of Interactive Metronome (IM) in the treatment of APD. IM is marketed as program that will improve sports performance, muscle coordination, and musical ability. It is also marketed as a treatment for processing disorders, presumably including APD. Clinicians need evidence-based support for their treatment decisions. IM can be a valuable tool for treating APD in any number of settings if its effectiveness can be demonstrated.

Research Question

This research was designed to determine whether IM would be an appropriate tool for the treatment of APD. The research question that was addressed was, Does IM training improve auditory processing as measured by performance on SCAN-C test items?

Definitions of Terms

According to the American Speech-Language Hearing Association (ASHA) working group on APD (ASHA, 2005), auditory processing "refers to the perceptual processing of auditory information in the central nervous system and the neurobiologic activity that underlies that processing and gives rise to electrophysiological auditory potentials" (p. 2).

Attention deficit is a disorder characterized by inattention, impulsivity/inhibition, and overactivity (Semrud-Clikeman, 1999). The Diagnostic and Statistical Manual of Mental Disorders-4 (American Psychiatric Association, 1994) divides the attention deficit population into predominantly inattentive, predominantly hyperactive-impulsive, and combined. For the purpose of this study, which is primarily concerned with APD and not attention deficit, the informal designation of attention deficit by parents or teachers who believed that a child was having difficulty learning because of an inability to sustain attention was used.

Auditory short-term memory (for the purposes of this research) refers to memory that involves recall of auditory information for a relatively short time, such as a few seconds.

Auditory synthesis is the ability to merge or blend phonemes into words. Auditory synthesis is an important skill for reading especially multisyllabic words.

The SCAN-C is a screening test for auditory processing disorders. Because it does not require an audiometric booth, or extensive training, it is a test that can be administered by speech pathologists and other educational professionals.

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Auditory figure ground refers to the ability to perceive auditory signals in the presence of background noise. One of the SCAN-C subtests addresses auditory figure ground.

IM is a training program that uses computer generated rhythms to improve attention span.

Phonemes are the sounds of human speech. Phonemes differ sufficiently from each other that substituting one for another would change the meaning of the word.

Auditory discrimination refers to the ability of the auditory system to discriminate between phonemes. Another term might be phonemic perception.

Semantics refers to the meanings of words. Semantic perception refers to the ability to hear a word and discern its meaning.

Chapter 2: Literature Review

Defining the Topic

The topic of disordered auditory processing has created considerable controversy. One source of this controversy has been the definition of the disorder.

Keith (1999) cited an ASHA task force definition stating in general terms that APD is a deficiency in one or more mechanisms or processes relating to a variety of auditory behaviors. He listed a number of behavioral criteria including (a) difficulty with auditory discrimination, (b) deficiencies in remembering and manipulating phonemes, (c) difficulty understanding speech in the presence of competing noise, and (d) frequent requests for information to be repeated. In a technical report from ASHA (2005), the following definition was used: “(C)APD is a deficit in neural processing of auditory stimuli that is not due to higher order language, cognitive, or related factors” (p. 2). The report also reasserted the belief that APD exists as a valid diagnosis.

Thayer and Dodd (1996) described auditory processing as “a complex analysis of the acoustic signal and a reintegration of that information into auditory patterns or gestalts” (p. 37). The authors also pointed out that there is no clear distinction between the central and peripheral hearing systems, which renders problematic the use of the term *central*. Further diagnostic uncertainty was introduced by some theorists who referred to phonological perception and others to semantic perception, both of which are affected by developmental factors.

Stark and Bernstein (1984) noted, “Central auditory processing refers most frequently to psychologically and behaviorally defined phenomena measured in relation to an auditory signal” (p. 57). Watkins (1990) preferred “difficulties in processing the speech signal in the absence of peripheral hearing impairment” (p. 63).

Jerger and Musiek (2000), in a consensus paper developed at the Bruton Conference, presented the definition of an auditory processing disorder as follows:

> A deficit in the processing of information that is specific to the auditory modality. It may be associated with difficulties in listening, speech understanding, language development, and learning. In its pure form, however, it is conceptualized as a deficit in the processing of auditory input. (p. 2)

Other childhood disorders such as hyperactivity, autism, and learning disabilities may present similar symptoms and are not well differentiated by tests that rely on behavioral responses.

A number of authors questioned whether APD exists as a distinct disorder separate from a language disorder

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(Friel-Patti, 1999; Keith, 1984; Rees, 1973) or from pansensory processing disorders (Cacase & McFarland, 1998).

Diagnosis by Testing and Behavioral Observations

Because APD is not well defined, testing and evaluation procedures are also controversial. Smoski et al. (1992) surveyed teachers’ observations of students’ behavior characteristics to develop a list of the behaviors that identify APD in children. Similarly, Witkin, Butler, and Whalen (1977) broke down auditory processing into five behavioral factors in order to select appropriate testing methods. These factors include short-term auditory memory; auditory synthesis, which involves the synthesis of unconnected fragmentary information; auditory figure ground; and oral language processing. The authors were surprised to note that no single factor of auditory discrimination emerged as significant but that language processing factors were most significant.

In a second analysis of the data, another set of five factors emerged. They were oral reading, auditory figure-ground, speech-sound discrimination, nonverbal reasoning, and oral language processing. Witkin et al. (1977) made a number of recommendations for diagnosis of APD. They recommended caution in the use of observations of auditory behavior in the classroom by untrained observers for the purpose of diagnosis, as in this study, instead of formal testing. They asserted the need for further studies of the relationship of APD to reading disabilities and the need to assess children with learning disabilities carefully on multiple factors, including auditory figure-ground.

In another use of behavioral observation for the purpose of diagnosis, Smoski et al. (1992) used a survey of teachers to develop a similar list of the behaviors that identify APD in children. They found that children with APD had a wide range of academic achievement including some who were above average and some who were below. Teachers were asked to rate APD children on the parameters of social behavior that are not necessarily related to APD. These included general disposition, ease of discipline, liking school, peer interaction and energy level. All of these were judged at or above average by teachers. Only concentration was rated below average. The authors also found a greater number of children receiving special reading help among the APD population.

The selection of appropriate testing has been discussed in a number of articles. Cacase and McFarland (1998) included pansensory processing disorders such as visual processing as well as developmental dyslexia, developmental dysphasia, attention deficit, and effects of otitis media. All of these deficits share behavioral and neurological symptoms with APD.

Singer, Hurley, and Preech (1998) preferred the use of a test battery and found that the binaural fusion test was most effective in differentiating children with both learning disabilities and presumed APD from a control group. Witkin et al. (1977) recommended caution in the use of untrained observers such as classroom teachers in the diagnosis of APD. In the Smoski et al. (1992) study, however, classroom behavioral judgments were called for, which teachers are qualified to make. Cautious use of such data may still be advisable.

Musiek and Chermak (1994) recommended different tests for different types of patients. Patients were divided into groups based on age and site of lesion with appropriate test batteries assigned to each group. For children, the authors recommended tests of dichotic digits, frequency patterns, competing sentences, and pediatric speech intelligibility. For patients with neurological involvement, they recommended auditory brain stem response, interaural timing procedures, masking level differences, and synthetic sentence identification.

The SCAN-C (Keith, 2000) uses four subtests to identify children who may benefit from treatment for APD.

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The four tests are filtered words, auditory figure-ground, competing words, and competing sentences.

Medical and Traditional Management

Tillery et al. (2000) investigated the effects of methylphenidate (Ritalin) on processing abilities of attention-deficit children. Attention was measured by a continuous processing test. The researchers found that, although attention was increased with the drug, there was no improvement in processing as measured by the staggered spondaic word test, the speech-in-noise test, and phonemic synthesis. Although it is reasonable to assume that improved attention will lead to improved processing, it appears that it is not always the case.

Greenspan (1999) included APD in considering treatment of children with attention disorders. He cited the distractibility of APD children and their frequent need for repetition of directions. Most of his recommendations were for environmental management rather than direct treatment.

Numerous therapeutic models for treatment of APD have been explored. Keith (1999) listed important behaviors that should be addressed in therapy. He recommended teaching students to follow directions, listen and anticipate, ask relevant questions, answer questions, and use written notes. He also stressed developing self-monitoring and self-evaluation skills. He noted that treatment can be by management or remediation. Management includes environmental modifications, perceptual, cognitive, and compensatory training. Compensatory training includes speech-sound discrimination, auditory analysis, phonemic synthesis, and auditory figure-ground training. Cognitive training involves message comprehension skills. Perceptual training includes sound localization, auditory discrimination, auditory pattern recognition, temporal resolution, temporal masking, temporal integration, and temporal ordering.

Tallal (1984) recommended training in temporal auditory processing for children with phonemic processing difficulties. She argued that temporal processing deficits are the cause of phonemic processing deficits and that remediation must begin with improvement of temporal processing.

Tallal et al. (1996) used acoustically modified speech to slow and stress the distinctive differences between phonemes. To accomplish this, the waveform of the signal was changed. They compared children trained with this modified speech to children who used computer games designed to enhance processing thresholds. The group who were trained in temporal processing showed greater improvements in speech discrimination and language comprehension.

In an apparent reference to Tallal et al. (1996), Craighead (1999) urged caution in the use of treatments that are not sufficiently supported by research. A similar caveat had been expressed by Rees (1973).

Chermak and Musiek (1992) used what they called a comprehensive approach. They recommended training of listening and problem solving skills. Long-term gains, they asserted, were best accomplished by the teaching of language-learning and metacognitive skills.

IM uses rhythm to increase attention and, as is claimed by the developer of the program, can also improve processing ability (Casilly, n.d.). This possible connection with language processing is also suggested by Shaffer et al. (2001), although no research has been published addressing that specific connection.

Improvement in golf swing accuracy was demonstrated by Libkuman, Otani, and Steger (2002), who compared IM-trained golfers with a control group who read golf improvement literature. The IM-trained golfers showed improvement measured by the distance of the golf ball from the pin. It was suggested that the difference in performance was due to improved timing of the golf swing.

Shaffer et al. (2001) investigated the effects of IM

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on a number of dimensions of attention deficit and hyperactive disorder (ADHD) in children including language processing. They divided 56 boys diagnosed with ADHD into three groups. One group was trained with IM. Another group played video games. A third group received no formal intervention or therapy at all. The Interactive Metronome group showed significant improvement in a number of parameters including language processing, control of aggression, and attention.

Koomar et al. (2001), in a single case study, found IM to be an effective instrument for the improvement of timing and rhythm. The authors claimed these abilities are fundamental to developing complex problem-solving skills.

Summary

Although the precise nature of auditory processing disorders remains uncertain, the considerable effects of this disorder demand attention. It is not unlikely that APD plays an etiological role in a number of disorders. With its unclear definition, the cause of the APD itself becomes difficult to treat. Most of the treatments cited in the literature deal with the symptoms and do not treat the problem directly.

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Chapter 3: Method

The research question that was addressed was, Does IM training improve auditory processing as measured by performance on SCAN-C test items?

Testing and training took place in the office of this researcher and on the premises of the cooperating school, both of which are in a small northeastern city, population 39,000. The town is located in a county with a population of 266,466. Of this total, 6.4% of the population is below the poverty level (U.S. Census Bureau, 2004). The school is a parochial school with 116 children in prekindergarten through eighth grade. Neither the office suite nor the school’s therapy room was sound treated, but both had a quiet environment appropriate for SCAN-C testing. The SCAN-C was standardized by its developer in both a quiet environment and an audiometric booth. No significant differences were found between the two conditions (Keith, 2000). Subjects were pretested with the SCAN-C test for auditory processing, treated with IM training, and posttested with the SCAN-C.

Population

Six male and two female subjects between the ages of 8-14 years were used for this study. All subjects were greater than 6 years of age, as that is the minimum age

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recommended by IM for the training. None of the subjects was receiving any other treatment for APD. In order to participate, subjects had to be able to follow the directions required by the IM training program. Although 10 children were recruited, only 8 completed the training. All the children were considered by their teachers and parents to be deficient in attention. When soliciting subjects for this study, this researcher asked parents and teachers to refer students who they thought were attention deficit. They were told that, if the children made enough errors on a test of APD, they would receive treatment for attention deficit at no charge. No formal testing for attention was done. Since this study was not investigating attention deficit, it was not considered necessary to quantify or otherwise formalize the diagnosis of attention deficit. No investigation into the effect of IM training on attention deficit was attempted.

One male and one female subject had a diagnosis of Asperger’s Syndrome. These children required additional time to learn to perform all the exercises required by the IM program but ultimately completed the training with results not unlike the other trainees.

Parents of subjects were interviewed prior to inclusion in the study in order to discuss the study and acquire informed consent. Parents were questioned regarding their children's hearing, and no child with a reported hearing loss was included in the study.

Subjects underwent IM training, which took 15 to 17 one-hour sessions over a 6-week time period. Pre and post testing with the SCAN-C was conducted by this investigator, who is a qualified examiner as defined by the SCAN-C developer. The manual that accompanies the SCAN-C (Keith, 2000) requires that the user be "knowledgeable in the administration and interpretation of tests designed for special education programs for children with learning or processing problems" (p. 7) Examiners may include speech pathologists, audiologists, and other professionals such as special educators. Test-retest reliability was reported with an interval of 2 days to 6 weeks and ranged from .65 to .82 (Keith, 2003).

IM training uses rhythm to increase attention span. Trainees match a computer-generated tone using prescribed body movements over an increasing length of time. Trainees wear a switch on one hand and, for foot exercises, tap on a switch on the floor. The foot switch is connected to a junction box, which is connected to the computer. The hand switch is similarly connected using wireless technology. The 13 different left, right, and bilateral body movements include clapping, tapping a hand against the ipsilateral thigh, tapping one or both toes, tapping with one or both heels, tapping with a toe while balancing on the other foot, and alternating a hand tap and a toe tap. Repetitions of each exercise increase with each session and reach as many as 2,000 repetitions of a particular exercise as well as a few hundred repetitions of other exercises per session. When doing 2,000 repetitions, the subject is concentrating on the rhythm for up to 37 minutes within the 1-hour session. In a given session, for example, a trainee might be instructed to clap two hands together 1,500 times, tap the left hand on the left thigh 300 times, tap two heels 300 times, and tap with the toes 300 times. Each session begins with a short-form test requiring 54 hand claps without the guide sounds and an additional 54 with the guide sounds.

Each 1-hour session included a variety of the movements and usually required a total of more than 3,000 taps or repetitions. The program for each session and session goals are described in a training guide (see appendix). The computer measured the accuracy of each tap and returned a score for each exercise that represented the average deviation in milliseconds from an exact match with the computer-generated tone over the course of the exercise.

During training, the subjects received feedback through headphones on the accuracy of each tap. The feedback took the form of different sounds, known as guide sounds, in each ear. Taps prior to the reference beat generated a sound in the left ear and taps after the reference beat generate a sound in the right ear. There was a unique sound for taps that exactly matched the reference beat, another for sounds within 15 milliseconds of the reference, and another for sounds that were beyond the running average that was determined by the program during each exercise. The results were then used to determine progress in the training.

Training required at least 15 one-hour sessions. In this study, trainees were seen two to three times per week. Three of the subjects were unable to consistently complete all the prescribed exercises in every 1-hour session. Consequently, additional sessions were scheduled. Because of frustration apparent on the part of the subjects, as well as available time constraints, four of the subjects were still unable to complete as many repetitions as were prescribed by the program. IM training was conducted by this investigator, who was trained and certified by the IM company to administer IM training.

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Instrumentation

The SCAN-C Test for Auditory Processing Disorders in Children-Revised (Keith, 2000) is a screening test of auditory processing that is administered individually. Subjects listen through headphones to instructions and stimuli recorded on a compact disc. To respond, the subject needs only to repeat what is heard. According to a technical report (Keith, 2003), this avoids cross-modality confusion that might be present in the cognitively more demanding task of identifying pictures in an array and pointing to the correct one.

The test has four subtests. The filtered words and auditory figure-ground subtests are speech tests in which the stimulus words have been distorted or presented in the presence of background to reduce intelligibility and simulate real listening conditions. The competing words and competing sentences subtests are dichotic listening tests. Different words or sentences are presented simultaneously, one word or sentence to each ear.

The filtered words subtest tests the ability to hear distorted speech. The SCAN-C manual (Keith, 2000) states that a low-pass filter was used at “1000 Hz with filter roll-off of 32 dB/octave so that the high frequency wounds were eliminated” (p. 16). Children with auditory processing

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disorder may misunderstand such speech. This difficulty may be the cause of some receptive language disorders (Keith). The child is asked to repeat words that sound muffled. The test stimuli are one-syllable words that have been low-pass filtered at 1000 Hz. Three practice and 20 test words are presented to the right ear. Then two practice words and 20 test words are presented to the left ear.

The auditory figure-ground subtest tests the ability to understand words in the presence of background noise. Children with auditory processing disorder often have difficulty understanding speech in noisy environments such as classrooms (Keith, 2000). In this subtest, single syllable words are presented in the presence of a competing conversation or story. The child is expected to repeat the stimulus words heard in the presence of this background noise. Two practice words and 20 test words are presented to the right ear, and then two practice and 20 test words are presented to the left ear.

In the competing words subtest, different monosyllabic words are presented in each ear and the subject is directed to repeat the word heard in one ear. The child hears two words simultaneously-one word presented to each ear. First, two practice word pairs and 15 test word pairs are presented. The child is instructed to repeat both words, repeating the word heard in the right ear first. Then, a second set of two practice word pairs and 15 test word pairs are presented. The child is directed to repeat both words, saying the one heard in the left ear first.

Competing words is a test of ear advantage or dominance, which has been shown to be related to maturational delays and neurological disorganization often seen in APD. The competing words subtest enables the examiner to assess the child's ability to understand competing speech signals (sometimes called binaural separation). The competing words subtest is a dichotic task that is used to assess function of neurologic pathways of the auditory system (Keith, 2000). Poor overall performance on this subtest may indicate a developmental delay in maturation or underlying neurological disorganization or damage to auditory pathways. The competing words subtest also assesses ear advantage. Left-ear advantage can indicate failure to develop left hemisphere dominance for language. Abnormalities shown by dichotic words test results are related to a wide range of specific disabilities, including auditory processing disorder and language disabilities (Musiek & Pinheiro, 1985).

Similar to competing words, *competing sentences* uses sentences in the same way to further examine ear dominance

(Keith, 2003). This subtest, as in competing words, is designed to address neurological organization. This subtest allows a comparison with competing words but on a higher linguistic level since it requires the repetition of sentences instead of single words (Keith, 2000). Pairs of sentences are presented to the right and left ears simultaneously. Unlike the competing words subtest, the child is instructed to listen to and repeat only the stimuli presented in one ear, while ignoring stimuli presented to the other ear. First, two practice sentence pairs and 10 test sentence pairs are presented. The child is instructed to repeat only the sentence heard in the right ear. Then, another set of practice and test sentence pairs are presented. This time, the child is instructed to repeat only the sentence heard in the left ear.

The test provides a raw score that is interpreted as an age-normed standard score. The test places scores within one standard deviation of the mean as normal. Scores greater than one standard deviation from the mean are borderline, and more than two standard deviations from the mean are considered disordered. In the current study, the total and subtest raw scores were used. Since the test uses only three categories--normal, borderline, and disordered--the use of raw scores allowed a more sensitive indication of changes in SCAN-C performance although it was not a claim to be diagnostic for APD. For this study, children were administered the SCAN-C while seated in a quiet room. The test CD was played on a Sony DEJ-621 portable CD player with Sony MDR-V600 circumaural headphones.

In a review of the SCAN-C (Berg & Spitzer, 2005), a problem was identified regarding construct validity. Auditory processing is concerned with what happens to the signal on the perceptual level. Ultimately, it is a precognitive skill. A child with no knowledge of English, however, would not do as well as a child with some knowledge of the meanings of English words. Being able to repeat the words is likely to imply some knowledge of their meaning. Additionally, the inclusion of both single-word and sentence dichotic listening tasks for comparison implies that there is some influence by higher cognitive processes.

Although the SCAN-C is a screening test, it was chosen for this study because it can be administered by this researcher who is not an audiologist. Other APD tests can be administered only by an audiologist in a soundproof environment. It was believed that, because the test is designed to identify disorders of auditory processing, improvement on the test would indicate a change in auditory processing ability. The test has a total of 130 items. Although no inference is made for the diagnosis of APD by the SCAN-C, an assumption is made that improvement in SCAN-C total raw score implies improvement in the skills that comprise auditory processing.

The equipment required to administer the IM is available only from the IM company for a cost of $3,000. The package includes the software, hand and foot switches, the control unit, a set of circumaural headphones, earphones for monitoring the sounds by the trainer, and 100 hours of use. Additional hours are available for $10 per hour. The user must provide the computer equipment. IM presents a metronome beat to a subject through headphones. The frequency of the beat is adjustable by the trainer but is normally set at 54 beats per minute for most subjects as was done during this research with two exceptions. In the case of one of the subjects diagnosed with Asperger's, the tempo, normally set at 54 beats per minute, had to be slowed for 10 minutes to allow him to match his hand movements better with the metronome beat. One of the other subjects became agitated by the guide sounds and complained that the task was too difficult. The difficulty setting was changed to allow him to be as much as 200ms off the target beat for three of the earlier sessions. This subject finished the program with a performance that was comparable to that of the other subjects. Trainees wear headphones and a hand switch and, for some tasks, also tap on a foot switch on the floor.

Some exercises require the trainee to be standing. For exercises not involving balance, trainees may sit at the discretion of the trainer. The trainer is also permitted to modify the exercises to accommodate physical disabilities or achieve trainee-specific needs. For example, wheelchair-bound trainees would be able to perform all exercises seated and hemiparetic trainees might need to perform all hand exercises with only one hand. The switches allow the computer to measure the accuracy of each hand or foot tap. The program returns an accuracy score in milliseconds and also records the number of perfect matches. Scores can be grouped to obtain scores for performance on tasks involving only hands or only feet. During training, subjects receive feedback through the headphones that indicates the accuracy of their matching of the beat.

The program includes a short form assessment (SFA) and a long form assessment (LFA). The SFA is performed at the beginning of each session and includes 54 repetitions with two hands without the guide sounds and 54 repetitions with the guide sounds. This assessment helps the trainee to concentrate on the metronome beat to the exclusion of the guide sounds. It also is an indication to the trainer of the extent to which the trainee is confused or distracted by the guide sounds. The LFA includes 30 repetitions of each of the exercises. The average millisecond score of the exercises in the LFA can be used to track progress and also to determine when the training has been successfully completed.

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Chapter 4: Results

Two sets of scores were generated by the subjects of this applied dissertation research project. Pre- and posttest total raw SCAN-C scores were compared for significant changes using a dependent samples student *t*-test. The IM program includes the LFA, which averages performance on all of the exercises and reports a millisecond score. This assessment was given before training, at Session 7 (which is called midterm), and after the last session. It was expected that, with improved accuracy and concentration, scores would decrease. All eight subjects showed a significant decrease in the IM millisecond scores when the total pretest and posttest results were compared.

The significance of this change in scores was demonstrated by a *t*-test wherein $t(14) = -4.22$, $p = .001$. Results of the IM LFAs are summarized and presented in Figure 1. The decrease in these scores indicates an improvement in the ability to sustain accuracy of the tapping over time.

Significant increases in scores were also obtained on the SCAN-C test. A *t*-test, $t(14)$, resulted in a *t* value of -3.90 and a probability of .002. The average increase in

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SCAN-C scores for all subjects (*n* = 8) was 24%. The average increase for the males (*n* = 6) was 26% and for females (*n* = 2) was 21%. The average age of the eight subjects was 10 years. Those under 10 (*n* = 3) achieved an average increase in SCAN-C scores of 34%, whereas those 10 and over (*n* = 5) had an average improvement of 19%. Improvement on the SCAN-C was evident for all subjects as summarized in Figure 2.

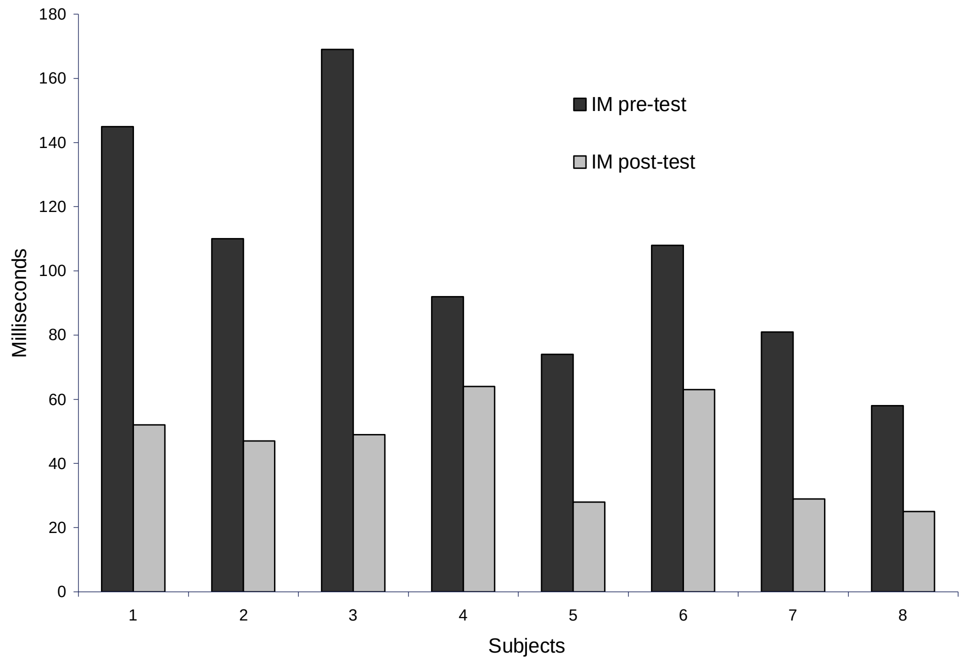

Figure 1. Changes in IM millisecond scores.

A comparison of subtest results was accomplished and summarized in Figure 3. Individual subtest scores were averaged across subjects. It was expected that, because IM is a program that is designed to increase attention, most of the improvement should have been in the filtered speech and figure ground subtests, which are more sensitive to attention. However, the average increase in subtest scores was greater for Subtests 3 and 4, which are the tests of dichotic listening.

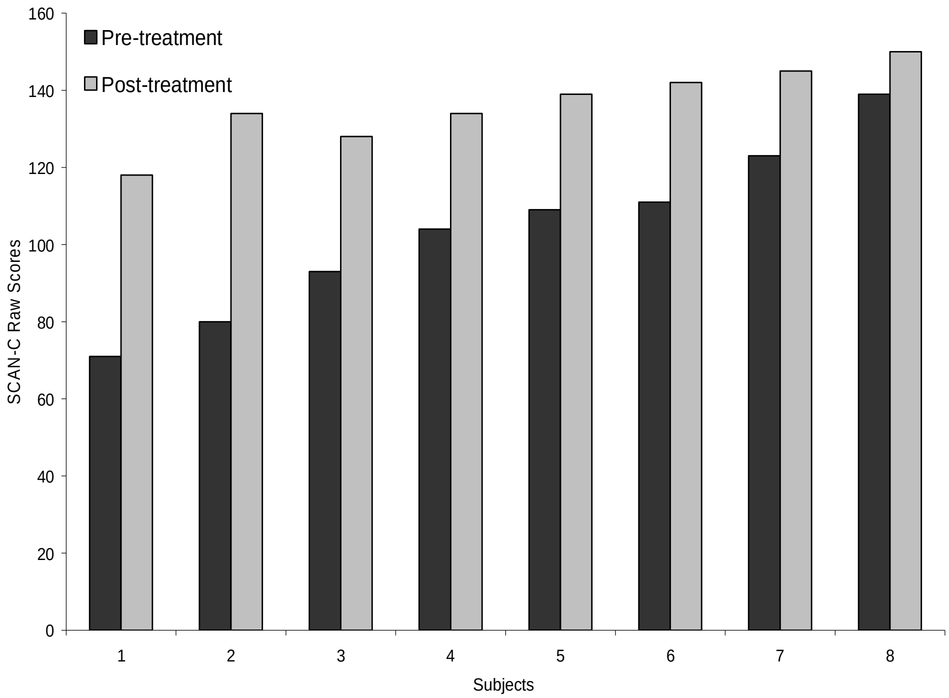

Figure 2. Changes in SCAN-C raw scores.

These tests are more related to neural organization. The implication, therefore, is that IM has an effect not only on attention but, perhaps to a greater extent, on neurological organization.

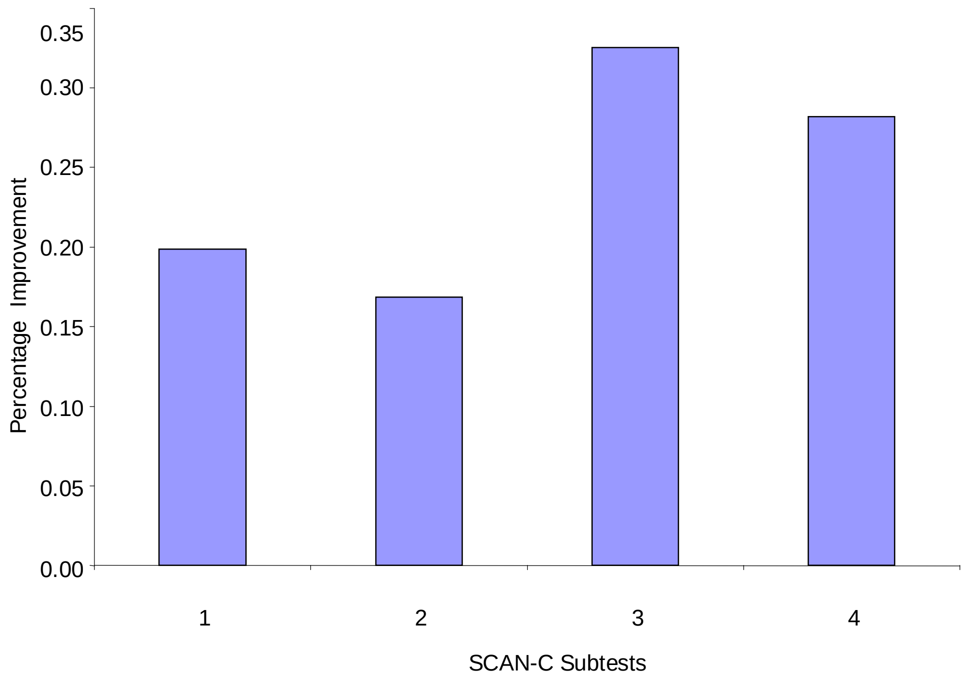

Figure 3. Percentage changes in SCAN-C subtests.

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Chapter 5: Discussion

Overview of Applied Dissertation

Treatment for APD is approached through a number of different strategies. These include direct therapy, environmental modification, and computerized instruction. There is a need, however, for research to support the efficacy of these treatments (ASHA, 2005). IM is a treatment that is being used for attention deficit. The current research was designed to determine if this treatment may also be effective for APD. The SCAN-C is a screening test for APD that can be administered by a speech-language pathologist. Changes in SCAN-C raw scores were used to indicate the effect that IM training might have on APD. As a result of this research, a strong correlation (p = .002) was demonstrated between IM training and improvement in SCAN-C scores. Percentage increases in SCAN-C scores were also compared by gender and age. Males achieved scores slightly higher than females, although the ratio of male to female subjects was 3:1, which might skew that result. Subjects younger than 10 years achieved scores higher than those achieved by those 10 or over.

Implications of Findings

Based on these results, IM can be considered an appropriate treatment for APD. However, during the

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implementation of this research, some difficulties arose. The program requires considerable commitment by the trainer, the trainee, and in some cases, the parents and the children's teachers and school administrators. As noted, the program requires at least 15 one-hour sessions. The child needs to be brought to these sessions; therefore, someone must be willing and available to provide transportation. The busy schedules of parents and children sometimes made two to three sessions per week impossible. If administered in a school setting, the program would require the cooperation of classroom teachers to allow students who may already be at academic risk to make up work missed during time out of class.

During the implementation of this study, many sessions had to be rescheduled because of competing family and school activities. This caused the length of the program to be extended. In one case, a child was taken out of school on vacation for a week. When this child returned, some of the skills needed for IM had to be taught again. The child's absence from school also made missing instructional time for IM training problematic.

The IM program is somewhat demanding physically. It is also repetitious and, therefore, does not readily sustain the interest of a child. The ability of the trainer to motivate trainees becomes crucial, especially with younger children. At least one of the subjects complained of physical discomfort and needed rest periods during training. One child became very frustrated by the demands of the program and spent parts of the early sessions crying. With encouragement and temporary adjustment of the program settings, he was able to finish the training successfully.

In spite of these difficulties, IM remains a viable choice for speech-language pathologists, occupational therapists and other professionals treating APD. Although scheduling two to three 1-hour sessions per week can be difficult, the program can be completed in about 15 hours. There is no indication from this research that other interventions including direct therapy and environmental modifications should not be used in conjunction with IM.

Limitations

Because of the availability of subjects in the geographical area of this study and the expense and time required for training, only 8 subjects were used. This small sample makes it impossible to stratify and generalize results by gender, age, or diagnosis. A larger sample size would also make generalization of the results to the given population easier to support statistically.

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The IM program specifies a total number of repetitions for completion of the program. Because of practical considerations such as scheduling and behavior, not all the subjects completed the same number of repetitions. It is not known what effect, if any, this discrepancy might have had on the results.

In this study, all the IM training was done by the same trainer. Although this trainer was certified by IM to provide IM training, such training is also provided by individuals with a wide variety of professional backgrounds. Although the total number of repetitions would remain the same, differences might arise in methods of motivation. It is not known whether differences in backgrounds would result in differences in the approach to training and, consequently, different results.

All the subjects in this study were considered to have attention deficit. It is possible that, because of their poor attention skills, their performance was not representative of children who are not attention deficit.

The SCAN-C test was used to demonstrate a change in auditory processing ability. The test is not diagnostic but, rather, it is a screening test. No inferences can be made, therefore, regarding a diagnosis of APD. It was assumed, however, that changes in the raw scores on the

SCAN-C could be related to changes in auditory processing ability. This assumption remains untested.

Recommendations

A need for additional research is suggested by the results of this study. Recommendations include the following:

1. A similar study with a larger number of subjects would enable stronger statistical support for the results.

2. A larger study could compare performance by age, gender, and ethnicity. Differences may be found that would suggest ideal ages for implementation of IM treatment. Studies by gender would help establish expectations for male and female trainees.

3. Diagnosis of APD is commonly done by an audiologist. A study using pretests and posttests for APD administered by an audiologist could make more definitive statements about IM training’s effect on APD.

4. All the subjects in the current study were considered to have an attention deficit disorder. Studies with other populations exclusively such as autism spectrum disorder or learning disability, as well as those with no other diagnosis, could provide additional information for generalization.

5. The IM training in this study was done by a speech-

language pathologist. Another study might compare results of training provided by other professionals such as occupational or physical therapists, psychologists, or educational specialists.

6. Although the IM program specifies a minimum number of repetitions, a specified tempo, a minimum number of sessions, a target millisecond score, and a menu of exercises, there is nothing in the literature to support any of these requirements. It is not clear whether more repetitions would bring about greater results and what would be the point of diminishing returns. Additionally, can similar results be obtained with fewer repetitions over fewer and longer or more and shorter sessions? The program also requires trainees to perform exercises using hands and feet. No specific explanation is offered as to the rationale behind this. Further research might test the value of involving the both arms and legs in the training. As the program is used for other goals such as improving athletic performance and balance, perhaps recommendations can be developed for a different menu of exercises prescribed to address specific needs.

7. In this research, posttesting was done upon completion of the training. No additional testing was done. A follow-up study might be done to determine carryover of

the effects. SCAN-C testing after 6 months and again after a year might show additional improvement, loss of improved performance, or stabilization.

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Appendix

Interactive Metronome Training Guide

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interactive metronome®

IM Training Guide

Standard 15 Session
Training Plan

Trainer Name: ____

Trainee Name: ____

Date of Birth: _____/_____/_____

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Session 1: (1,676 reps)

Initial Long Form Assessment

As you may recall from the IM Training Familiarization section, the IM Long Form Assessment includes 14 tasks that require the trainee to perform a variety of upper and lower body movements in time with the IM reference tone. It serves three purposes: to analyze existing capabilities; to gather baseline data needed to select the proper training plan; and to draw improvement comparisons since it is given before, midway through, and after the training program. The Long Form Assessment should take twenty to thirty minutes depending on whether you choose to have the trainee perform the optional "Attend Over Time."

Attend Over Time (AOT)

If you suspect that a trainee's assessment scores are only reflective of the very short duration of the Long Form, add the 'Attend-Over-Time' test to the end of each assessment administered.

Getting Started

Start a new trainee file by selecting “File” then

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“New” from the menu bar and naming the file with the trainee’s initials followed by the last four digits of the social security number (or other identification number). There should be a total of seven digits (e.g. JJD4567). If he/she does not have a middle name, use “X” in the place of that middle initial. Then, from the menu bar, select “Edit” and enter the “Trainer” and “Trainee” information (“Trainee” same as the file name).

Note: Make sure the trainee is wearing comfortable clothing and non-skid shoes.

What to Remember ***(please read all items)***

- The date will be automatically entered for the session; the program will use the date the computer is using, so be sure it is correct.
- The metronome icon or “F2” on the keyboard will start and stop each task, but keep in mind that no data will be recorded should you need to stop a Long Form Assessment task before its completion.
- The trainee must complete all 14 tasks of the assessment in order to generate a "Long Form Calculations" report.
- The program will automatically advance to the next task upon completion of the previous one. Each task is numbered should you need to manually select the next one.

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- The first four tones of all LFA tasks (and some other tasks) are for practice. The system begins calculating with the fifth tone.
- If the hits do not register, stop the task to check the triggers and the motion being used.

What to Tell the Trainee

- “The reference tone you will hear sounds like a cowbell; this is the metronome beat that you want to hit. All your trigger hits should be **ON** the beat and not in reaction to it. The last task **will have other sounds, but just focus on the cowbell.**”
- “While performing the tasks, do not watch the computer screen; concentrate only on the reference tone. “
- “During all tasks, try to avoid quick, ballistic, jerky movements. All motions should be continuous and fluid.”
- “Try not to miss a beat, but if one is missed, keep going because the IM program will calculate only registered responses.”
- “Do not touch the foot trigger before beginning any of the foot tasks because doing so will cause responses to be recorded incorrectly.”

Do’s and Don’ts during Training

- Securely place the hand trigger on the reported

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dominant hand.

- Make sure the trainee stands comfortably away from the computer desk.
- Do not allow the trainee to listen to the IM sounds or practice any motions prior to taking the Long Form Assessment (LFA).
- Before each task, briefly adjust the trigger, describe and demonstrate the correct movements, and explain how to activate the appropriate trigger correctly. **Note**: You may use the verbal descriptions in Appendix C.
- Do not open any other programs during training. All computer applications including screen savers should be shut off prior to the session.
- Once the task has started, you may physically demonstrate and correct the motion, but only during the first four count-in beats.
- Move through the tasks rapidly to maintain focus.

Begin the Assessment

1. With the trainee file open, select and click "Long Form Testing" from the Task Mode Selector drop-down menu.
2. Three boxes will appear above that field. Check the box labeled "Pre."
3. Select task "1 - Both Hands" from the Task Selector drop-down menu.
4. Click the metronome icon or press the "F2" on the keyboard to begin.

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Long Form Assessments Scores Sheet

To best assess the needs of the trainee, you should take notice of the very early, early, very late, and late percentages as well as the timing tendency. You can use the form below or generate a “Long Form Calculations” report from the “Reports” menu.

Date____/____/______

Task	**ms.**	**Early %**	**Late %**	**Tendency**
1. Both Hands				
2. Right Hand				
3. Left Hand				
4. Both Toes				
5. Right Toe				
6. Left Toe				
7. Both Heels				
8. Right Heel				
9. Left Heel				
10. Right Hand/Left Toe				
11. Left Hand/Right Toe				
12. Balance Right Foot				
13. Balance Left Foot				
14. Repeat #1 – with Guide Sounds				

Pre tested Long Form Battery Calculations:

Hands average: ___________ Feet average: ___________

Average: __________ Tendency: Early ______% Late ______%

Lowest Ms. Score: __________ Bursts: __________

IAR High: __________

Optional - Attend-Over-Time Test

Average: __________

IAR High: ______ Bursts: ______ SRO%: ______

Goal(s): During each session, along with Regular Training, the Short Form should be administered to measure the trainee's ability to stay on task for a short period of time. For this first session, help the trainee understand the guide sounds and learn the motions used in IM training. You may want to listen along with the trainer set of headphones and make sure he/she comprehends which sounds correlate to which type of response. Remind the trainee to focus on the metronome tone. For the hand exercises, demonstrate making continuous circles and tapping in the middle. For the foot exercise, show how to tap each toe and return it to the starting position. Once again, state that all motions should be smooth and not snappy or ballistic. Also, you should begin tracking the total number of

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repetitions in the area provided at the end of each session.

Short Form

1. Select Short Form Testing from the drop-down box.
2. From the next drop-down box, select and have the trainee complete the following tasks:

Ex. 1 – Both Hands (no Guide Sounds)

ms. avg. ______

Ex. 2 – Repeat #1 with Guide Sounds

ms. avg. ______

Regular Training

1. Select “Regular Training” from the drop-down box.
2. Select the appropriate task listed below.
3. Check the “Guide Sounds” box.
4. Manually select the number of repetitions, when necessary.
5. Have the trainee complete the following tasks:

Note: If the optional “Attend Over Time” test was given as part of the initial assessment, reduce the number of repetitions from each of the following tasks by 100.

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Ex. 1 Both Hands (200 reps.) **ms.**

avg.______

Ex. 1 Both Hands (300 reps.) **ms.**

avg.______

Ex. 4 Both Toes (300 reps.) **ms.**

avg.______

Ex. 3 Left Hand (300 reps.) **ms.**

avg.______

Date____/____/______ reps to-date: required 1,676

completed _______

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Session 2: (2,408 reps.)

Goal(s): During this session, help the trainee correct timing tendencies (continually staying on one side of the beat). After the short form, regular training will begin with tasks to attempt countering the timing tendency. For those tasks only, instruct the trainee to hit opposite his/her tendency, but after a period of time to relax again. The trainee likely will move back toward the initial tendency noted, so explain that this is what he/she is learning to adjust.

Short Form

1. Select “Short Form Testing” from the drop-down box.
2. From the next drop-down box, select and have the trainee complete the following tasks:

Ex. 1 – Both Hands (no Guide Sounds)

ms. avg. ______

Ex. 2 – Repeat #1 with Guide Sounds

ms. avg. ______

Regular Training

1. Select “Regular Training” from the drop-down box.
2. Select the appropriate task listed below.
3. Check the “Guide Sounds” box.

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4. Remove the check from the “Auto-Difficulty” box.
5. Manually select the number of repetitions, when necessary.
6. Have the trainee complete the following tasks:

Ex. 1 - Both Hands (500 reps.) **ms. avg.** ______

Ex. 4 - Both Toes (300 reps.) **ms. avg.** ______

7. Check the “Guide Sounds” box.
8. Check the “Auto-Difficulty” box.
9. Have the trainee complete the following tasks:

Ex. 2 - Right Hand (300 reps.) **ms. avg.** ______

Ex. 3 - Left Hand (300 reps.) **ms. avg.** ______

Ex. 4 - Both Toes (300 reps.) **ms. avg.** ______

Ex. 5 - Right Toe (300 reps.) **ms. avg.** ______

Ex. 6 - Left Toe (300 reps.) **ms. avg.** ______

Date____/____/______ reps to-date: required 4,084 completed _______

Session 3: (2,508 reps.)

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Goal(s): Continue countering the timing tendency. The trainee should comfortably stay before or after the beat for at least eight reps. Explain that it is better to hit opposite the initial tendency than to stay far off beat for more than three reps. Warn the trainee when the third tap is not on the beat. During this session, explain what a Burst is (measure of capacity to focus, be attentive, and execute sequential activity); how to attain one (four consecutive hits within fifteen milliseconds of the reference tone); and the importance of increasing the number (indicates an improvement in these capacities). The trainee should aim for a goal of 4 bursts during this session.

Short Form

1. Select “Short Form Testing” from the drop-down box.
2. From the next drop-down box, select and have the trainee complete the following tasks:

Ex. 1 - Both Hands (no Guide Sounds)

ms. avg. ______

Ex. 2 - Repeat #1 with Guide Sounds

ms. avg. ______

Regular Training

1. Select the appropriate task listed below.
2. Check the “Guide Sounds” box.

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3. Verify that there is no check in the “Auto-Difficulty” box.
4. Manually select the number of repetitions, when necessary.
5. Have the trainee complete the following tasks:

Ex. 1 - Both Hands (500 reps.) **ms. avg.** _______

Ex. 4 - Both Toes (400 reps.) **ms. avg.** _______

5. Check the “Guide Sounds” box.
6. Check the “Auto-Difficulty” box.
7. Have the trainee complete the following tasks:

Ex. 10 - Right Hand/Left Toe (500 reps.) **ms. avg.** _______

Ex. 11 - Left Hand/Right Toe (500 reps.) **ms. avg.** _______

Ex. 3 - Left Hand (300 reps.) **ms. avg.** _______

Ex. 7 – Both Heels (200 reps.) **ms. avg.** _______

Date____/____/______ reps to-date: required 6,592 completed _______

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Session 4: (2,508 reps.)

Goal(s): Continue countering the tendency and then attempt to improve hand/foot control. Also, attempt to increase the number of bursts to 5.

Short Form

1. Select “Short Form Testing” from the drop-down box.
2. From the next drop-down box, select and have the trainee complete the following tasks:

Ex. 1 - Both Hands (no Guide Sounds)

ms. avg. ______

Ex. 2 - Repeat #1 with Guide Sounds

ms. avg. ______

Regular Training

1. Select the appropriate task listed below.
2. Check the “Guide Sounds” box.
3. Remove the check from the “Auto-Difficulty” box.
4. Set the “Difficulty” selector to **50**.
5. Manually select the number of repetitions when necessary.
6. Have the trainee complete the following task:

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Ex. 4 - Both Toes (400 reps.) **ms. avg.** ______

7. Check the "Auto-Difficulty" box.
8. Have the trainee complete the following tasks:

Choice of Hands Ex.________ (1000 reps.) **ms. avg.** ______

Ex. 10 - Right Hand/Left Toe (400 reps.) **ms. avg.** ______

Ex. 11 - Left Hand/Right Toe (300 reps.) **ms. avg.** ______

Ex. 2 - Right Hand (300 reps.) **ms. avg.** ______

Date____/____/______ reps to-date: required 9,100 completed ________

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Session 5: (2,408 reps.)

Goal(s): The trainee should continue hitting on the beat and correcting motions such as controlling heel movements. Explain that this session is preparation for the upcoming Midterm Long Form Assessment and he/she should strive to improve In-A-Rows. **All Regular Training sessions from this point on should be performed with the "Guide Sounds" and "Auto-Difficulty" boxes checked, unless otherwise recommended.** Burst Goal = 6

Short Form

Ex. 1 - Both Hands (no Guide Sounds)
ms. avg. ______
Ex. 2 - Repeat #1 with Guide Sounds
ms. avg. ______

Regular Training

Ex. 4 - Both Toes (400 reps.) **ms. avg.** ______
Ex. 1 - Both Hands (1200 reps.)
ms. avg. ______
Ex. 12 - Bal. Rt. Foot/Tap Lt. Toe (100 reps.)
ms. avg. ______
Ex. 13 - Bal. Lt. Foot/Tap Rt. Toe (100 reps.)
ms. avg. ______
Ex. 7 - Both Heels (200 reps.) **ms.**

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avg. _______

Choice of Foot Ex.________ (300 reps.) **ms.**

avg. _______

☐ *Check here* if a *personal best* was achieved on the 1200 reps. task.

Date____/____/_______ reps to-date: required 11,508

completed ________

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Session 6: (2,408 reps.)

Goal(s): Catch up on the required number of reps. to this point. Before starting the session, calculate the total number of reps. completed so far, and if it is short of the expected number, add extra at your discretion. You may want to explain the necessity of completing the required number to the trainee. Burst Goal = 12

Short Form

Ex. 1 - Both Hands (no Guide Sounds)
ms. avg. ______
Ex. 2 - Repeat #1 with Guide Sounds
ms. avg. ______

Regular Training

Ex. 1 - Both Hands (500 reps.) **ms. avg.** ______
Choice of any Ex._______ (1000 reps.)
ms. avg. ______
Ex. 13 - Bal. Lt Foot/Tap Rt. Toe (100 reps.)
ms. avg. ______
Ex. 12 - Bal. Rt. Foot/Tap Lt. Toe (100 reps.)
ms. avg. ______
Ex. 8 - Right Heel (300 reps.) **ms. avg.** ______
Ex. 9 - Left Heel (300 reps.) **ms.**

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avg. ______

☐ *Check here* if a *personal best* was achieved on the 1000 reps. task.

Date____/____/______ reps to-date: required 13,916

completed _______

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Session 7: (2,376 reps.)

Goal(s): Perform the Midterm Long Form Assessment. There is an additional, warm-up which, at your discretion, can be performed prior to the assessment or immediately afterwards. After reviewing the results of the midterm, determine whether the trainee has shown the ability to return to the beat quickly (within two or three beats). If this is not the case and you feel it necessary, discuss adding extra sessions to help the trainee with this goal. For the remaining sessions, the Burst goal should be attained **during one task instead of throughout the session.** Burst goal - 16

Short Form

Ex. 1 - Both Hands (no Guide Sounds)

ms. avg. ______

Ex. 2 - Repeat #1 with Guide Sounds

ms. avg. ______

Warm-up

Select the three tasks the trainee has the most difficulty with. With regular training selected, have him/her perform 200 reps each for a total of 600 reps. Since this is a warm-up, there is no need to record the scores.

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Long Form Testing

1. Select and click "Long Form Testing" from the Task Mode Selector drop-down menu.
2. Check the box labeled "Mid."
3. If not already showing, select task "1 - Both Hands" from the Task Selector drop-down menu.
4. Click the metronome icon or press the "F2" on the keyboard to begin.

Regular Training

Choice of any Ex.________ (1000 reps.)

ms. avg. _______

Select the worst scoring task from the Midterm (not ex. 12 or 13)

Ex.________ (200 reps.) **ms. avg.** _______

☐ *Check here* if a *personal best* was achieved on the 1000 reps. task.

Date____/____/_______ reps to-date: required 16,292

completed ________

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Long Form Assessments Scores Sheet

Date____/____/______

Task	**ms.**	**Early %**	**Late %**	**Tendency**
1. Both Hands				
2. Right Hand				
3. Left Hand				
4. Both Toes				
5. Right Toe				
6. Left Toe				
7. Both Heels				
8. Right Heel				
9. Left Heel				
10. Right Hand/Left Toe				
11. Left Hand/Right Toe				
12. Balance Right Foot				
13. Balance Left Foot				
14. Repeat #1 – with Guide Sounds				

Midterm Long Form Battery Calculations:

Hands average: ___________ Feet average:
____

Average: ___________ Tendency: Early ______%
Late ______%

Lowest Ms. Score: ___________ Bursts: ___________
IAR High: ___________

Optional - Attend-Over-Time Test

Average: ___________

IAR High: _______ Bursts: _______ SRO%: _______

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Session 8: (2,408 reps.)

Goal(s): The trainee should attempt to improve the three worst scoring tasks from the midterm (except tasks 12 and 13). Burst goal -18 (during one task)

Short Form

Ex. 1 - Both Hands (no Guide Sounds)

ms. avg. _______

Ex. 2 - Repeat #1 with Guide Sounds

ms. avg. _______

Regular Training

Worst Midterm Ex. ________ (200 reps.)

ms. avg. _______

2nd Worst Midterm Ex. ________ (200 reps.) **ms. avg.** _______

3rd Worst Midterm Ex. ________ (200 reps.) **ms. avg.** _______

Choice of Hands Ex.________ (1500 reps.)

ms. avg. _______

Ex. 3 - Left Hand (200 reps.) **ms. avg.** _______

☐ *Check here* if a *personal best* was achieved on the 1500 reps. task.

Date____/____/_______ reps to-date: required 18,700

completed ________

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Session 9: (2,508 reps.)

Goal(s): The trainee should continue improving on the worst Midterm task (not Ex. 12 or 13) and practice getting "back on beat" within one tone.

Burst goal - 22 (one task)

Short Form

Ex. 1 - Both Hands (no Guide Sounds)

ms. avg. ______

Ex. 2 - Repeat #1 with Guide Sounds

ms. avg. ______

Regular Training

Worst Midterm Ex._______ (200 reps.) **ms. avg.** ______

Choice of any Ex. _______ (2000 reps.)

ms. avg. ______

Worst Midterm again Ex._______ (200 reps.) **ms. avg.** ______

☐ *Check here* if a *personal best* was achieved on the 2000 reps. task.

Date____/____/______ reps to-date: required 21,208

completed _______

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Session 10: (2,508 reps.)

Goal(s): This session, continue improving on the worst Midterm task (not Ex. 12 or 13). Burst goal - 20 (one task)

Short Form

Ex. 1 - Both Hands (no Guide Sounds)

ms. avg. ______

Ex. 2 - Repeat #1 with Guide Sounds

ms. avg. ______

Regular Training

Choice of Hands Ex. _______ (1500 reps.)

ms. avg. ______

Worst Midterm Ex._______ (300 reps.) **ms. avg.** ______

Ex. 7 - Both Heels (300 reps.)

ms. avg. ______

Ex. 4 - Both Toes (300 reps.)

ms. avg. ______

☐ *Check here* if a *personal best* was achieved on the 1500 reps. task.

Date____/____/______ reps to-date: required 23,716

completed _______

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Session 11: (2,508 reps.)

Goal(s): Burst goal - 20 (one task)

Short Form

Ex. 1 - Both Hands (no Guide Sounds)

ms. avg. ______

Ex. 2 - Repeat #1 with Guide Sounds

ms. avg. ______

Regular Training

Choice of Hand/Toe Ex. _______ (1000 reps.)

ms. avg. ______

Ex. 4 - Both Toes (500 reps.) **ms. avg.** ______

Ex. 7 - Both Heels (500 reps.)

ms. avg. ______

Ex. 3 - Left Hand (400 reps.)

ms. avg. ______

☐ *Check here* if a *personal best* was achieved on the 1000 reps. task.

Date____/____/______ reps to-date: required 26,224

completed _______

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Session 12: (2,508 reps.)

Goal(s): At this point, the trainee should be able to make corrections within one or two reps and should not be off the beat by more than 30 ms. in any direction. Continue working to correct this if it is not the case. Also, to keep interest and/or renew enthusiasm, you may want to allow the trainee to pick one task for this session. Burst goal - 30+ (one task)

Short Form

Ex. 1 - Both Hands (no Guide Sounds)

ms. avg. ______

Ex. 2 - Repeat #1 with Guide Sounds

ms. avg. ______

Regular Training

Choice of any Ex. _______ (2000 reps.)

ms. avg. ______

Ex. 7 - Both Heels (400 reps.) **ms. avg.** ______

☐ *Check here* if a *personal best* was achieved on the 2000 reps. task.

Date____/____/______ reps to-date: required 28,732

completed _______

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Session 13: (2,508 reps.)

Goal(s): Once again, to keep interest and/or renew enthusiasm, you may want to allow the trainee to pick one task for this session. Burst goal - 30+ (one task)

Short Form

Ex. 1 - Both Hands (no Guide Sounds)

ms. avg. ______

Ex. 2 - Repeat #1 with Guide Sounds

ms. avg. ______

Regular Training

Choice of any Ex. _______ (2000 reps.)

ms. avg. ______

Worst Midterm Ex._______ (200 reps.) **ms. avg.** ______

2nd Worst Midterm Ex._______ (200 reps.) **ms. avg.** ______

☐ *Check here* if a *personal best* was achieved on the 2000 reps. task.

Date____/____/______ reps to-date: required 31,240

completed _______

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Session 14: (2,508 reps.)

Goal(s): If the trainee has reached the training goals in terms of millisecond average, explain that the remaining sessions are important to anchor the achievement. If the goals have not been met, discuss extending the number of sessions and why it is important. Burst goal - 30+ (one task)

Short Form

Ex. 1 - Both Hands (no Guide Sounds)
ms. avg. ______

Ex. 2 - Repeat #1 with Guide Sounds
ms. avg. ______

Regular Training

Choice of any Ex. _______ (2000 reps.)
ms. avg. ______

Worst Midterm Ex._______ (200 reps.) **ms. avg.** ______

2nd Worst Midterm Ex._______ (200 reps.) **ms. avg.** ______

☐ *Check here* if a *personal best* was achieved on the 2000 reps. task.

Date____/____/______ reps to-date: required 33,748

completed _______

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Session 15: (2,076 reps.)

Goal(s): This normally will be the last session and will include the Post test Long Form Assessment. The Regular Training tasks are listed immediately under the Short Form but can be administered before or after the assessment according to your discretion. Burst goal - 40+ (one task)

Short Form

Ex. 1 - Both Hands (no Guide Sounds)

ms. avg. ______

Ex. 2 - Repeat #1 with Guide Sounds

ms. avg. ______

Regular Training

Ex. 4 - Both Toes (300 reps.)

ms. avg. ______

Ex. 7 - Both Heels (200 reps.)

ms. avg. ______

Choice of Hands Ex.______ (1000 reps.)

ms. avg. ______

☐ Check here if trainee got a personal best on the above 1000 rep task.

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Long Form Testing

1. Select and click “Long Form Testing” from the Task Mode Selector drop-down menu.
2. Check the box labeled “Post.”
3. If not already showing, select task “1 - Both Hands” from the Task Selector drop-down menu.
4. Click the metronome icon or press the “F2” on the keyboard to begin.

Date____/____/______   reps to-date: required 35,824

completed _______

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Long Form Assessments Scores Sheet

Date____/____/______

Task	**ms.Early %**	**Late %**	**Tendency**
1. Both Hands			
2. Right Hand			
3. Left Hand			
4. Both Toes			
5. Right Toe			
6. Left Toe			
7. Both Heels			
8. Right Heel			
9. Left Heel			
10. Right Hand/Left Toe			
11. Left Hand/Right Toe			
12. Balance Right Foot			
13. Balance Left Foot			
14. Repeat #1 – with Guide Sounds			

Post test Long Form Battery Calculations:

Hands average: ___________ Feet average: ___________

Average: ___________ Tendency: Early ______% Late ______%

Lowest Ms. Score: ___________ Bursts: ___________

IAR High: ___________

Optional - Attend-Over-Time Test

Average: ___________

IAR High: _______ Bursts: _______ SRO%: _______

Additional Sessions

If a trainee has not met the completion goals, and you are able to extend the number of sessions, use the Session 14 format for those sessions. For the last session, follow the Session 15 format.

Notes or Observations:

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Session Short Form Records

	SF date	Task 1	Task 2
Day 1			
Day 2			
Day 3			
Day 4			
Day 5			
Day 6			
Day 7			
Day 8			
Day 9			
Day 10			
Day 11			
Day 12			
Day 13			
Day 14			
Day 15			

Additional Sessions

	SF date	Task 1	Task 2
Day 16			
Day 17			
Day 18			
Day 19			
Day 20			
Day 21			
Day 22			
Day 23			
Day 24			
Day 25			

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IM Training Program Personal Best Achievements

Best Short Forms Pt 1 _____

Date ____/____/_______

Pt 2 _____ Date

____/____/_______

Best 500 rep task Exercise # ____ ms. ____

Date ____/____/______

Best 1000 rep task Exercise # ____ ms.

____ Date ____/____/______

Best 2000 rep task Exercise # ____ ms.

____ Date ____/____/______

Best In-A-Row ____ Exercise # ____ ms. ____

Date ____/____/______

Best 4 Bursts ____ Exercise # ____ ms. ____

Date ____/____/______

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Best IAR % ____ Exercise # ____ ms. ____

Date ____/____/______

Best IAR # ____ Exercise # ____ ms. ____

Date ____/____/______

Pre tested overall ms. avg. ____ Post test overall ms. avg. ____

Note. From *Interactive Metronome: IM Training Guide*, by The Interactive Metronome company, 1997, Grand Rapids, MI: Author. Copyright 1997 by The Interactive Metronome company LLC. Reprinted with permission.

Interactive Metronome® training for a 9-year-old boy with attention and motor coordination difficulties

Synopsis:

This case study shows IM's training results for a 9-year-old boy with attention and motor coordination difficulties being treated by physical therapists.

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Melinda L. Bartscherer, PT, MS & Robin L. Dole, PT, EdD, PCS

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Interactive Metronome® training for a 9-year-old boy with attention and motor coordination difficulties

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The purpose of this case report is to describe a new intervention, the Interactive Metronome,®[1] for improving timing and coordination. A nine-year-old boy, with difficulties in attention and developmental delay of unspecified origin underwent a seven-week training program with the Interactive Metronome.® Before, during, and after training timing, accuracy was assessed with testing procedures consistent with the Interactive Metronome® training protocol. Before and after training, his gross and fine motor skills were examined with the Bruininiks-Oseretsky Test of Motor Proficiency (BOTMP). The child exhibited marked change in scores on both timing accuracy and several BOTMP subtests. Additionally his mother relayed anecdotal reports of changes in behavior at home. This child's participation in a new intervention for improving timing and coordination was associated with changes in timing accuracy, gross and fine motor abilities, and parent reported behaviors. These findings warrant further study.

Introduction

This case report discusses the use of a new computerized intervention that is aimed at improving attention, timing, sequencing, and coordination. Initial reports indicate that this technology, the Interactive Metronome® (IM)[1], may be a useful tool in increasing attention, promoting academic skills, and decreasing aggression in young boys with attention deficit hyperactivity disorder (Shaffer et al, 2001). The intervention is gaining popularity in the media and parents of children with attention and motor coordination difficulties are seeking out individuals who are trained in the approach. Physical therapists need to be aware of the intervention and the relevant science to support it, in order to provide effective consultation and recommendations to their patients and families.

Improving timing, sequencing, and coordination is often a goal of physical therapy but can be quite difficult to accomplish. Overall, therapists have little at their disposal to draw on for guidance other than "common sense" interventions, which appear to have little more than face validity. The purpose of this case report was to describe the application of the IM Intervention on timing for one child and

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Information and data in this case report, in part, was presented at the APTA Combined Sections Meeting in Boston, Massachusetts (2002).

This case report was completed in partial fulfillment of the requirements of Ms. Bartscherer's Doctor of Science degree, Rocky Mountain University of Health Professions, Provo, Utah.

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present the ways in which this child changed over the course of seven weeks.

Evaluating this intervention for scientific merit is important for evidence-based physical therapy practice. This report will also discuss what is currently known regarding the scientific validity of this new intervention and use this information to provide possible explanations for the outcomes reported in this case.

Case description

"John" was a nine-year-old, right-handed, African-American male, whose mother was interested in reports in the news media about a training program that claimed to help improve attention and organization. She described her son as having "difficulty concentrating" and not being "very coordinated." She related that it took him "a long time to get anything done," and that his teachers were concerned over his lack of ability to complete tests within the required timeframe. Additionally he "never liked to color, draw, play with playdough, or do cutting," but has "always been good at figuring things out that interested him." She also commented that he made loose knots in his shoes and it was difficult for him to button his pants.

During the year prior, he attended a private school that focused on experiential learning and therefore did not receive any special education or therapeutic services. At his parents' request, he had not been officially evaluated for learning difficulties, attention problems, or other developmental delays to avoid having him "labeled." He also was not taking medications during the time of this intervention. His mother reported a normal birth and a medical history negative for trauma or illnesses.

Examination

The child was a quiet, thin boy who appeared slightly small for his age. He was polite and followed directions well. During the initial session, it was apparent that he had difficulties with speech articulation that made it difficult to understand him the majority of the time. Additionally, he had difficulty coordinating the movements that comprise the initial metronome testing sequence and got easily tangled in the wires for the headphones and hand trigger that are used in both testing and training sessions. During the initial session, the Interactive Metronome® long-form test (IM LFT) and the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) (Bruininks, 1978) were administered.

Interactive metronome® program

The Interactive Metronome® is a PC-based version of a traditional music metronome and was originally developed for improving timing accuracy in musicians. The equipment utilized for this program included a laptop computer with 200 MHz Pentium Processor, Windows 98 and IMPro 5.0 software. Additional hardware included a hand trigger, foot trigger, and two stereo headphones. The hand trigger is a small circular pressure sensitive trigger approximately 1″ in diameter. It connects by Velcro to a cuff strap that attaches around the individual's hand. The foot trigger consists of two 1″ × 10″ trigger strips aligned in parallel and placed inside a vinyl pad. Both hand and foot triggers are connected to the computer by cables. The stereo headphones are connected to a splitter and then to the computer, thus allowing both the trainer and participant to hear the metronome beat and feedback sounds.

The IMPro 5.0 software generates a computer-based metronome at a set frequency of 54 beats per minute and, through guide sounds, provides bandwidth feedback to the learner following each practice trial (beat of the metronome). The learner performs 1 of 13 tasks and tries to activate the trigger in time with the reference beat of the metronome. The program calculates timing error (absolute error in milliseconds) for each task performed in the session. Additionally recorded for each task are: number of trials considered very early, early, late, and very late, number of trials completed, percentage of trials in which the timing error is 15 milliseconds (ms) or less, and the greatest number of trials in a row in which the timing error is 15 milliseconds or less.

Feedback on timing error, via "guide sounds," is given during training at a relative frequency of 100%. Feedback is auditory only and heard by the learner as high and low tones through stereo headphones. If the learner activates the trigger prior to the metronome beat, the guide sounds are heard in the left ear.

If trigger activation occurs following the metronome beat the guide sounds are heard in the right ear. If trigger activation is within 15 milliseconds of the metronome beat the guide sounds are heard in both ears.

Interactive metronome® testing

The IM LFT is comprised of 14 tasks. The first 13 tasks (see Table 1) are performed with the metronome reference beat only, and the last task (task number 14) is a repeat of the first task and is performed with the metronome beat and guide sounds. When the guide sounds are turned on, the child will hear a second sound that is separate from the reference beat and occurs at the time the trigger is hit. This timing of this sound indicates how close the child's trigger activation is to the metronome reference beat. The guide sounds appear in the left or right ear (indicating either being before or after the metronome beat) and with lower and higher tones (indicating how far off the beat). As the child tries to hit the trigger in time with the metronome beat, timing is measured as the number of milliseconds before or after the beat. Average milliseconds are

Table 1. Descriptions of the 13 IM tasks.

IM task	Description
Both hands	Both hands are moved in circles such that the trigger is hit in midline followed by the hands moving up, out, and around. Circles are approximately 10″ in diameter.
Right hand	The right hand makes a horizontal circle making contact with the thigh then moving forward, out, and back.
Left hand	The left hand makes a horizontal circle making contact with the thigh then moving forward, out, and back.
Both toes	One foot moves forward to tap the toes on the trigger pad while weight is supported on the other foot. Feet are alternated.
Right toe	Weight is supported on the left foot while the right foot toe taps on the trigger pad. The heel of the tapping foot remains on the floor.
Left toe	Weight is supported on the right foot while the left foot toe taps on the trigger pad. The heel of the tapping foot remains on the floor.
Both heels	The trigger pad is placed behind the individual. The individual alternately taps heels on the trigger pad.
Right heel	Weight is supported on the left foot while the right heel taps on the trigger pad. The toe of the tapping foot remains on the floor.
Left heel	Weight is supported on the right foot while the left heel taps on the trigger pad. The toe of the tapping foot remains on the floor.
Right hand/left toe	This is a combination of right hand alternated with left toe. Thus, the hand movement is slowed to occur over two beats (every other beat) as is the left toe.
Left hand/right toe	This is a combination of left hand alternated with right toe. Thus, the hand movement is slowed to occur over two beats (every other beat), as is the left toe.
Balance right foot/tap left	The individual balances on the right foot while keeping the left foot in the air and tapping the left toe on the trigger pad.
Balance left foot/tap right	The individual balances on the left foot while keeping the right foot in the air and tapping the right toe on the trigger pad.

calculated for each of the tasks. Upper limb average is calculated with those activities involving the arms and lower limb average with those activities involving the legs, including tasks that combine upper and lower limbs. Sufficient test-retest reliability ($r = .85$ to .97) for the IM LFT has been reported (Cassily and Jacokes, 2001).

The results of the initial IM LFT revealed that the child had significant timing and movement coordination difficulties. Table 2 describes his timing accuracy for each of the IM LFT items and the calculated upper limb, lower limb, and combined averages. The average time off of the beat at the initial LFT was 159.44 ms. According to the Interactive Metronome Indicator Chart (2003), the average pre-test performance on the long-form test for children between 9 and 10 years of age is in the range of 55–79 ms. Upon closer examination, it was noted that he was less accurate with his feet than with his hands. Additionally, those tasks requiring opposite upper and lower limb coordination were much less accurate than those relying on just one limb or alternating bilateral upper or lower limbs.

Qualitatively, the child exhibited timing deficiency patterns of the disassociative and hyperballistic types. A disassociative pattern is one in which there is no clear association between the child's response of hitting the target and the beat of the metronome. Rather, the responses appear chaotic and random without a discernable pattern. At times the responses are very early, sometimes late, sometimes the individual will respond several times in between beats, other times a beat will be totally missed. In this situation, the individual has difficulty interpreting the metronome beat in order to synchronize his or her movements to it. This difficulty led to the inability to calculate a millisecond average for the first task during his initial long form test (LFT; see Table 2). Additionally, he exhibited movements, which were hyperballistic; rather than being of uniform and smooth speed throughout the movement pattern, his movements were first slow and then very fast, forceful, and ballistic as he moved to hit the trigger. These two patterns are among the six deficiency pattern's that can be identified with the IM testing and training protocol (Burpee et al, 2001; Shaffer

Table 2. Timing accuracy (milliseconds off of the beat) on IM LFT–initial, midterm, and final sessions.

IM task	IM LFT initial (ms)	IM LFT midterm (ms)	IM LFT final (ms)
Both hands	No score obtained*	47.06	23.32
Right hand	53.37	27.38	34.50
Left hand	140.00	33.92	24.86
Both toes	76.11	75.11	26.19
Right toe	337.67	55.47	25.30
Left toe	129.93	51.04	28.07
Both heels	49.48	63.70	26.08
Right heel	69.11	85.10	61.19
Left heel	135.03	75.63	34.97
Right hand/left toe	275.00	78.37	43.88
Left hand/right toe	229.22	24.47	25.93
Balance right foot	193.79	105.35	40.90
Balance left foot	311.56	61.93	21.87
Both hands with guide sounds	110.61	39.13	24.40
Hands average	138.19	36.87	26.77
Feet average	180.69	67.62	33.44
LFT average	159.44	52.25	30.11
Normal for age	55–79		

*Child did not perform enough repetitions in the allotted time to determine a score for this task.

et al, 2001). These represent various timing difficulties that can be exhibited qualitatively and quantitatively with the program, and have been termed dissociative, contraphasic, hyper-ballistic, hyper-anticipatory, hypo-anticipatory, and auditory hypersensitivity.

The child also exhibited motor planning difficulties, which were worse with his legs than his arms. When doing the tasks of alternating toe taps, unilateral toe taps, or alternating heel taps, he had difficulty organizing the movement without hand over foot assistance. His foot would drift out of the target field or he would spontaneously shift to a different task. He was unable to continue the task pattern for more than 3 to 5 repetitions without assistance.

Motor skill testing

The child's motor skills were assessed via administration of the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP). The BOTMP is a standardized, norm referenced test used to assess gross and fine motor skills in children between the ages of 4.5 and 14.5 years of age. The purported uses of the test include making decisions about educational placement, assessing gross and fine motor skills, developing and evaluating motor training programs, and assisting researchers and clinicians. Psychometric properties have been reported with established face validity, content validity, internal consistency, test-retest ($r = .88$), and inter-rater reliability ($r = .98$; Bruininks, 1978). The test is divided into gross motor, upper-limb coordination, and fine motor subtests. Gross and fine motor as well as total battery composites are calculated by converting the raw scores to standard scores based on the child's age. Percentile ranks and stanines can then be determined.

The results of the BOTMP revealed that John exhibited significant delays in both gross and fine motor skills, with the greater deficiencies noted in fine motor skills. The Battery Composite revealed that he scored below the 1st percentile rank and in the first stanine when compared to children of similar age (see Table 3).

Evaluation

According to the Diagnostic and Statistical Manual of Mental Disorders-Fourth Edition

Table 3. Results of Bruininiks-Oseretsky test of motor proficiency - initial and final sessions.

BOTMP complete battery	Point score		Standard score		Composite score		Percentile rank		Stanine	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Gross motor subtests										
Running speed and agility	8/15	8/15	10	10						
Balance	8/32	17/32	1	3						
Bilateral coordination	10/20	11/20	13	14						
Strength	16/42	17/42	10	11						
Gross motor composite			34	38	31	34	3	6	1	2
Upper limb coordination	15/21	12/21	8	2						
Fine motor subtests										
Response speed	9/17	13/17	15	23						
Visual-motor control	12/24	13/24	2	3						
Upper limb speed and dexterity	26/72	32/72	2	7						
Fine motor composite			19	33	25	39	1	14	1	3
Battery composite			61	73	24	30	<1	2	1	1

(American Psychological Association, 1994), the child exhibited many of the behavioral characteristics consistent with two specific diagnoses; attention deficit hyperactivity disorder—inattentive type and developmental coordination disorder. Though he had not been formally diagnosed with either of these conditions, the result of motor skill testing revealed that his performance was markedly below that of his same aged peers and his parents confirmed that his inattentiveness, poor motor coordination, and impaired motor skills were negatively impacting his participation at school and home.

Diagnosis and prognosis

According to the Guide to Physical Therapist Practice, the child's difficulties are consistent with the preferred practice pattern 5B: Impaired Neuromotor Development (American Physical Therapy Association, 2001). Given that his motor skills were so far below his peers and acknowledging what is known from the literature on children with developmental coordination disorder (Barnhart, Davenport, Ebbs, and Nordquist, 2003), his difficulties are not likely to improve without intervention and can be expected to contribute to problems of low self-esteem and poor social interactions. The child would be a candidate for traditional physical therapy intervention aimed at improving his overall motor coordination and specific skills needed for active participation with his family and peers. The Guide provides an estimate of number of visits between 6 and 90 in order to achieve the expected and desired outcomes of intervention. Based on the examination findings and the information found in the literature (e.g. Pless, Carlsson, Sundelin, and Persson, 2001; Polatajko et al, 1995), it would be reasonable to expect an initial program of intervention to cover at least 10 to 20 sessions.

Intervention

The Interactive Metronome® intervention took place over a 7-week period during the summer when the child was off from school. During this time, he did not receive other therapy services nor did he participate in any school, academic or sports related activities, other than what he did at home with his family.

The Interactive Metronome® intervention consists of approximately 15 to 20 sessions of practice using a variety of upper and lower limb tasks as are found in the IM LFT. Sessions were scheduled for three times weekly, with at least one day of no training in between sessions. During the first half of the program, the primary goals were to learn the tasks and the meaning of the guide sounds that were used to provide feedback on performance. The focus of the last half of the program was on increasing accuracy and consistency. Within the program, the child optimally works up from being able to do 100 to 200 repetitions of a single task without rest to a maximum of 2,000 repetitions of a single task without rest. Repetitions are set at a frequency of 54 beats per minute; therefore a 2,000 repetition task takes approximately 40 minutes to complete.

Each session began with a retention test, the short form test (IM SFT), which consists of 2 trials of 54 repetitions (1 minute) each of the "both hands" task. For the both hands task, John moved both hands in a circular fashion in front of his body and activated the hand trigger when his hands came together. For the first trial in the IM SFT, the child heard only the metronome reference beat. In the second trial, he heard the metronome reference beat and the guide sounds. After the IM SFT, he engaged in several tasks with the total number of repetitions in a single session ranging from 1,500 to 2,500. Each session lasted approximately 1 to 1.5 hours.

In order to help decrease the dissociative timing pattern and improve his ability to perform the tasks required of the IM program, the child participated in four recommended pre-sessions prior to starting the typical 15 session IM protocol. The pre-session training was to aid in understanding the meaning of the metronome beats and guide sounds and developing basic skill at hitting the trigger in time with the metronome beat. The number of pre-sessions was not predetermined, rather pre-sessions were continued until his dissociative pattern had decreased and his understanding of the connection of his movements to hit the trigger and the metronome beat had improved. Tasks practiced during the pre-sessions included providing hand-over-hand

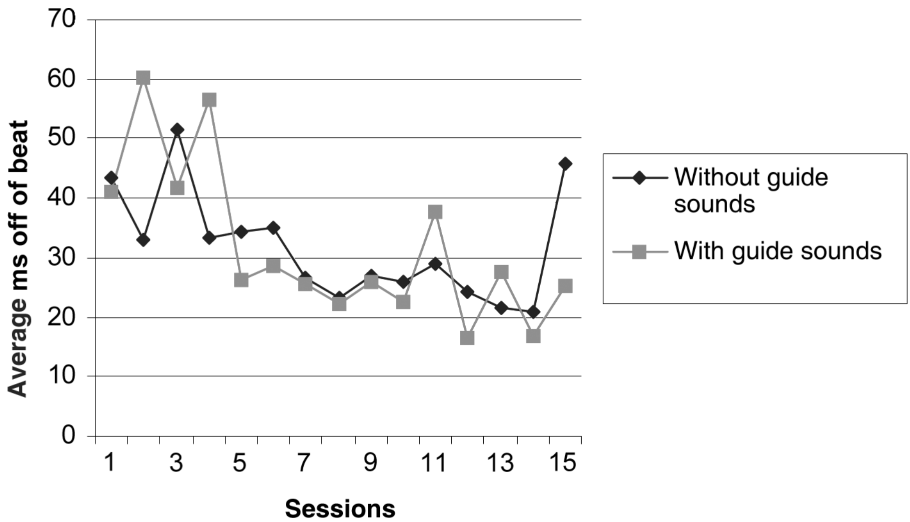

Figure 1. Short Form Test scores over time.

assistance, playing "patty cake," tapping knees then clapping hands, "high fives," and using verbalizations on the beat, in addition to the regular tasks of "both hands" and "both toes." On the fourth pre-session, the child had decreased his short form test score to 43.43 seconds without feedback sounds and 40.98 seconds with feedback sounds and it was determined that he was ready to complete the 15 session program (see Figure 1).

As the child progressed through his sessions, several items were recorded for each task practiced including the number of "right on" repetitions in a row (IAR) and the number of "bursts." Being "right on" the beat is defined as being within 15 milliseconds of the beat, with four "right ons" in a row considered a burst. These are determined by the IM software and tracked on a spreadsheet through each session. He was encouraged to do his best with the present goals relating to the number of IARs and bursts he was working toward. In general, the goals were based on what was achieved in previous sessions and his motivation. Personal best scores for bursts and IARs were recorded (see Table 4).

Example training session

All sessions were conducted in a closed and quiet room. The selection of tasks and repetitions to perform per task in a given session is prescribed in the standard IM protocol. The computer was set up on a table and both John and the therapist wore headphones. The therapist could hear the same sounds and feedback that the child heard while he practiced each task.

Table 4. Personal best records during training.

Session number	Burst record	IAR record	Task	Number of repetitions in task
2	5		Right hand	300
4	13	11	Both hands	1,000
5	19		Both hands	1,200
7	41		Both hands	1,000
9	65		Both hands	2,000
10	72	12	Both hands	1,500

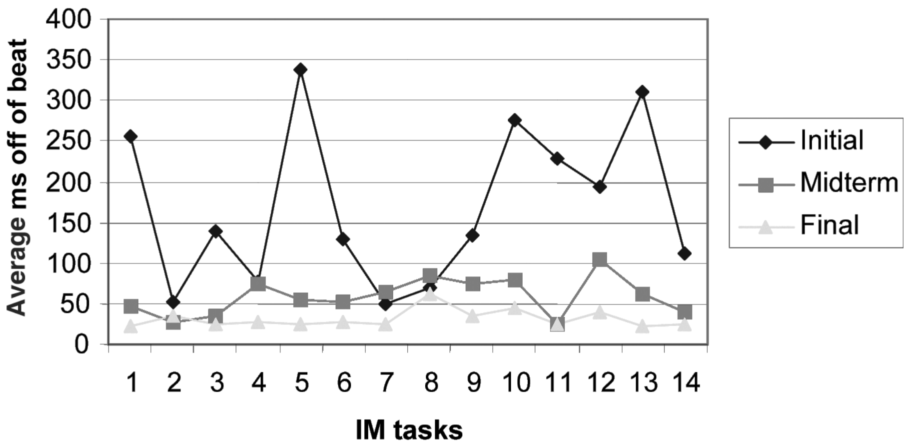

Figure 2. Performance on each task of the Long Form Test—initial, midterm, and final.

He stood for all tasks and was allowed to sit in between tasks to rest. The child had difficulty managing the cables for the hand trigger and headphones coming from the computer. He frequently became entangled such that he had difficulty doing the tasks. To improve this, he faced away from the computer so that all cables went away from his back going to the computer. Because of his difficulty with his foot movement, the floor trigger tended to move. This problem was solved by placing Velcro on the bottom of the trigger, keeping it firmly in place on the carpeted floor.

All training sessions began with the IM SFT. A verbal description and visual demonstration of the task to be performed was given prior to beginning each task. Each session followed the protocol for use with the Interactive Metronome® and contained many of the same tasks that were included in the IM LFT. Initially, physical assistance was given to his feet. This was diminished over time such that by the 6th session he no longer needed physical guidance. For a description of how the program increases the amount of time spent on a single task over the course of several sessions and the number of repetitions per session, see Table 5.

Outcomes

IM goals

Following four pre-sessions and 15 regular sessions of IM, the child had achieved many of the goals related to successfully completing the IM training protocol. He was able to perform a 2000 repetition task that required him to stay focused and moving to the metronome beat for 40 minutes. He achieved a high of 72 bursts and a high of 12 IARs ("right on" hits of the trigger in a row), each within a single 1000 or more repetition task. He was able to pay attention to the task such that he consistently corrected his pattern within one to three beats of the metronome. The child no longer required physical guidance to perform any of the movements. Qualitatively, his movements appeared much more coordinated and he had developed a new smoothness to his movements reflective of his less ballistic tendencies.

Short form tests

The child had consistent decreases in average milliseconds off the beat as seen by his short form test results (see Figure 1). This figure represents his averages during the 15-session protocol. He began at session one with SFT results in the 40-millisecond range and was able to steadily decrease these to the 20-millisecond range over the 15 sessions.

He was able to achieve many personal bests with regard to number of IARs and bursts throughout the training sessions. Table 4 represents each new record. He made quick and consistent gains in the first ten sessions. Though he continued to do well in the last 5 sessions he was

Table 5. Session descriptions to illustrate how time and repetitions on task was increased.

Session number	Number of repetitions	Description of session
Session 2	Approx. 2,400	• IM SFT (108 repetitions) • 500 repetitions of correcting faulty timing (purposefully going before or after the beat) • 300 repetitions each of correcting faulty timing in both toes, right hand, left hand, both toes, right toe, and left toe (total – 1,800)
Session 6	Approx. 2,400	• IM SFT (108 repetitions) • 500 repetitions of staying before or after the beat • 1000 repetitions of the child's choice • 100 repetitions each of balance on one foot, tap with the other (total – 200) • 300 repetitions each of right and left heel (total – 600)
Session 10	Approx. 2,500	• IM SFT (108 repetitions) • 1500 repetitions of non-leg choice • 300 repetitions each of improving the worst task from the midterm long form test, both heels, and both toes (total – 900)
Session 13	Approx. 2,500	• IM SFT (108 repetitions) • 2000 repetitions of the child's choice • 200 repetitions each of the two worst tasks from the midterm long form tests (total – 400)

not able to top the records set on session ten. As can be seen, all of his records were set with upper extremity tasks performed over relatively large numbers of repetitions (1000+ repetitions).

Long form tests

As noted in Table 2, the child made notable gains in his timing accuracy over the course of training. He began IM training with an overall timing accuracy of 159.44 ms off of the beat. By the midterm IM LFT (session 7 in the 15 session protocol) he had decreased this to 52.5 ms and by the final IM LFT had decreased this to 30.11 milliseconds. Based on the Interactive Metronome Indicator Chart (2003), for individuals of his age these scores represent a change from approximating a severe timing deficiency (160–259 ms) to being above average for his age (below 37 ms). The areas of his largest improvements included tasks with his left hand, right toe, combining hand on one side with foot on other, and balancing on one foot while tapping with the opposite toe. As seen in Figure 2, the child showed a trend toward decreased variability across the 14 tasks when comparing the initial, midterm, and final long form tests.

Motor skills testing

With regard to his performance on the BOTMP, the child again made appreciable changes over the course of seven weeks. As can be seen in Table 3, he made gains on standard scores in every subtest except for running speed and agility, and upper limb coordination. Most notably, however, are the improvements in response speed, visual motor control, and upper limb speed and dexterity. Of clinical significance is the change in percentile rank (a measure of how his skills compare to his same age peers) seen in the fine and gross motor composites as well as the battery composite. The child improved in the gross motor composite from performance in the 3rd percentile to the 6th percentile. In the fine motor composite, he improved from the 1st percentile to the 14th percentile. Lastly, he improved in the battery composite from the below the 1st percentile to the 2nd percentile. This is important clinically when considering he did not engage in any specific therapeutic interventions or recreational activities geared at improving the skills tested in the BOTMP.

Also worthy of note is the change seen in point scores on the BOTMP. In their study of the use of the BOTMP, Wilson, Polatajko, Kaplan, and Farris (1995) recommend that if this test is being used to evaluate change over time, an assessment of changes in point scores may be more reflective of change than standard and test composite scores. This provides an evaluation of the child's current performance with previous performance rather than the child's current performance relative to children from the normative sample, which would require that the child show improvements that obtained quicker than what is obtained through time and maturation. A review of the child's performance in point scores on the BOTMP (see Table 3) shows that he made the largest improvements in balance, response speed, visual-motor control, and upper limb speed and dexterity. Smaller changes were noted in bilateral coordination and strength. No change was noted in running speed and agility, and a decline in performance was noted with upper limb coordination.

Parent observations

During the second half of the training sessions, the child's parents reported changes they had noticed in his behavior. His father noted that he was more cooperative with his sister evidenced by decreased resistance to sharing TV time and in choosing sides in the car. His mother described a rule in their house that requires him to read to his younger sister everyday. Usually this turned into an argument or a fight very quickly. During the latter part of the IM training his mother noticed that the fighting had stopped and that he was now reading to his sister for 15 to 20 minutes without difficulty.

She also reported that he appeared more willing to take risks. This was evidenced to her when he asked her if he could try riding his father's bicycle and then asked for a similar "big bike" for his upcoming birthday. This was surprising to her because he had many previous, unsuccessful attempts at trying to learn to ride, and she thought he had given up. She was also surprised because his father's bike had thumb gears, which he was now able to manage.

He had been practicing math problems, as this was an area identified by his teacher as being problematic in school as he was unable to complete a series of math problems in a timely manner. His mother felt that his speed had picked up significantly during the course of IM training. She also noted that his handwriting was age-appropriate after the intervention training. She described that it had been difficult to distinguish lower from upper case letters and that he typically made all of his letters the same size. His mother reported that there was now greater distinction between the lower and uppercase letters.

Discussion

This case report discussed the outcomes related to timing and motor coordination in a 9-year-old boy after participation in a 7-week program of training with a specialized computer program using a metronome beat and guided feedback. Several notable changes occurred that might be attributable to the intervention, including the changes observed on the IM LFT, IM SFT and the BOTMP. Also of interest, however, are the anecdotal changes reported by the child's parents, some of which were related to motor function but most of which were related to affective or organizational behavior.

The literature related to the phenomenon of timing itself, specifically related to finger tapping (Ivry, 1996), and the neuroanatomical correlates related to timing (Rao et al, 1997) may be helpful in explaining the potential effect of the Interactive Metronome® training. Irvy (1996) and others (Ivry and Hazelton, 1995; Ivry and Keele, 1986) have studied the phenomenon of timing for several decades. In a frequently cited study, the results led to the hypothesis that there may be a common and central timing mechanism that governs all movements (Ivry and Hazelton, 1995). This "central clock" may be responsible for the breadth of timing issues ranging from perception of time, such as having a sense for how long a minute is or being able to distinguish between music that has a fast tempo versus a slow tempo, to being able to precisely time one's movements to an external source such as an orchestra conductor or precisely time one's agonists to antagonists in order to reach out for a glass of water. A main tenet of the theory of a central clock is that if one could find a means for training the central clock then the timing and coordination of all movements may improve. There is evidence that children considered to be "clumsy" may have altered time perception (Williams, Woollacott, and Ivry, 1992). While the child was not officially diagnosed as being clumsy or having developmental coordination disorder, he presented with many of the typical motor behaviors of children with this diagnosis. He also exhibited initial scores on the BOTMP that indicated significant delays in gross and fine motor skills.

Similar to the IM training process, experimental studies of timing of movement at the functional level using a metronome have been done to train gait in adults with central nervous system dysfunction such as stroke (Prassas, Thaut, McIntosh, and Rice, 1997) and Parkinson's Disease (McIntosh, Brown, Rice, and Thaut, 1997; McIntosh, Rice, Hurt, and Thaut, 1998). This work has shown a positive training and carryover effect with metronome training. In a training protocol that lasted three weeks, changes in temporal and kinematic components of gait were noted immediately after the training and continued through a one-month follow up (McIntosh, Rice, Hurt, and Thaut, 1998; Thaut, Kenyon, Schauer, and McIntosh, 1999).

This child was able to synchronize his movements to the beat of the metronome during the training protocol. Unlike the studies by Thaut and colleagues (Thaut, Kenyon, Schauer, and McIntosh, 1999; Thaut, McIntosh, Rice, and Prassas, 1993), however, the synchronization was not immediate. In the present case, the child required significant physical assistance and guidance to entrain his movements to the beat. One difference may lie in the presence or absence of a timing deficiency pattern and if one is present, the type of pattern. In this case report, the child exhibited a disassociative pattern that may have represented a lack of an accurate internal time precept.

The studies that used metronome training for gait were done without guide sounds or feedback and the training was task-specific. In this case, the child received guide sounds that provided feedback on accuracy. In addition the movements practiced during training were the same as those on the long and short form tests, but they were not the same as those tested on the BOTMP. It is logical to assume that practicing thousands of repetitions of a task would lead to improved performance on those tasks when a retention test without feedback is given. Evidence in the motor learning literature supports this notion (Schmidt and Lee, 1999; Shumway-Cook and Woollacott, 2001). Findings less explainable are the improvements observed in the BOTMP. The child did not practice the BOTMP test items, was not engaged in therapy interventions for motor skills, and was not involved in additional recreational activities during the weeks of IM training. If it were true that the IM training was associated with the change in BOTMP scores, this may lend support for the central clock theory. The IM training may in some way impact the function of a central time keeper such that when it is called into action for even a small set of movements and functions, overall movement and function are improved.

The child presented here exhibited some behavioral changes that where not strictly related to motor skills. His parents reported changes in his risk taking, ability to get along with his sister, ability to put his own desires aside for the sake of his sister, and his ability to stay focused to read and complete timed math problems. The connection of these behaviors to IM training appears, at the surface to be more remote. An experimental study examining the effects of IM on academic, affective, and motor performance in children with ADHD showed significant changes in the area of affective control. The children who received IM training were also significantly less aggressive (Shaffer et al, 2001) following 15 sessions of IM.

Alternative explanations

This case report was not a controlled study and as such, cannot assert that IM training contributed to the observed changes in this specific child. It is possible that other factors played a role. This child had the opportunity to work on isolated motor skills with feedback for approximately 20, one to one, 30 minute sessions. This could have accounted for some improvement in movement performance. Additionally, he received one to one instruction and attention by an adult. This may have been highly motivating to this child and contributed to the observed changes.

The child's parents were highly vested in seeing positive change in their son. Though the training was provided free of charge, they were making significant efforts to bring their son to the training and had sought out the training specifically for the types of changes noted. Their vested interest in observing change may have contributed not only to their positive interpretation of his actions but their interest may also have impacted John's behaviors.

Lastly, IM training itself is complex and multifaceted. The training program includes approximately 35,000 repetitions. Instantaneous feedback is provided on 100% of the practice trials, and there are 13 specific tasks practiced. One could hypothesize that any one of these variables may have led to the behavioral outcomes; for example, the shear number of repetitions of a task could lead to a practice effect. Further investigation is needed to understand how each of the IM components may contribute, individually and collectively, to improved timing, coordination and attention.

Conclusion

This case report provides clinical evidence that this intervention can be applied safely, and was well tolerated by the child. It also appeared to be associated with positive changes in behaviors as reported by parents and as evidenced in clinical measures. The results of this case report also raise intriguing questions that warrant future research that is well designed and controlled. Such research would help to clarify the relationship between IM training and behavioral changes including those that are motoric, affective, and organizational. If a relationship can be established, the next step may be to identify whether there are key components at play or whether the combination of IM factors is the critical aspect. In addition to forging an improved understanding of the effects of IM in children such as the child presented in this case, it will also be important to determine if a training effect occurs in other populations.

Acknowledgements

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

Synopsis:

A summary of a study using fMRI in defining the organs of the brain activated in repetitive auditory-motor training and the potential of IM to make improvements in those areas.

Year:

2004

Publication:

White paper presented at national PM&R conference 2004

Author:

Dr. Neal Alpiner: MD

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.

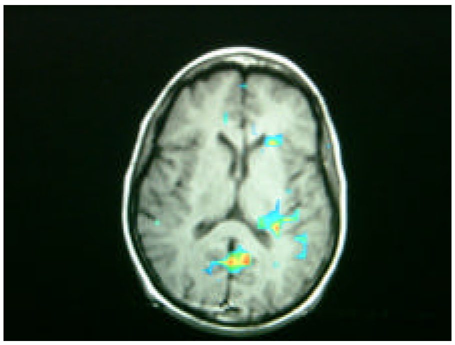
RESULTS: 5/7 subjects revealed increased activity at right Calcrine Sulcus, 3/7 showed bilateral increased activity at Cingulate Gyrus. 5/7 subjects showed increased activity at left posterior Temporal Gyrus, 2 patients show bilateral increased temporal activity. 3/7 patients show increased activation 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.

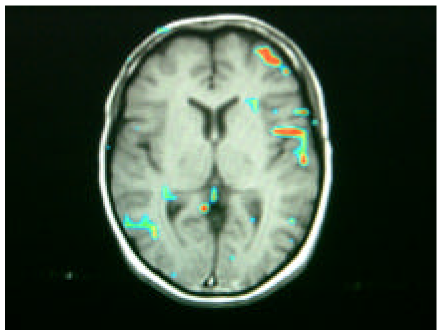
CONCLUSION: Auditory-motor processing is complex, working through multipal neuronetworks. This present study provides a preliminary analysis of possible structures involved, specifically: Cingulate Gyrus, Temporal Gyrus, Superior Frontal Gyrus. Of note is the significance of bilateral activation for 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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Improving Motor Planning and Sequencing to Improve Outcomes in Speech and Language Therapy

Synopsis:

Dr. LorRaine Jones, a Speech-Language Pathologist helps explain the connection between IM's timing exercises and improvements in speech and language therapy.

Year:

2004

Publication:

White paper presented at national ASHA conference 2004

Author:

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

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Material

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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."

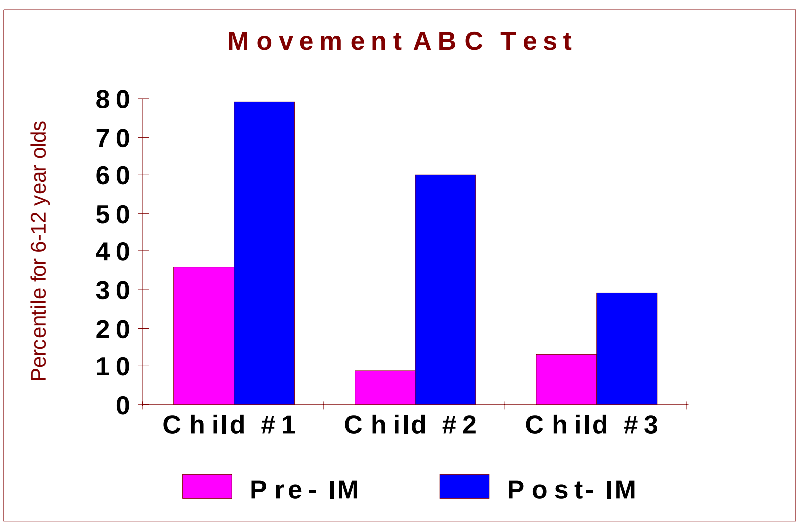
Interactive Metronome combines the principles of a traditional, musical metronome with the precision of a personal computer to create engaging interactive training exercises. Its patented auditory guidance system progressively challenges participants, to improve their motor planning, sequencing and timing, 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 <u>Movement ABC Test.</u> 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.

Synopsis:

A study of 13 patients measured across a broad spectrum of function shows that gains made with IM are still present 6 months after therapy was completed.

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Lee E. Jacokes, Ph.D.

PATHWAYS CENTER
FINAL STATISTICAL ANALYSIS

Interactive Metronome, Inc.

Prepared by Lee E. Jacokes, Ph.D.

May 2003

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

Synopsis:

A white paper by psychologist Dr. Susan Diamond explaining the scientific background to the benefits seen by using IM.

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Processing speed and motor planning: the scientific background to the skills trained by Interactive Metronome® technology
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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).

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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 priopriocepti ve 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

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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

Synopsis:

This study of 40 4th and 5th grade "at risk" children showed dramatic gains in reading and math fluency in only 4 weeks. 40 similar students in the control group showed no improvement at all.

Year:

2003

Publication:

White paper presented at the annual meeting of the National Association of Elementary School Principals

Author:

Dr. Cindy Cason, Ph.D.

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.

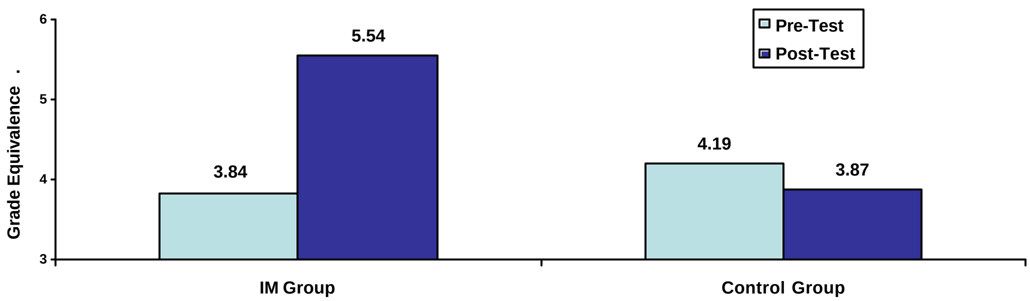
Results – Reading

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).

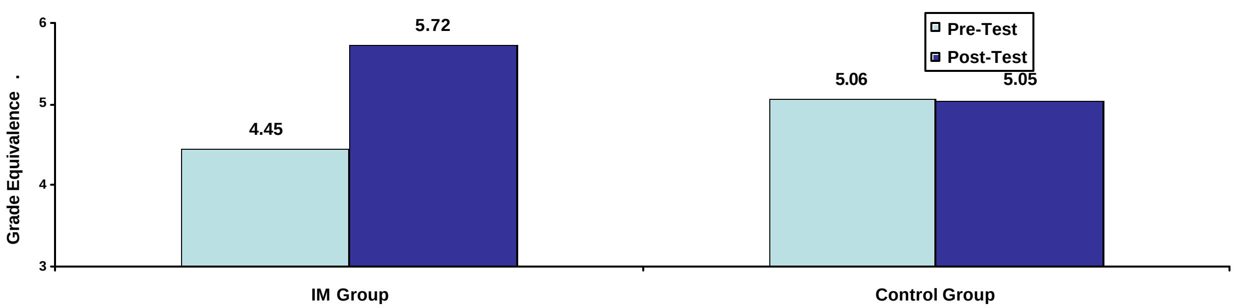
The STAR results showed that the students increased from an average of one to two grade levels. Students who received the IM training achieved a strong result in their fluency and comprehension during STAR testing. As a group, the students who received the IM intervention increased their Ability-Achievement 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.

Interactive Metronome - Underlying Neurocognitive Correlates of Effectiveness

Synopsis:
A white paper by psychologist Dr. Patrick Gorman explaining the underlying neurocognitive mechanisms of IM training.

Year:
2003

Publication:
White paper

Author:
Dr. Patrick Gorman

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, lamish, 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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Training in Timing Improves Accuracy in Golf

Synopsis:

This published study demonstrates a connection between IM's timing exercises and improvements in complex movements as seen in dramatic improvements in golf shot accuracy.

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Training in Timing Improves Accuracy in Golf

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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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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	Session 2	Session 3	Session 4	Session 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

Task	IAR Pre	IAR Post	Target deviation Pre	Target deviation 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)

	IAR		Target deviation	
Task	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

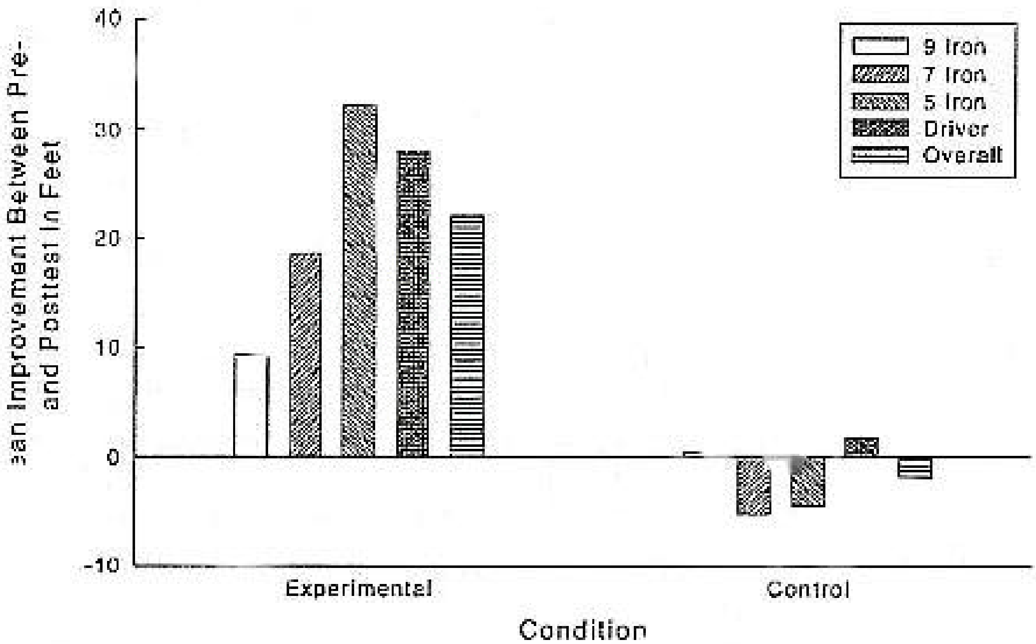

FIGURE 1. Mean improvement as a function of club and treatment group.

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-

[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

Synopsis:

A study of 585 children found significant correlations between the students' mental timing as measured by IM and their academic performance in reading, math, language, science, social studies and personal study skills. This study shows that brain timing plays a foundational role in a child's academic performance.

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TIMING IN CHILD DEVELOPMENT

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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

	Metronome Timing			Musical Timing	
Variable	*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

	Metronome Timing[b]				Musical Timing[c]		
Age	*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 ($p < .05$) f rom 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 Achieveme nt 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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Theoretical and Clinical Perspectives on the Interactive Metronome®: A View From Occupational Therapy Practice

Synopsis:

This published white paper includes the perspective of six Occupational Therapists describing IM's usefulness in addressing school, home and social relationship problems in children.

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

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

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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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Effect of Interactive Metronome® Training on Children with ADHD

Synopsis:

A study of 56 pre-teen boys diagnosed with ADHD found that those using IM showed statistically significant improvement in attention and concentration, motor coordination, language processing, reading and math fluency and the ability to control impulsivity.

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Effect of Interactive Metronome® Training on Children With ADHD

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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.*

Shaffer, R. J., Jacokes, L. E., Cassily, J. F., Greenspan, S. I., Tuchman, R. F., & Stemmer, P. J., Jr. (2001). Effect of Interactive Metronome® training on children with ADHD. *American Journal of Occupational Therapy, 55,* 155–162.

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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 regulation, including inhibition (Schonfeld, Shaffer, & Barmack, 1989), speed, rhythm, coordination, and overflow (Barkley, Koplowitz, Anderson, & McMurray, 1997; Denckla, Rudel, Chapman, & Krieger 1985; Piek, Pitcher, & Hay, 1999). Gillberg and Gillberg (1988) described a group of children with deficits in attention, motor control, and perception (termed DAMP syndrome), and in a recent study, Kadesjo and Gillberg (1998) found considerable overlap between attention deficits and motor clumsiness. In this group of children, the combination of both attentional and motor problems tends to worsen the prognosis (Hellgren, Gillberg, Bagenholm & Gillberg, 1994; Hellgren, Gillberg, Gillberg, & Enerskog , 1993). Piek et al. (1999) demonstrated that the severity of inattentive symptomatology in boys with ADHD is a significant predictor of motor coordination difficulties. Furthermore, recent work has suggested that approximately half of all children with developmental coordination disorder (DCD) have moderate to severe symptoms of ADHD, and a diagnosis of DCD at 7 years of age has been associated with restricted reading comprehension at 10 years of age (Kadesjo & Gillberg, 1999).

According to the Developmental, Individual-Difference, Relationship model (Greenspan 1992; Greenspan & Wieder, 1999), which uses dynamic systems theory (Gray, Kennedy, & Zemke, 1996a, 1996b; Smith & Thelen, 1993) to understand children's adaptive and maladaptive behavior, a child brings a variety of unique processing capacities, including motor planning and sequencing, into interactions with others and the physical environment in order to construct complex adaptive patterns, such as attending to and carrying out multistep actions in school and at home. Furthermore, considerable overlap exists in the neural networks involved in ADHD and the regulation of timing and the motor planning. These networks involve the prefrontal and striatal regions of the brain. A study using functional magnetic resonance imaging demonstrated that children with ADHD had subnormal activation of prefrontal systems responsible for high-order motor control (Rubia et al., 1999).

The relationship between motor regulation and attentional and executive functions suggests that technologies aimed at strengthening motor planning, sequencing, timing, and rhythmicity may have a role in improving the capacity to attend and learn (Greenspan, 1992). The Interactive Metronome®, a patented, PC-based interactive version of the traditional music metronome developed in 1992 (Cassily, 1996), is a new educational technology aimed at facilitating a number of underlying central nervous system processing capacities hypothesized to be involved in motor regulation. Noninteractive metronomes have been used as temporal teaching tools since being invented in 1696 by Étienne Loulié. The Interactive Metronome is the first to use the capabilities of modern computers to add an interactive element to this traditional tool. Instead of users having to rely on their own mental estimations of their temporal accuracy, the Interactive Metronome provides accurate (to .5 ms), real-time guide sounds to indicate users' temporal accuracy as they perform a series of prescribed movements. The tonally and spatially changing guide sounds enable users to deliberately correct their rhythmicity and timing errors as they are occurring.

Preliminary studies have shown that the level of a person's performance on the Interactive Metronome that involves planning, timing, and rhythmicity of motor regulation correlates with the severity of developmental, learning, and attentional problems, improvements in academic performance, and age-expected performance changes during the school years (Kuhlman & Schweinhart, 1999). Children with a range of developmental and learning problems in special education classes who trained on the Interactive Metronome have demonstrated gains in motor performance compared with a similar group without such training who demonstrated no gains over the same period (Stemmer, 1996).

Libkuman and Otani (1999) showed that Interactive Metronome training can improve motor control, focus, and athletic performance in golfers. The present study is the first controlled clinical trial of Interactive Metronome training on a group of children who meet the DSM-IV criteria for ADHD (American Psychiatric Association, 1994). The purpose of this study was to determine the effects of the Interactive Metronome on selected aspects of motor and cognitive skills in a group of children with ADHD.

Method

Design

This research used an experimental pretest–posttest measurement design (see Table 1). An Interactive Metronome treatment group was compared with a video treatment group and a traditional control group receiving no interventions.

Sample

Participants were drawn from the population of 6-year-old to 12-year-old boys with ADHD living in the greater metropolitan area in which the study was conducted. Seventy-

Table 1
Experimental Research Design

Treatment Group	Pretesting	Training	Posttesting
Interactive Metronome® (n = 19)	•	15, 1-hr sessions over a 3-week to 5-week period	•
Video game (n = 19)	•	15, 1-hr sessions over a 3-week to 5-week period	•
Control (n = 18)	•	None	•

five volunteers verified clinically as meeting DSM-IV criteria for ADHD by pediatricians, pediatric subspecialists, and psychologists or psychiatrists were recruited through local school districts, physicians, psychologists, psychiatrists, and advertisements in a local newspaper. All testing and treatments were given at no cost to the participants' parents. Test administrators screened, pretested, and posttested each child who was randomly assigned to them. All test administrators were paid, qualified psychometricians or licensed occupational therapists certified in administering their respective tests. Test administrators were not informed about the study's purpose and were blind to who received what treatment.

As a result of the screening, 19 boys were dropped from the volunteer pool because they either did not meet the clinical or research criteria or had severe learning, cognitive, neurological, anxiety, or depression problems. Demographically, the 56 qualified participants were 6 years to 12.5 years of age. Eighty-six percent were Caucasian, and 14% were of other races. Thirty-two percent had parents or guardians with annual incomes under $40,000, 38% from $40,000 to $69,000, and 30% with $70,000 or more. Eighty percent had parents or guardians with a college education.

Both parents and children were told that the purpose of the study was to "explore the use of nonpharmacological methods in the treatment and management of ADD and ADHD" and that the "treatments to be used in the study were interactive, computer-based treatment programs." No further information about the study was provided until completion of treatment and posttesting. One participant was belligerent toward his administrator and was removed from the study after the 2nd day. After completion of the study, the participants assigned to the video game and control groups received the Interactive Metronome treatment.

Instrument

Three major categories of performance were targeted for evaluation. The assessments were selected from those most commonly used by the psychological, occupational therapy, and educational communities. Only assessments that have been shown to be reliable and valid were used (see reference for each instrument). Summary and subtest scores from the following instruments were used to assess these categories of performance:

- *Attention and concentration:* (a) Tests of Variables of Attention (TOVA) is a 25-min computer-based assessment and one of the most widely used objective measures of ADHD (Greenberg & Dupuy, 1993). (b) Conners' Rating Scales–Revised (CRS-R), Teacher and Parent versions, is a questionnaire completed by the parents and teachers and one of the most widely used subjective measures of ADHD (Conners, 1990). (c) Wechsler Intelligence Test for Children–Third Edition is a well-known and widely accepted test of intelligence for children (Wechsler, 1992). (d) Achenbach Child Behavior Checklist is a questionnaire completed by parents that measures internalized problems and external behaviors (Achenbach & Edelbrock, 1991).
- *Clinical functioning:* (a) CRS-R. (b) Achenbach Child Behavior Checklist. (c) The Sensory Profile assesses auditory, visual, activity level, taste/smell, body/position, movement, touch, and emotional/social functioning (Dunn & Westman, 1995). (d) Bruininks-Oseretsky Test for Motor Efficiency (selected subtests) assesses bilateral coordination and upper-limb coordination, speed, and dexterity (Bruininks, 1978).
- *Academic and cognitive skills:* (a) Wide Range Achievement Test (WRAT 3) (reading and writing) assesses reading decoding, spelling, and math computation. (b) Language Processing Test assesses basic language (Wilkinson, 1993).

Participants were pretested and posttested at the same time of the day to control for medication schedules and circadian rhythms. On tests that offered equivalent forms, a different form was used for the posttesting than for the pretesting. The period between pretesting and posttesting was 4 to 5 weeks.

Test Administrators

The Interactive Metronome and video game group participants were randomly assigned to paid research administrators who treated participants of both groups. The administrators were college graduates, students, or persons without advanced degrees and with no previous formal therapy and teaching experience. Each administrator received 6 hr of instruction on both the Interactive Metronome and the video games.

Environments and treatment schedules for both groups were matched. Administrators followed a daily treatment regimen guide that controlled the structure of the sessions, time spent in conversation, and amount of encouragement given. Each participant was asked not to share his experiences with the other participants.

Procedure

Interactive Metronome group. The patented Interactive Metronome apparatus used in the study included a Pentium computer, the Interactive Metronome software program, two sets of headphones, and two contact-sensing triggers. One trigger, a special glove with a contact sensor attached to the palm side, sensed exactly when the triggered hand made contact with the other hand while clapping or 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.

In a dynamic systems model (Smith & Thelen, 1993), critical variables, such as the ability to plan and sequence actions, may influence a broad array of adaptive functions, including attention (Greenspan, 1992).

Directions for Future Research

The results of the current study suggest directions for further research, including replications of the current study on larger populations (which might permit the identification of characteristics associated with different patterns of response to metronome training), on girls, and on more socioeconomically diverse populations to observe potential components of different environmental contexts. Further research could also investigate subgroups that are based on both metronome performance and the child's processing profile.

Specific variations of the Interactive Metronome training process also need exploring, including increasing the number of sessions and overall repetitions, timing accuracy goals, and varying length of follow-up time to observe stability of the treatment effect. In addition, further research is needed to understand more fully both the dynamic systems and the underlying central nervous system mechanisms involved in motor regulation as well as the way in which Interactive Metronome training influences these processes. The Interactive Metronome may be the first technology that can allow the creation of a database and classification of "timing" to help compare the effects of interventions that influence timing in a variety of perceptual-motor processes.

Conclusion

From a dynamic systems perspective (Gray et al., 1996a, 1996b; Smith & Thelen, 1993), many processes, including the timing and rhythmicity of motor behavior, influence motor planning. In turn, motor planning interacts with other factors, including learning opportunities and environmental demands, to influence patterns of self-regulation and functioning at home, in school, and with peers. Until recently, interventions to strengthen these capacities have been limited to working with overt or surface behavior in educational or therapeutic settings. The present study suggests that Interactive Metronome training can improve aspects of attention, motor, and perceptual-motor functioning; cognitive and academic performance; and the control of aggression in children with major attentional problems. Hence, Interactive Metronome training may complement existing interventions for these children. ▲

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