

Effect of Methylphenidate on Time Perception in Children With Attention-Deficit/Hyperactivity Disorder

Ronald L. Baldwin

University of Arkansas for Medical Sciences—Arkansas
Children's Hospital

Rebecca A. Flake

University of Arkansas at Little Rock

Julie B. Meaux

University of Central Arkansas

John J. Chelonis

University of Arkansas for Medical Sciences—Arkansas
Children's Hospital, University of Arkansas at Little
Rock, and National Center for Toxicological Research

Mark C. Edwards and Charles R. Feild

University of Arkansas for Medical Sciences—Arkansas
Children's Hospital

Merle G. Paule

University of Arkansas for Medical Sciences—Arkansas
Children's Hospital and National Center for Toxicological
Research

The effects of methylphenidate (MPH) on performance of a time-production task were studied in 17 children with attention-deficit/hyperactivity disorder who participated in 1 test session on and 1 off MPH. Participants held a response lever down for at least 10 but no longer than 14 s. Administration of MPH had no effect on the number of correct responses or on the mean duration of lever holds. MPH administration significantly decreased timing response variability, increased holds of 10- to 11-s duration, and decreased lever holds of extremely short durations. These results indicate that administration of MPH resulted in more precise timing performance without changing the mean duration of lever holds, suggesting an enhancement in working memory.

Attention-deficit/hyperactivity disorder (ADHD) is one of the most common neurobehavioral disorders in childhood

(see American Academy of Pediatrics, 2000; Jaska, 1998) and is characterized by developmentally inappropriate levels of inattention, impulsivity, and hyperactivity that are pervasive in several settings. Children with ADHD are unable to respond to cues from the behavior of others, are inept at taking turns, and have an impaired sense of time (Barkley, Koplowitz, Anderson, & McMurray, 1997; Kerns, McInerney, & Wilde, 2001). They often exhibit a decreased ability to learn from previous experience and typically exhibit impulsive behavior, poor decision making, and risky behavior (Barkley, Fischer, Edelbrock, & Smallfish, 1990; DiScala, Leschchier, Barthel, & Li, 1998; Gittelman, Mannuzza, Shenker, & Bonagura, 1985; Milberger, Biederman, Faraone, Chen, & Jones, 1997).

Ronald L. Baldwin, Mark C. Edwards, and Charles R. Feild, Department of Pediatrics, University of Arkansas for Medical Sciences—Arkansas Children's Hospital. John J. Chelonis, Department of Pediatrics, University of Arkansas for Medical Sciences—Arkansas Children's Hospital; Department of Psychology, University of Arkansas at Little Rock; and Division of Neurotoxicology, National Center for Toxicological Research, Jefferson, Arkansas. Rebecca A. Flake, Department of Psychology, University of Arkansas at Little Rock. Julie B. Meaux, Department of Nursing, University of Central Arkansas. Merle G. Paule, Department of Pediatrics, University of Arkansas for Medical Sciences—Arkansas Children's Hospital, and Division of Neurotoxicology, National Center for Toxicological Research.

Some of the data reported in this article were presented at the meeting of the Association for Behavioral Analysis, Toronto, Ontario, Canada, May 2002, and at the meeting of the Behavioral Toxicology Society, Research Triangle Park, North Carolina, April 2002. We thank Jimmie Birdsong and Johnathan Kennedy for assistance in identifying and recruiting participants; Shannan Stewart for assistance in conducting the experiment; Donna Blake, LenEll Kelley, Joe Meehan, Jim Parker, and Martin Jackson for their assistance in managing the data; and Richard Rassmussen for maintenance of the apparatus.

Correspondence concerning this article should be addressed to Ronald L. Baldwin, Department of Pediatrics, University of Arkansas for Medical Sciences—Arkansas Children's Hospital, 800 Marshall Street, Little Rock, AR 72202. E-mail: baldwinronaldL@uams.edu

One of the significant impairments that children with ADHD exhibit is compromised time perception (Barkley et al., 1997; Kerns et al., 2001; Meaux & Chelonis, 2003). This can lead to significant problems given that most activities in which children engage are temporally based. For example, classes and activities begin and end at particular times, and the child must manage his or her time with respect to schoolwork, homework, chores, and other activities. It has been suggested that children with ADHD have difficulty with behaviors that are time-based because they perceive time intervals as lasting longer than they really do (Barkley et al., 1997; Kerns et al., 2001). Also, given that children with ADHD have difficulty learning from previous experience (see Barkley et al., 1997), it is likely that they would be unable to adjust their timing abilities to compen-

sate for any deficiencies. Previous research has found that children with hyperactivity and ADHD exhibit impaired performance on tasks of time production or time reproduction when compared with control children (Barkley et al., 1997; Capella, Gentile & Juliano, 1977; Kerns et al., 2001; Meaux & Chelonis, 2003). In one study by Capella et al. (1977), children were asked to indicate (produce) time intervals of 15, 30, and 60 s. The experimenter first dropped a ball to signal the start of the time interval and then the children dropped a ball after they believed the desired time interval had passed. In a second study by Capella et al. (1977) children were asked to indicate time intervals of 7, 15, and 30 s. The experimenter asked the child to press a switch to begin a time interval and then to press the same switch to signal the end of the interval. In both studies, children with hyperactivity were found to produce time intervals that were longer than those targeted (overproduce) compared with control children. In experiments by Barkley et al. (1997), a time-reproduction task was used during which children with ADHD viewed a red light that was illuminated for varying durations. The children were then required to turn on a flashlight for the same duration that the red light had been illuminated. Children with ADHD were found to make significantly larger absolute errors in time reproduction than were control children, and most of these errors were manifest as errors in overproduction of the targeted time intervals.

However, research using a time-estimation (vs. a time-production) procedure failed to find differences in timing ability between children with and without ADHD. Specifically, Senior, Towne, and Huessy (1979) attempted to replicate the Capella et al. (1977) studies by comparing the ability of children with ADHD, children with emotional disturbances, and children with cognitive impairment to verbally estimate a time interval. The results indicated that there were no significant differences between groups of children on this time-estimation task (Senior et al., 1979). However, only 6 hyperactive children participated in that study, thus limiting the power. Another explanation for the disparity of findings between the Senior et al. and other studies is that the Senior et al. study only required children to verbally estimate time intervals, whereas other studies required children to produce responses of specific durations. Recent research conducted by Meaux and Chelonis (2003) used a time-reproduction task in which children were asked to view a light for a period of time, verbally estimate the amount of time the light was on, and then reproduce that interval by holding down a response lever for the targeted duration. It was demonstrated that performance on the time-estimation component of this task, in which children verbally reported the time interval, was similar for children with ADHD and control children. Both children with and without ADHD overestimated time intervals and became less accurate as interval durations increased; however, children with ADHD significantly underproduced time intervals in relation to children without ADHD. Similar findings have been reported in which teenagers with ADHD have demonstrated impairments in time reproduction but not estimation (Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001).

Given the problems in time production exhibited by children with ADHD and the therapeutic effect of methylphenidate (MPH) to enhance performance of a variety of executive functions in children with ADHD (Barkley et al., 1997; Chelonis et al., 2002), it is important to evaluate how MPH might affect time production in children with ADHD. Stimulant medications have been found very effective in controlling the target symptoms of inattention, impulsivity, and hyperactivity that characterize ADHD (see Barkley et al., 1997). One line of evidence suggesting that stimulant medication would affect both time production and estimation in children with ADHD is derived from work on scalar timing theory. Scalar timing theory is a physiological model of time perception that suggests that an internal clock and reference memory are key to time perception (Fetterman & Killeen, 1990; Meck, 1996). This theory postulates that the speed of the internal clock is determined by a pacemaker, which continuously emits pulses at regular intervals. It is hypothesized that the rate of accumulation of these pulses determines the perceived amount of time that has passed. If the rate of pulse emission from the internal clock (i.e., clock speed) is increased, more pulses would accumulate in a shorter period of time, hence time production would be shorter and estimation would be longer. If the rate of pulse emission (clock speed) is decreased, time production would be longer and estimation would be shorter. Reference memory is postulated to store the initial setting of the internal clock. This value would then be used for determining the length of the interval being timed. Instability in reference memory is hypothesized to lead to random errors in timing ability (Meck, 1983).

It is possible that different stages of temporal processing could involve separate brain regions and could be modified by different neurotransmitter systems (Meck, 1996). For example, the internal clock used to time durations in the seconds to minutes range appears to be linked to dopaminergic function in the basal ganglia (Meck, 1983, 1996). Dopamine agonists, such as the amphetamines, have been found to result in the underproduction of time intervals in rats and pigeons (Mayorga, Popke, Fogle, & Paule, 2000; Meck, 1983, 1996; Paule et al., 1999). Therefore, it has been postulated that these agents increase the rate of pulse emissions, thus increasing clock speed. Alternatively, in nonhuman primates (rhesus monkeys) performing a time-production task, neither amphetamine nor cocaine produced any dramatic or systematic changes in their production of time intervals. Specifically, neither drug produced a lengthening of the duration of the targeted lever holds (which would have supported a role in slowing clock speed), and only one of several doses of each drug evidenced a shortening of targeted holds (suggestive of speeding up the clock). In monkeys, the dopamine antagonist, chlorpromazine, increased the rate of production of correct-duration lever holds, decreased the production of incorrect-duration holds, and slightly shifted hold durations toward shorter values. These findings suggest that dopaminergic blockade in primates may alter time-production performance by increasing internal clock speed (Paule et al., 1999). However, none of

the previous research on monkeys examined how dopamine agonists and antagonists affected precision (variability) in timing behavior.

Although it is known that central nervous system stimulants that are able to augment dopaminergic function in humans (e.g., MPH and amphetamine) clearly enhance a variety of executive functions in children with ADHD (Barkley et al., 1997; Chelonis et al., 2002), it is unknown how they might affect timing behavior in this population. In studies using a time-reproduction paradigm, Barkley et al. (1997) used five different time durations to test the effect of three different doses of MPH (compared with placebo) in 12 children with ADHD. Children with ADHD became less accurate than did control children as targeted durations increased and when distractions were added. Further, MPH did not significantly enhance timing performance in children with ADHD. These results were surprising given that MPH has been shown to improve a variety of other executive functions in children with ADHD (Ahmann, Waltonen, & Olson, 1993; Barkley, 1990; Barkley, Koplowitz, & McMurray, 1991).

The purpose of the present study was to examine the effects of MPH on timing ability in children with ADHD using a prospective time-production task that used a single-target interval of 10 to 14 s. Participants repeatedly produced this interval during each test session. None of the other studies of children used a procedure that provided for the production of enough trials to provide a meaningful measure of the variability (precision) of timing responses. The present procedure allowed for an examination of the effects of MPH on both accuracy and precision of time production. We hypothesized that MPH would decrease variability in a time-production procedure because previous research has demonstrated that MPH significantly enhances short-term memory in children with ADHD (Chelonis et al., 2002). Because MPH enhances short-term memory, according to scalar timing theory it would also enhance timing precision.

Method

Participants

The participants in this study consisted of 17 children (12 boys and 5 girls) who were 7 to 13 years of age and were recruited from outpatient clinics at the Arkansas Children's Hospital in Little Rock, Arkansas. Informed consent was obtained from the parents, and assent was obtained from each child. Children were included in this study if they had a *t* score greater than 65 on the Hyperactive subscale of the parent's version of the Conners' ADHD/DSM-IV Scale (CADS; Conners, 1997) and had a current prescription from a physician for MPH for the treatment of ADHD. Fifteen children also had a *t* score of greater than 65 on the Inattention subscale of the CADS; the other 2 had a score of 64. All children met *Diagnostic and Statistical Manual of Mental Disorders* (4th ed.; DSM-IV; American Psychiatric Association, 1994) criteria for ADHD on the basis of interviews by a child psychologist, psychiatrist, or pediatrician that were conducted as part of the child's evaluation prior to treatment. Children were excluded from this study if (a) their full-scale intelligence score was 70 or below, as measured by the Kaufman Brief Intelligence Test (KBIT; Kauf-

man & Kaufman, 1990); (b) their achievement scores in reading, arithmetic, and spelling were 70 or below, as measured by the Wide Range Achievement Test (WRAT-3; Wilkinson, 1993); or (c) they were diagnosed with schizophrenia, major depressive disorder, or pervasive developmental disorder, as measured by the Child Symptom Inventory (CSI; Gadow & Sprafkin, 1997).

All children participated in two experimental sessions that were separated by at least 2 weeks but not more than 6 weeks. Children participated in one test session after they had taken their prescribed dose of MPH more than 1 but less than 2 hr prior to testing (on MPH). For the other test session at least 18 hr had to have elapsed since children took their last prescribed dose of MPH (off MPH). The order of these sessions was randomly assigned; 11 children participated in their first session off MPH and the other 6 participated in their first session on MPH. Children received either 5 mg ($n = 5$), 10 mg ($n = 7$), 15 mg ($n = 2$), or 20 mg ($n = 3$) MPH preparation prior to the test session. The mean dose was 0.32 mg/kg with a range of 0.12 to 0.62 mg/kg.

Apparatus

Participants performed the temporal response differentiation (TRD) task in a small sound-attenuated room that was 2.4 m long \times 2.4 m wide \times 2.4 m high. A fluorescent ceiling light illuminated the room throughout the entire TRD task. The child's behavior could be continually monitored during test sessions by the experimenter through a one-way mirror located on one of the walls of the room. A table with a television monitor was positioned against the center of the wall that was opposite the one-way mirror. Audio and visual directions were played on this monitor prior to starting the task. The experimental apparatus was attached to the center of the wall adjacent to the monitor. The apparatus consisted of a large wooden cabinet that was 182 cm tall \times 60.8 cm wide \times 50.4 cm deep, a response panel, and nickel dispenser. The response panel and nickel dispenser were mounted on the surface of the cabinet. Figure 1 shows the response panel that was located on the front of the apparatus 60.8 cm above the floor. The response panel was 65.4 cm high \times 55.6 cm wide. A round speaker, 6 cm in diameter, was located 7.3 cm below the top edge of the panel. White noise was delivered through this speaker to mask extraneous sounds during testing. The panel contained two types of response manipulanda and a variety of stimulus lights. The response manipulanda used in the TRD task was the leftmost of four retractable response levers that were located 35.5 cm from the bottom edge of the speaker. Each response lever was 5 cm wide and extended 3 cm from the apparatus. The response levers were centered in a horizontal row, each 3.5 cm apart. Positioned 22 cm below the response panel and 15 cm from the left edge of the apparatus was a tray in which reinforcers (nickels) were delivered. The tray was 15 cm wide \times 10 cm deep \times 7.5 cm tall. The stimulus lights and the other manipulanda on the response panel were not used during the TRD task. The activation and presentation of the left retractable lever and recording of responses were automated using a computerized system developed at the National Center for Toxicological Research.

Procedure

Before testing, the experimenter requested that the parents complete several forms regarding their demographics and the physical and educational history of the child. The child was escorted into the testing room (described above) by the experimenter. The child was told that he or she would play five games (tasks) and that the instructions for each game would be shown on the television

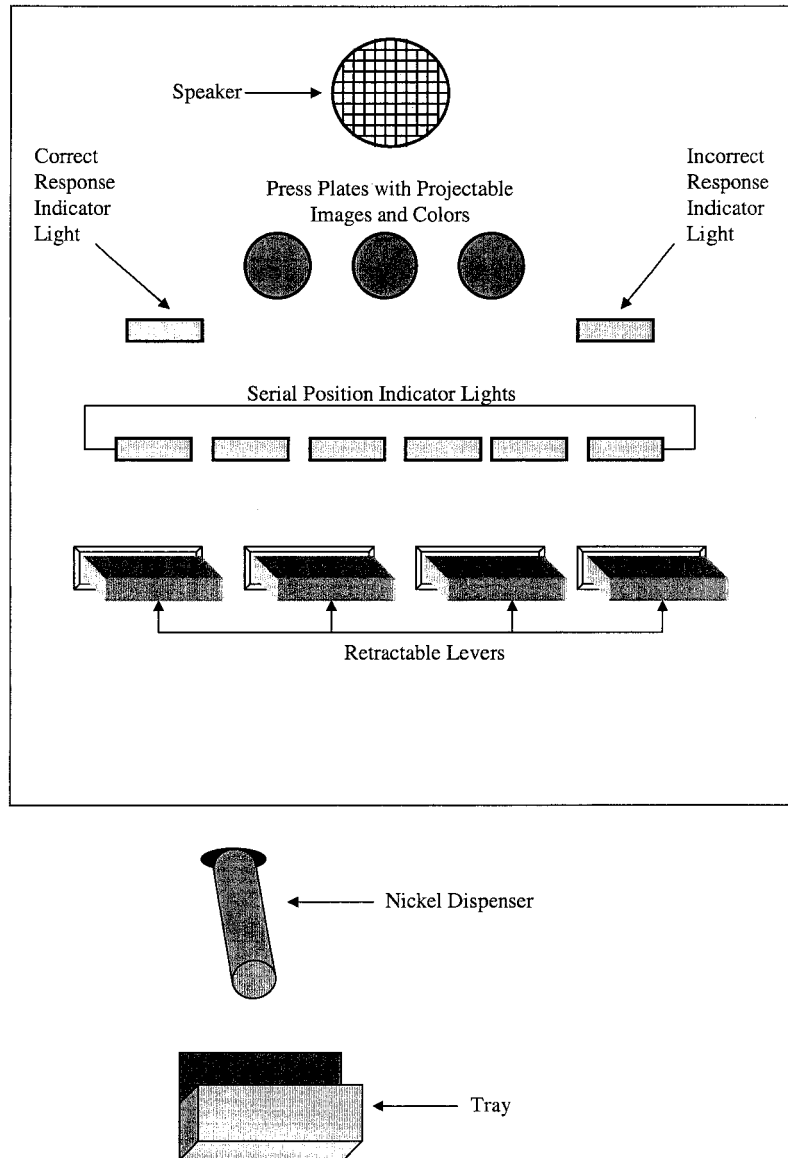


Figure 1. Diagram of the apparatus. Only the left response lever was used for the temporal response differentiation task. The tube and tray are where nickel reinforcers were dispensed.

monitor before each game began. After introducing the child to the testing room, the experimenter left the room to start the videotaped instructions that were used for the standardization of instructions for all participants and to eliminate the large amount of time needed to train children to perform the task. Before the TRD task, the following instructions were presented on the television monitor to the child:

You will notice on the panel in front of you [the narrator points to the row of response levers on the panel], that at the bottom there are four levers. In this game, the lever at the far left, here [the narrator points to and touches the lever at the far left], will come out of the machine [the response lever on the far left extends from the machine]. To receive a nickel, you must hold the lever down like this [the narrator presses down the extended response lever, and receives a nickel]. This is a

very hard game [the narrator presses down the extended response lever again]; so don't give up if you don't do well right at first. Keep trying and you'll get it right. Remember, hold the lever down for at least 10 seconds, but not anymore than 14 seconds, and then let it up [the narrator stops pressing down the response lever and receives a nickel]. We hope you do well at this game. Remember, it's a hard game, so don't give up.

When the videotaped instructions ended, the experimenter reentered the room and asked the child whether he or she understood the instructions. All children indicated that they understood the instructions and required no further explanation of the task. After the child stated that he or she understood the instructions, the experimenter left the testing room, closed the door, and initiated the task.

The task began with the response lever on the far left end of the row of response levers extending from the panel. A trial was initiated when the child pressed the response lever and ended when it was released. If the child held the response lever in the depressed position for 10 to 14 s, a nickel was dispensed. If the lever was held in the depressed position for less than 10 s or greater than 14 s, a nickel was not dispensed. The next trial began as soon as the response lever was depressed again. The TRD task lasted for 10 min, or until 30 nickels were earned.

Each testing session consisted of five tasks presented in the following order: progressive ratio, conditioned position responding, TRD, delayed matching-to-sample, and incremental repeated acquisition (see Paule, Cramner, Wilkins, Stern, & Hoffman, 1988, for a description of each task). Although five tasks were performed each session, only the TRD data are being reported here. A 1- to 2-min break occurred between tasks, during which the experimenter replenished the supply of nickels and presented the instructions for the next task. The experimenter observed the participants during portions of each of the five tasks and completed the Conners' parent questionnaire at the end of the testing session. It took approximately 55 min for the children to complete all five tasks. Each participant's nickels were counted at the end of the testing session. Children could earn a maximum of \$8 for correct responses during the entire session. The experimenter supplemented the child's earnings as necessary so that each child received a minimum of \$5. Following completion of the five tasks, the verbal and matrices sections of the KBIT were administered to the child, after which the child was escorted back to his or her parent(s) in the waiting room, and completed questionnaires were collected. Parents received a \$5 gift certificate to Wal-Mart as compensation for bringing their child in for each session.

Results

Figure 2 shows the means and standard errors for the number of trials (lever holds) initiated during the TRD task and the number of correct-duration lever holds by children

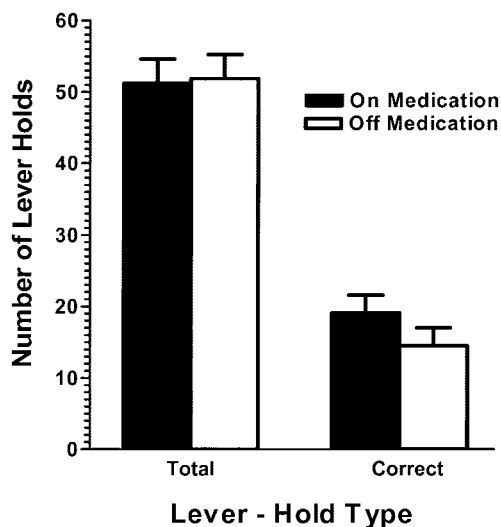


Figure 2. Means and standard errors for the total number of trials initiated and the total number of correct lever holds for children with attention-deficit/hyperactivity disorder on and off methylphenidate.

with ADHD on and off MPH. Children initiated a similar number of trials on and off MPH, $t(16) = -0.13$, $p = .90$. Children made more correct lever holds when on MPH than when off; however, this difference was shown to be only a trend according to a two-tailed repeated measures t test, $t(16) = 1.79$, $p = .09$.

Figure 3 shows the means and standard errors for the mean duration of lever holds and standard deviations of the duration of lever holds for children on and off MPH. The mean and standard deviation of the duration of lever holds was calculated for each child on and off medication. MPH did not significantly alter the mean lever-hold durations, $t(16) = 0.84$, $p = .42$. Further examination of the data revealed that for 7 children, administration of MPH decreased their mean lever-hold duration, and for 10 children, administration of MPH increased their mean lever-hold duration. Administration of MPH significantly decreased response variability (i.e., standard deviation of lever holds), $t(16) = -2.63$, $p < .05$. Administration of MPH decreased the variability of lever-hold durations in 13 and increased variability in 4 of the children tested. Further analysis revealed a small and nonsignificant correlation between reduction in standard deviation and MPH dose, $r(16) = -0.24$, $p = .38$.

Figure 4 shows the means and standard errors for the number of lever holds in each 1-s bin for children on and off MPH. The lever-hold durations were divided into 21 separate time bins by truncating each value for lever-hold duration to create an integer value. Children off MPH exhibited a less well-defined peak at the 10-s time bin (i.e., made less responses at the mode) than when on MPH. Further, they consistently made more lever holds at each time bin at the extreme ends of the distribution when off medication than when on. Specifically, there were no instances in which the mean number of responses across children off medication was less than when on medication in the 0- to 4-s time bins and in the 14-s and greater time bins, which is significantly less than would be expected by chance. Repeated measures t tests were conducted to determine whether administration of MPH affected the number of lever holds for each of the 1-s bins for children with ADHD. Administration of MPH significantly decreased the number of lever holds that were less than 1 s, $t(16) = -2.97$, $p < .01$, and significantly increased the number of lever holds in the 10-s bin, $t(16) = 2.45$, $p = .03$.

Discussion

The results of the present study show that MPH significantly improved the timing performance of children with ADHD. This was evidenced by significant decreases in the variability of lever-hold durations, decreases in the number of very short (less than 4 s) lever holds, and increases in lever holds of correct (reinforced) duration, especially in the 10-s time bin. These results suggest that the administration of MPH increased the precision of timing behavior by decreasing the spread of lever holds within the target interval and by decreasing the number of inappropriate responses at time intervals that were distant from the target

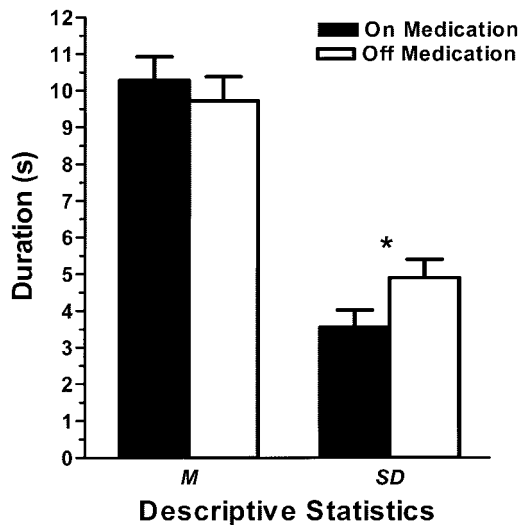


Figure 3. Means and standard errors for the mean and standard deviation of lever-hold durations, calculated for each child on and off methylphenidate. The asterisk indicates statistically significant differences between treatment conditions.

interval. These findings are unique because none of the previous research on timing ability in children with ADHD or in nonhuman primates examined the precision (variability) of responding. The finding that MPH decreased variability in responding is especially interesting given that reinforcers were provided for correct responses (typically not used when assessing timing in humans) and that other studies have shown reinforcement alone often decreases response variability (see Schwartz, 1982). The present findings clearly demonstrate that even in the presence of reinforcement, response variability decreased with the administration of MPH.

Although the results of the present study suggest that MPH increased the precision of timing behavior, they do not suggest that MPH affected the time interval at which the peak lever-hold duration occurred (timing accuracy). In other words, we are not postulating that the rate of pulse emission by the internal clock was affected by MPH because the mean of the lever-hold durations was similar for children on and off MPH. This finding is similar to findings noted in nonhuman primates (see Paule et al., 1999; Schulze & Paule, 1990) wherein the dopaminergic stimulants amphetamine and cocaine did not systematically shift the mean of the population of lever-hold distributions in subjects performing an identical TRD task. Analyses of just the total trials (lever presses) made and the number of correct lever holds data (see Figure 2) also revealed no significant effects of MPH. These observations are similar to those of Barkley et al. (1997), which showed a lack of significant medication effect on performance of a time-reproduction task. However, in the present study there was a clear trend toward increased correct responses for children on MPH, an effect that was not evident in the Barkley et al. (1997) study. This difference might have been due to the use of a placebo

control condition in the Barkley et al. (1997) study (vs. the use of a “no-medication” control condition in the current study) or to the longer time intervals used in a time-reproduction task in the Barkley et al. (1997) studies.

The lack of an MPH-induced shift in peak of the response duration distributions might also have resulted from the fact that the children in the present study had extensive experience in a variety of situations both on and off MPH as part of their treatment for ADHD. Meck (1983) demonstrated that with chronic amphetamine exposure, animal subjects were able to readjust their timing behavior from a shift toward shorter intervals back to a distribution of timing responses that was similar to their predrug exposure distribution. Therefore, it is possible that children with ADHD who have a history of MPH treatment have developed a type of tolerance to some of its effects on timing ability. The fact that MPH did significantly decrease response variability in this task, however, suggests that at least some aspects of timing behavior do not become tolerant to repeated exposure to stimulant medication. Previous research has demonstrated that stimulant medication enhances working memory in children with ADHD (Chelonis et al., 2002; Evans, Gualteireri, & Amara, 1986; Gittelman-Klein & Klein, 1975; Sprague, Barnes, & Werry, 1970; Swanson & Kinsbourne, 1976). If working memory is important for the precision of timing behavior, and MPH improves this aspect of memory, then it follows that children with ADHD would exhibit an improvement in timing precision while on MPH.

Although it is also possible that participants were experiencing mild “withdrawal” symptoms 18 hr after taking their last stimulant medication (i.e., when they were off MPH), the data remain relevant for several reasons. Children undergoing chronic stimulant treatment are often in this exact situation. In addition, withdrawal symptoms as-

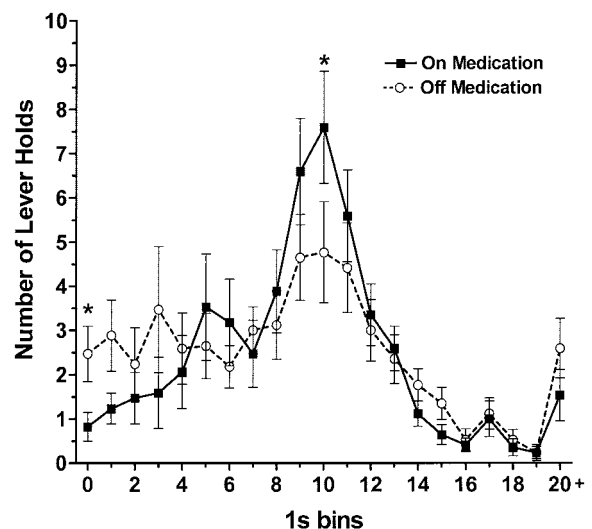


Figure 4. Means and standard errors for the number of lever holds of specific durations blocked into 1-s (1s) intervals for children on and off methylphenidate. The asterisk indicates statistically significant differences between treatment conditions.

sociated with chronic stimulant medication, generally studied in adult substance abusers, tend to manifest only after very long-term administration at relatively high doses. It is unknown whether similar sequelae occur in children. In a review of stimulant drugs and vigilance performance (Koelega, 1993), it was stated that "Evidence from several studies does not support the hypothesis that improvements are only a recovery of withdrawal-induced impairment" (p. 1). The implication here is that the poorer performance observed in subjects in the nondrugged state is not a reflection of disrupted function caused by symptoms brought about by or associated with acute drug withdrawal.

In addition, recent studies in nonhuman primates have shown that infant and juvenile subjects are much less sensitive to the behavioral effects of stimulants than are adults (Paule, 1997). Thus, the likelihood of young human participants exhibiting withdrawal phenomena appears less than that for adults, and the positive effects of stimulant treatment likely are not due to treatment of withdrawal symptoms.

This research is the first to clearly demonstrate differences in timing ability as a result of administration of MPH in children with ADHD. Administration of MPH was found to significantly decrease variability of lever-hold durations (i.e., increase precision). Although it may be argued that these results may be due to practice effects because more children received MPH on the second test session, this is unlikely because of the 6 children who received MPH on the first session, all but 1 demonstrated a decrease in variability of lever-hold durations after administration of MPH. Further, this study did not control for dose effects of MPH because a range of doses was used. However, it is unlikely that this had much effect on the results because the correlation of dose with decreases in variability was small and not significant. Finally, it would be useful to replicate this research using placebo control conditions to make this work more comparable with the Barkley et al. (1997) research.

These findings indicate that variability in responding appears to decrease with the administration of MPH. This suggests that administration of MPH might enhance the ability of children with ADHD to more consistently apply successful strategies in problem solving. These results also suggest that deficits in timing ability noted while off MPH are a result of deficits in working memory and are not due to differences in the speed of a postulated internal clock (i.e., peak time intervals were the same in both the on and off conditions). These findings also suggest that any intervention that enhances working memory in children with ADHD would also enhance timing ability in these children.

References

- Ahmann, P. A., Waltonen, S. J., & Olson, K. A. (1993). Placebo-controlled evaluation of Ritalin side effects. *Pediatrics*, *91*, 1101–1106.
- American Academy of Pediatrics. (2000). Clinical practice guideline: Diagnosis and evaluation of the child with attention-deficit/hyperactivity disorder. *Pediatrics*, *105*, 1158–1170.
- American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: Author.
- Barkley, R. A. (1990). *Attention deficit hyperactivity disorder: A handbook for diagnosis and treatment*. New York: Guilford Press.
- Barkley, R. A., Edwards, G., Laneri, M., Fletcher, K., & Metevia, L. (2001). Executive functioning, temporal discounting, and sense of time in adolescents with attention deficit hyperactivity disorder (ADHD) and oppositional defiant disorder (ODD). *Journal of Abnormal Child Psychology*, *29*, 541–556.
- Barkley, R. A., Fischer, M., Edelbrock, C. S., & Smallfish, L. (1990). The adolescent outcome of hyperactive children diagnosed by research criteria: I. An 8-year prospective follow-up study. *Journal of the American Academy of Child and Adolescent Psychiatry*, *29*, 546–557.
- Barkley, R. A., Koplowitz, S., Anderson, T., & McMurray, M. B. (1997). Sense of time in children with ADHD: Effects of duration, distraction, and stimulant medication. *Journal of the International Neuropsychological Society*, *3*, 359–369.
- Barkley, R. A., Koplowitz, S., & McMurray, M. B. (1991). Attention deficit disorder with and without hyperactivity: Clinical response to three dose levels of methylphenidate. *Pediatrics*, *87*, 519–531.
- Capella, B., Gentile, J. R., & Juliano, D. B. (1977). Time estimation by hyperactive and normal children. *Perceptual and Motor Skills*, *44*, 787–790.
- Chelonis, J. J., Edwards, M. C., Schulz, E. G., Baldwin, R. L., Blake, D. J., Wenger, A., & Paule, M. G. (2002). Stimulant medication improves recognition memory in children diagnosed with attention-deficit/hyperactivity disorder. *Experimental and Clinical Psychopharmacology*, *10*, 400–407.
- Conners, C. (1997). *Conners' Rating Scales*. Toronto, Ontario, Canada: Multi-Health Systems.
- DiScala, C., Leschchier, I., Barthel, M., & Li, G. (1998). Injuries to children with attention deficit/hyperactivity disorder. *Pediatrics*, *102*, 1415–1421.
- Evans, R. W., Gualteireri, C. T., & Amara I., (1986). Methylphenidate and memory: Dissociated effects in hyperactive children. *Psychopharmacology*, *90*, 211–216.
- Fetterman, J. G., & Killeen, P. R. (1990). A componential analysis of pacemaker-counter timing systems. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 766–780.
- Gadow, K. D., & Sprafkin, J. (1997). *Child Symptom Inventory—4 norm manual*. Stony Brook, NY: Checkmate Plus.
- Gittelman, R., Mannuzza, S., Shenker, R., & Bonagura, N. (1985). Hyperactive boys almost grown up: I. Psychiatric status. *Archives of General Psychiatry*, *42*, 937–947.
- Gittelman-Klein, R., & Klein, D. F. (1975). Are behavioral and psychometric changes related in methylphenidate-treated hyperactive children? *International Journal of Mental Health*, *4*, 182–198.
- Jaska, P. (1998). *Fact sheet on attention deficit/hyperactivity disorder*. Retrieved July 27, 2002 from <http://www.add.org>
- Kaufman, A. S., & Kaufman, N. L. (1990). *Kaufman Brief Intelligence Test*. Circle Pines, MN: American Guidance Services.
- Kerns, K. A., McInerney, R. J., & Wilde, N. J. (2001). Time reproduction, working memory, and behavioral inhibition in children with ADHD. *Child Neuropsychology*, *7*, 21–31.
- Koelega, H. S. (1993). Stimulant drugs and vigilance performance: A review. *Psychopharmacology*, *111*, 1–16.

- Mayorga, A. J., Popke, E. J., Fogle, C. M., & Paule, M. G. (2000). Similar effects of amphetamine and methylphenidate on the performance of complex operant tasks in rats. *Behavioural Brain Research, 109*, 59–68.
- Meaux, J. B., & Chelonis, J. J. (2003). Time perception differences in children with and without ADHD. *Journal of Pediatric Healthcare, 17*, 64–72.
- Meck, W. H. (1983). Selective adjustment of the speed of internal clock and memory processes. *Journal of Experimental Psychology: Animal Behavior Processes, 9*, 171–201.
- Meck, W. H. (1996). Neuropharmacology of timing and time perception. *Cognitive Brain Research, 3*, 227–242.
- Milberger, S., Biederman, J., Faraone, S. V., Chen, L., & Jones, J. (1997). ADHD is associated with early initiation of cigarette smoking in children and adolescents. *Journal of the American Academy of Child and Adolescent Psychiatry, 36*, 37–44.
- Paule, M. G. (1997). Age-related sensitivity to the acute behavioral effects of cocaine and amphetamine in monkeys. *Neurotoxicology and Teratology, 19*, 241–242.
- Paule, M. G., Cramner, J. M., Wilkins, D., Stern, H. P., & Hoffman, E. L. (1988). Quantitation of complex brain function in children: Preliminary evaluation using a nonhuman primate behavioral test battery. *Neurotoxicology, 9*, 367–369.
- Paule, M. G., Meck, W. H., McMillan, D. E., McClure, G. Y. H., Bateson, M., Popke, E. J., et al. (1999). The use of timing behaviors in animals and humans to detect drug and/or toxicant effects. *Neurotoxicology and Teratology, 21*, 491–502.
- Schulze, G. E., & Paule, M. G. (1990). Acute effects of *d*-amphetamine in a monkey operant behavioral test battery. *Pharmacology Biochemistry and Behavior, 35*, 759–765.
- Schwartz, B. (1982). Reinforcement induced behavioral stereotypy: How not to teach people to discover rules. *Journal of Experimental Psychology: General, 111*, 23–59.
- Senior N., Towne, D., & Huessy, D. (1979). Time estimation and hyperactivity, replication. *Journal of Perceptual and Motor Skills, 49*, 289–290.
- Sprague, R. L., Barnes, K. R., & Werry, J. S. (1970). Methylphenidate and thioridazine: Learning, reaction time, activity and classroom behavior in disturbed children. *American Journal of Orthopsychiatry, 40*, 615–628.
- Swanson, J. M., & Kinsbourne, M. (1976, June 25). Stimulant-related state-dependent learning in hyperactive children. *Science, 192*, 1354–1357.
- Wilkinson, G. S. (1993). *Wide Range Achievement Test administration manual*. Wilmington, DE: Wide Range.

Received September 11, 2002

Revision received March 27, 2003

Accepted August 28, 2003 ■

Low Publication Prices for APA Members and Affiliates

Keeping you up-to-date. All APA Fellows, Members, Associates, and Student Affiliates receive—as part of their annual dues—subscriptions to the *American Psychologist* and *APA Monitor*. High School Teacher and International Affiliates receive subscriptions to the *APA Monitor*, and they may subscribe to the *American Psychologist* at a significantly reduced rate. In addition, all Members and Student Affiliates are eligible for savings of up to 60% (plus a journal credit) on all other APA journals, as well as significant discounts on subscriptions from cooperating societies and publishers (e.g., the American Association for Counseling and Development, Academic Press, and Human Sciences Press).

Essential resources. APA members and affiliates receive special rates for purchases of APA books, including the *Publication Manual of the American Psychological Association*, and on dozens of new topical books each year.

Other benefits of membership. Membership in APA also provides eligibility for competitive insurance plans, continuing education programs, reduced APA convention fees, and specialty divisions.

More information. Write to American Psychological Association, Membership Services, 750 First Street, NE, Washington, DC 20002-4242.