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.*

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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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