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Sense of time in children with ADHD: Effects of duration, distraction, and stimulant medication

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Abstract

A recent theory of ADHD predicts a deficiency in sense of time in the disorder. Two studies were conducted to test this prediction, and to evaluate the effects of interval duration, distraction, and stimulant medication on the reproductions of temporal durations in children with ADHD. Study I: 12 ADHD children and 26 controls (ages 6–14 years) were tested using a time reproduction task in which subjects had to reproduce intervals of 12, 24, 36, 48, and 60 s. Four trials at each duration were presented with a distraction occurring on half of these trials. Control subjects were significantly more accurate than ADHD children at most durations and were unaffected by the distraction. ADHD children, in contrast, were significantly less accurate when distracted. Both groups became less accurate with increasing durations to be reproduced. Study II: Tested three doses of methylphenidate (MPH) and placebo on the time reproductions of the 12 ADHD children. ADHD children became less accurate with increasing durations and distraction was found to reduce accuracy at 36 s or less. No effects of MPH were evident. The results of these preliminary studies seem to support the prediction that sense of time is impaired in children with ADHD. The capacity to accurately reproduce time intervals in ADHD children does not seem to improve with administration of stimulant medication. (*JINS*, 1997, *3*, 359–369.)

Keywords: ADHD, Time, Methylphenidate.

INTRODUCTION

Current clinical consensus holds that attention deficit hyperactivity disorder (ADHD) involves two primary areas of impairment, these being inattention and impulsive–hyperactive behavior. These deficits are believed to arise early in childhood (typically before age 7 years) and to be relatively persistent over time (American Psychological Association, 1994). A recent theoretical model of ADHD (Barkley, 1994, 1997) argues that the central deficiency in the disorder is one of impaired behavioral inhibition. This impairment is believed to result in secondary deficiencies in four executive functions that contribute to self-regulation, these being (1) working memory and sense of time; (2) self-regulation of emotional and motivational states; (3) the internalization of speech; and (4) reconstitution, or the formation of novel, complex behavioral sequences. These executive functions influence motor control, fluency, and syntax, permitting the regulation of behavior by internally represented information and the self-regulation of behavior relative to time (Fuster, 1989, 1995).

A number of predictions about ADHD are made by this model, many of which remain untested. One such prediction is that children with ADHD should manifest an impairment in the development of sense of time and its associated retrospective and prospective functions (i.e., hindsight and forethought) as a consequence of poor behavioral inhibition (Barkley, 1994, 1997). Others have also discussed a possible link between impulsiveness and time perception independently of this model of executive functions (Gerbing et al., 1987; White et al., 1994), which would imply difficulties in time perception in those with ADHD.

The executive system of the prefrontal cortex generally, and the dorsolateral prefrontal cortex in particular, are be-

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lieved to be involved in the capacity to accurately judge and reproduce temporal durations (Nichelli et al., 1995), although other brain regions, such as the posterior parietal cortex may also be implicated in various aspects of time-keeping (Pastor et al., 1992). Research on patients with Parkinson's disease has demonstrated impaired time estimation and reproduction, further suggestive of a role for the frontal cortex in these aspects of sense of time (Pastor et al., 1992). An involvement of the dorsolateral prefrontal cortex in time reproduction may result from the fact that estimating temporal durations and using them to regulate motor responding requires the retention of sequences of information in short-term or working memory (Brown, 1990; Michon, 1985), a function also subserved by the dorsolateral prefrontal cortex (Fuster, 1989; Goldman-Rakic, 1995). Working memory has been shown to be deficient in children with ADHD, as reflected in tasks such as mental arithmetic, digit span, Tower of Hanoi, and imitation of hand movement sequences (Kemp & Kirk, 1993; Pennington et al., 1993; Barkley, 1994, 1997; Pennington & Ozonoff, 1996). These findings would further suggest that the estimation of temporal durations should be deficient in these children as well if such estimations are dependent on working memory, as has been hypothesized.

Previous research suggests that both children's and adults' time estimations and reproductions become less accurate with increasing duration of the time interval to be estimated, produced, or reproduced (Brown, 1985; Michon, 1985; Zakay, 1990, 1992). Results obtained from these three methods of testing, however, are not identical (Zakay, 1990). In time estimation paradigms, subjects are presented with a temporal duration and then verbally report its perceived duration (usually in seconds). For time productions, subjects are verbally told the length of time to be produced and then must produce it in some way by indicating the start and end points for the duration. In time *re*production tasks, subjects are presented with a duration of time but not told its length, as in time estimation above, and then must reproduce the duration in some way as in the time production approach. Time production tasks appear to be the easiest to perform and the least likely to assess subjective time sense as the individual is given a verbal numerical standard to use in producing the time interval. Time reproduction tasks are typically the most difficult, and are believed to more accurately represent subjective sense of time than the other methods (Zakay, 1990). Thus a reproduction paradigm was used here, as well as five different time durations.

Distracting events created during the presentation of a time interval have been found to decrease the accuracy of children's time reproductions for those distraction intervals relative to nondistraction intervals (Zakay, 1992). The distraction seems to cause subjects to make shorter time reproductions than had the distraction not occurred. The effect is similar to increasing the attentional demands of a task. More attention must be allocated to nontemporal task demands when distraction occurs during the presentation of the sample time duration, implying that accurate time sense requires allocating attentional resources to temporal cues and away from nontemporal or spatial ones (Brown, 1985; Zakay, 1990). Consequently, the studies reported here tested the children under conditions of distraction and nondistraction.

The purpose of the present series of preliminary studies was to evaluate the ability of ADHD children to accurately reproduce temporal durations and to investigate the effects of duration length, distraction, and stimulant medication on these temporal reproductions. As noted earlier, time reproduction paradigms are more difficult than estimation or production tasks and so the experiments reported below utilized a reproduction paradigm. A variety of temporal durations were used, as were distractions during some of the trials, in order to evaluate the nature of their effects and whether ADHD children differed from control children in these effects.

METHODS

Preliminary Survey

To first determine if a laboratory study of sense of time in ADHD children might be worthwhile, a survey of parents of ADHD children was conducted to evaluate the possibility of problems in their children that might be associated with an impaired sense of time. The sample surveyed consisted of two groups of children ages 8 to 13 years. One group was comprised of children who had been clinically diagnosed as having ADHD, and whose parents responded to a request mailed to 800 families inviting them to complete a survey on sense of time in children with ADHD. The second group consisted of children who did not have ADHD and whose families volunteered from the local community to complete the same survey. To obtain the ADHD children, questionnaires were distributed to the parents of children who had been patients at the ADHD Clinic at the University of Massachusetts Medical Center, patients from other clinics and mental health professionals known to the authors in Massachusetts, and members of ADHD family support groups. To be eligible for the survey, the children had to have been previously diagnosed by a mental health professional as having ADHD. A total of 91 ADHD children and their parents returned the surveys. Of these children, 62 (68%) were receiving psychiatric medication for management of their ADHD.

The names of parents of non-ADHD children were obtained using a "snowball" technique in which friends and associates of the authors were contacted who had children within the appropriate age range. These families were then questioned about further names of other families to contact who might also have children in this same age range, and so on. A total of 36 community control children and their parents agreed to complete the surveys. To be eligible, these control children had to have no history of significant behavioral problems as reported by the parents. The two groups did not differ significantly in their ages. The mean age for the ADHD children was 10.3 years ($SD = 1.6$) and that for the control group was 10.7 years ($SD = 1.43$).

Two questionnaires were constructed to evaluate children's sense of time, their referencing of time in their daily discourse with others, their ability to conform to directions containing time parameters, and their ability to meet deadlines associated with work assignments. The questionnaire contained multiple choice questions that dealt with the following topics: (1) the ability to judge the passage of time, (2) awareness of the passage of time, (3) how often they were prepared for deadlines concerning work assignments, (4) how far in advance they began preparing for assignments having deadlines, (5) how often they used retrospection or the recall of past events before responding in situations, (6) how often they used prospection or the anticipation of future events before responding, (7) how frequently they spoke about time with others, and (8) the extent to which distractions often interfered with the child's ability to accurately assess the passage of time. The parent's version contained 25 multiple choice questions, while the child's self-report version contained 30 questions similarly worded to those in the parent's version.

Results of the survey indicated that the children with ADHD were rated as having significantly more problems in these areas related to sense of time than were the control children, using both parent and child self-report. Given these initially promising results, we elected to undertake a preliminary study using laboratory testing of sense of time in a subset of these children. This preliminary study served to provide pilot testing of a newly designed apparatus for assessing time reproductions in children, the effect of distraction on these time reproductions, and whether the procedures would be sensitive to potential group differences between ADHD and control children.

Preliminary Laboratory Study

The subjects for this preliminary study were drawn from those who had participated in the initial survey. Two groups of children were tested. One group consisted of 32 children previously diagnosed with ADHD, and the second group were 32 non-ADHD children drawn from the community control group. All ADHD children were removed from their medication at least 24 hr prior to participating in this study, with the permission of their parents and treating physician. Again, the children ranged in age from 8 to 13 years. The mean age of the ADHD children was 10.7 years ($SD = 1.79$) and that for the community control children was 11.1 years ($SD = 1.62$). The groups were found not to be significantly different in their ages.

The procedures were similar to those used by Zakay (1992) in assessing sense of time in normal children. An electronic apparatus was constructed to assess children's time reproductions. The apparatus consisted of a large rectangular black box. In the center of the top surface of this box was a light fixture containing a red light bulb. In one corner of this top surface on the side facing the subject, a flashlight was mounted. In the other corner of this side was placed a hatch door. When activated by the examiner, this hatch door would spring open and a jack-in-the-box figure would pop up. This was used to create a distraction during the distraction condition trials. Next to the light bulb at the center of this box was a photodetector diode used to detect the length of time the light bulb was lit for each trial. It also served to measure the length of time the participant lit their flashlight when attempting to replicate the duration of time the display light had been lit. To do so, the photodetector diode was connected to a digital timer measuring time in hundredths of seconds. This timer along with the switch used to turn on the red light bulb were both located on the side panel facing the examiner out of view of the child. A second timer was connected to the light activation switch and this timer was used to present each of the predetermined time intervals of light to the child. When switched on, this timer controlled the presentation time of the light, turning it off when the interval expired. The timer used to control the presentation time of the red light was previously tested for its reliability. For durations of 6, 10, and 16 s, the means were 6.11, 9.97, and 15.80 s, with standard deviations of .23, .24, and .26, respectively.

Some of the ADHD children were tested in a clinic playroom at a medical center, although several different playrooms were employed. Other ADHD children and the control children were tested in their homes in a quiet room with no other family members present in the room. The study comprised two testing phases using the same apparatus described above. In Phase I, all participants were tested initially on a single retrospective trial of either 6 or 10 s followed by 20 prospective trials involving both 6- and 10-s intervals randomly sequenced. No distraction occurred in this phase. In Phase II, these same participants were then given 20 additional prospective trials employing both 10- and 16-s intervals, again randomly sequenced. In all of the Phase II trials, a distractor (jack-in-the-box) was presented midway through the interval.

The results of this preliminary study indicated that the apparatus and procedures detected significant group differences between the ADHD and control children in their time reproductions, but only for the prospective trials. ADHD participants made significantly larger errors of reproduction than controls during the 6- and 10-s trials (no distraction) as well as during the 10- and 16-s trials (with distraction). Both groups were found to increase the magnitude of their errors with increasing duration. A comparison of the 10-s intervals with and without distraction indicated that the effect of distraction was to increase the magnitude of the errors for both ADHD and control children. These findings were believed to be sufficiently promising to proceed with a more time consuming and rigorous investigation of the sense of time in ADHD and normal children and the effects of stimulant medication on the ADHD children's sense of time. In the formal study, the ADHD and control children were better defined, only prospective time reproductions were employed, a larger range of temporal durations was tested, and the distraction condition was now counterbalanced across these durations to more directly evaluate its effects on time reproductions in both groups.

Study I

Research participants

Two groups were employed in this study. The first group comprised the 12 ADHD children who were being tested for the effects of stimulant medication as reported in Study II below. The ADHD children ranged in age from 6.8 to 14.6 years. The children were consecutive referrals to a university medical center ADHD clinic whose parents or referring physicians had requested a double-blind, placebo-controlled evaluation of three doses of methylphenidate (MPH) offered to the local community as a service by this medical center clinic. The participants received a clinical diagnosis of ADHD based upon a structured diagnostic interview by a licensed child clinical psychologist employing the diagnostic criteria from the DSM-IV. These children also had to have T-scores above 65 on the Inattention Scale of the Child Behavior Checklist (Achenbach & Edelbrock, 1983). They had been screened by a pediatrician as being in good physical health and medically able to undergo the 4-week drug evaluation (see Study II below). The study had received approval from the medical center Institutional Review Board for research on human subjects and written consent of the parents was obtained. The mean age of the ADHD children was 11.2 years ($SD = 2.00$) and their mean IQ score on a well-standardized intelligence test given within the past 12 months was 102.1 ($SD = 9.34$).

The second group consisted of 26 children ranging in age from 6 to 13 years recruited using the same procedures as those used in the earlier preliminary study above. The mean age for the control group was 10.5 years ($SD = 1.66$) and the mean IQ was 106.7 ($SD = 9.71$). The ADHD and control groups were compared on age and IQ and found not to differ significantly.

Procedures

The ADHD and control children were testing using the same apparatus and testing procedures as in the preliminary study. The ADHD participants were tested in a clinic playroom at the ADHD clinic of a major medical center. Testing occurred weekly on four occasions as part of the drug evaluation described in Study II below. The results obtained from their placebo week were used in this study to contrast against those of the community control group, which was tested only once. A potential problem created by this procedure is that of a possible practice or boredom effect in the ADHD group if the subject received the placebo condition during the 2nd to 4th week of the drug trial. The number of subjects in each week who received the placebo was as follows: 3 in Week 1, 2 in Week 2, 1 in Week 3, and 6 in Week 4. Given that an unequal number of subjects received the placebo in each of these four possible weeks, it is not possible to analyze the results for an order effect to see if a potential practice effect may have existed. This is discussed later under limitations of the study and certainly must be viewed as qualifying the findings to be discussed below.

All participants were given the same instructions for the prospective time production trials, which were as follows: "I'm going to turn on this light (*pointing to the red light bulb*), and I want you to watch it carefully. When the light is turned off, I want you to turn on the flashlight to show me how long you think the light was on for and then when that time is over, turn the flashlight off." The experimenter then turned on the red bulb for one of the five durations of 12, 24, 36, 48, or 60 s after which the child attempted to reproduce the interval with a flashlight. The participant's time reproduction was measured by the photodetector diode and elapsed time indicator. This entire procedure was then repeated for a total of 20 prospective trials. Four trials were given at each of these five durations. These durations were presented in a randomized order but all participants received the same order. In half of the trials at each duration, a distraction was created while the display light was activated. The distraction created during each trial lasted approximately 4 s and occurred halfway through the time the display light was activated.

The control participants were tested on one occasion in an identical fashion to that used above for the ADHD subjects. However, for the convenience of these control families, some children were tested in a quiet room of their homes (typically the kitchen) from which other family members were excluded during testing, while others were tested at the same clinic where all ADHD children were tested.

Scoring

The raw time productions made by the participants were converted into two different scores, as recommended by Brown (1985). The first was an *absolute discrepancy score* which consisted of the absolute value of the magnitude of the discrepancy between the participant's time production and the interval presented to the child. This provides a measure of the magnitude of the errors made by the children, regardless of the direction of the error (under- *vs*. overestimate). Such a score is important because it is possible, both within and between participants, for errors to vary on either side of the sample interval presented to the child. It is conceivable that children with ADHD are more variable or erratic in their time reproductions in both directions around the sample interval than are control children. If absolute values were not employed, such variations around the sample duration could average out across trials or individuals to create means that reflect a higher degree of accuracy of the time productions than may actually have been the case. For instance, a participant with ADHD might produce discrepancies of -15, $+5$, $+15$, and -5 across four trials using a 6-s sample interval, resulting in an average across trials of 0, or perfect time reproduction. The same would be the case

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if these scores were for 4 separate participants with ADHD on a single 6-s trial. Thus, absolute discrepancy scores provide a clearer picture of accuracy in time reproduction regardless of the direction in which errors are being made by subjects.

However, it is important as well to determine if the participants tend to err in one direction more than the other (under- *vs*. overestimates) in these time reproductions. To address this issue as well as to create a standard score across the different time intervals used across trials, an *accuracy coefficient score* was created by dividing each of the participant's time reproductions by the time duration of the sample interval presented on that trial. Using such a coefficient, scores of 1.00 equal perfect reproduction of the sample interval, scores above 1.00 reflect overproductions, and scores below 1.00 reflect underproductions.

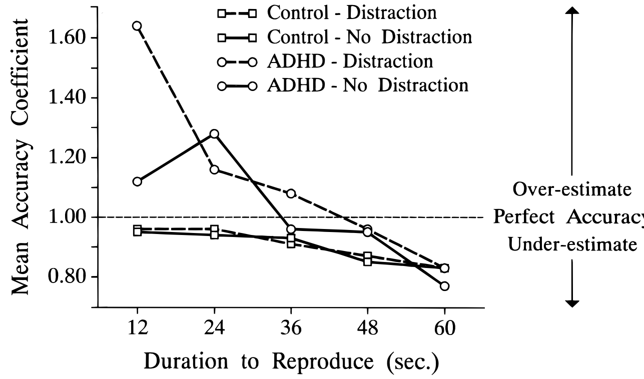

Fig. 1. The mean absolute magnitude of errors in the time productions of ADHD and control children at five different durations with and without distraction.

Results

The results for Study I were first analyzed using analysis of variance and a four factor design: 2 (groups) × 2 (distraction) × 5 (time durations) × 2 (trials) with repeated measures on the last three factors. The main effect for the last factor (trials) was not significant nor were any of the interactions including it. Therefore, this factor was eliminated from further discussion below.

Absolute discrepancy scores

The analyses revealed a significant main effect for group [$F(1,36) = 12.29$, $p < .002$], indicating that the ADHD group made significantly larger errors of time production than controls ($M = 11.55$ *vs*. 6.15, respectively). The main effect for distraction was also significant [$F(1,36) = 12.02$, $p < .002$], indicating that the distractor increased the magnitude of the discrepancies over those made in the non-distraction condition. The main effect for duration was significant [$F(4,144) = 24.13$, $p < .001$], with the magnitude of the discrepancy increasing with the duration to be reproduced. However, all of these main effects should be interpreted with caution, as there were several significant interactions found among these factors. While the interaction of Group × Duration was not significant [$F(4,144) = 0.47$, $p = .76$], the interaction of Group × Distraction was significant [$F(1,36) = 8.25$, $p < .007$]. This indicated that the distractor appeared to have no effect on the time productions of the control children, while significantly increasing the magnitude of discrepancies made in the reproductions of the ADHD group. Even this interaction must be qualified, however, by the finding of a significant three-way interaction of Group × Distraction × Duration [$F(4,144) = 3.42$, $p = .01$].

This interaction is shown in Figure 1, and suggests that both groups tended to increase the absolute magnitude of their errors of reproduction with increasing durations. The ADHD children made larger errors of estimation than the control children at most of the durations when no distractor was present, except perhaps at the 36-s interval. The distractor produced little effect on the productions of the control children regardless of the duration to be reproduced. In contrast, the presence of the distractor increased the magnitude of discrepancies made by the ADHD group, but primarily at the 12- and 36-s durations.

Coefficients of accuracy

To determine if these absolute discrepancies in time productions were likely to be in any consistent direction (under- *vs*. overestimations), the coefficient of accuracy scores were similarly analyzed. A main effect for group, again, was significant [$F(1,34) = 5.73$, $p = .02$], indicating that while normal children appeared, on average, to underproduce the time intervals ($M = 0.90$), children with ADHD appeared to overproduce them ($M = 1.07$). The main effect for distraction was also significant [$F(1,34) = 6.38$, $p < .02$], as was that for duration [$F(4,136) = 15.21$, $p < .001$], but so was the interaction of group with each of these factors and their three-way interaction [$F(4,136) = 4.85$, $p = .001$], qualifying the interpretation of these main effects. These results are graphically depicted in Figure 2.

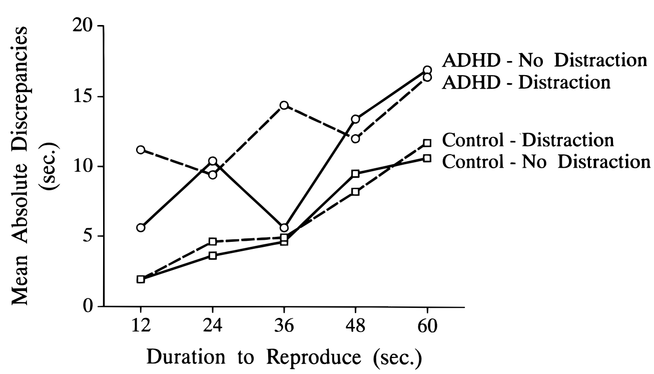

Fig. 2. The mean coefficient of accuracy scores for the time productions of ADHD and control children at five different durations with and without distraction.

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Figure 2 suggests that the control group produced time intervals that progressively *underreproduced* the duration of the interval with increasing durations to be reproduced and that the presence of the distractor had little impact on this pattern of reproductions. In contrast, the ADHD group produced time intervals that were initially *overreproductions* of the durations, moving progressively toward *underreproductions* with increasing durations to be reproduced, even matching the accuracy of the control group at the intermediate durations. The effect of distraction was to mainly increase the reproductions of ADHD children toward overestimations relative to their nondistraction scores for the same duration, mainly for the 12-, 36-, and 60-s durations.

Study II

The purpose of this study was to evaluate the effects of stimulant medication on the time reproductions of ADHD children.

Participants

The 12 ADHD children described above in Study I participated in this study.

Medication

All ADHD children underwent a 4-week, double-blind evaluation in which the child, parents, teachers, and research assistant conducting the testing were unaware of the medication–placebo order. Three doses of MPH and a placebo (lactose powder) were each given to the children on a twice daily basis (morning and noon) for a 7-day period. On the last day of that drug condition, the children were tested in the clinic according to the procedures described below. For this particular day, parents were requested to delay the morning or noon dose of medication such that it was to be given approximately 1 hr prior to the testing appointment. The doses of medication were 5, 10, and 15 mg of MPH given BID. However, the youngest child (age 6 years) received doses of 2.5, 5, and 10 mg, whereas the oldest child (14 years) received doses of 10, 15, and 20 mg of MPH. These three drug conditions for all participants are subsequently referred to as *low*, *medium*, and *high dose* conditions, respectively. Six possible orders of these dose conditions were created such that the high dose condition was always preceded by the medium dose condition and so this pair of conditions was treated as a single condition in creating the potential dose orders. Participants were then randomly assigned to one of these possible drug orders.

The medication was prepared by the hospital pharmacy such that the MPH and placebo were crushed and placed in white opaque gelatin capsules. This was done not only to disguise the distinctly bitter taste of MPH relative to the mildly sweet flavor of the placebo (lactose powder) but also to disguise the different doses of MPH used across the 4-week trial. Parents were given a single week's supply of medication at a time and then provided the child's school with sufficient capsules for the school week. The parents returned the bottles so that a pill count could be conducted to provide a means of checking that the medication had been used.

Apparatus and procedures

The same electronic apparatus and method of administration used in Study I was employed here. Durations of 12, 24, 36, 48, or 60 s were used. The participant were tested four times with each testing occurring on the last day of each drug condition (placebo, low, medium, and high doses). The participants were given a total of 20 prospective trials on each occasion of testing. Four trials were given for each of the five time durations with half of these four trials involving the distraction condition. A single randomized sequence of the durations and distraction conditions was created, and all participants received this same sequence for each of the four weekly testing sessions. The distraction lasted approximately 4 s and occurred halfway through the sample time duration.

Results

The scores were subjected to the same two scoring methods used in Study I above (absolute discrepancy and coefficient of accuracy). The converted scores were then analyzed separately using a four factor ANOVA: 4 (drug conditions) $\times$ 2 (distraction) $\times$ 5 (time durations) $\times$ 2 (trials) with repeated measures on all factors. Since the main effect for the trials (last) factor was not significant nor were any of the interactions that included it, this last factor was eliminated from further discussion of the analyses below.

Absolute discrepancy scores

As noted above, discrepancy scores reflect absolute inaccuracy in either direction of estimation (production). The analyses indicated no significant main effect for drug condition [$F(3,33) = 0.86$, $p = .47$], but a marginally significant main effect for distraction [$F(1,11) = 3.87$, $p = .07$]. Inspection of the means suggested that the distractor tended to increase the absolute magnitude of the discrepancy in time productions ($M = 9.82$ and 10.95 s, respectively). The main effect for duration was significant [$F(4,44) = 12.07$, $p < .001$], revealing an increase in the magnitude of discrepancies with increasing duration to be reproduced ($M = 6.42$, 8.50, 9.76, 11.63, and 15.64 s, for the 12-, 24-, 36-, 48-, and 60-s durations, respectively). The interaction of drug condition with either the distraction factor [$F(3,33) = 0.79$, $p = .52$], or the duration period, [$F(12,132) = 1.21$, $p = .28$], was not significant, nor was their three-way interaction [$F(12,132) = 1.19$, $p = .30$]. The interaction of the distraction factor with that of duration, however, was marginally significant [$F(4,44) = 2.47$, $p < .06$]. Inspection of the means suggested that the distractor tended to increase the absolute discrepancies at durations at or below 36 s but had little effect on the 48-s duration, and decreased the absolute discrepancy at the 60-s duration.

Coefficients of accuracy scores

The analysis of the coefficient of accuracy scores indicated that, as above, the main effect for drug condition was not significant [$F(3,33) = 0.90$, $p = .45$]. The main effect for the distraction condition, however, was significant [$F(1,11) = 6.62$, $p < .03$], indicating that the childrens' time productions were less accurate in the direction of overestimations during the distraction than during the nondistraction conditions. The main effect for the time duration factor was also significant [$F(4,44) = 10.73$, $p < .001$], indicating that accuracy was significantly affected as a function of the duration of the interval to be reproduced. Inspection of the means indicated that participants tended to overproduce the 12- and 24-s intervals ($M = 1.31$ and 1.17, respectively) while increasingly underreproducing the 36-, 48-, and 60-s intervals ($M = 0.99$, 0.91, and 0.82, respectively). In general, the effect appeared to be a linear, progressive move in the direction of underreproducing intervals of increasingly longer durations. None of the interactions involving drug condition were significant. However, the interaction of distraction with temporal duration approached significance [$F(4,44) = 2.41$, $p = .06$], suggesting that the distractor tended mainly to affect the accuracy of reproductions for the 12- and 60-s intervals. This is in contrast to the findings for absolute discrepancy scores which demonstrated that the distractor increased the magnitude of discrepancy primarily for the 12- to 36-s intervals. This difference in results most likely indicates that distractors increase the magnitude of errors made by ADHD children, especially at shorter durations, but not necessarily in any consistent direction (over- *vs*. underreproductions).

DISCUSSION

After completing the studies reported above but while preparing this paper, the authors became aware of a pair of much earlier studies (Cappella et al., 1977) that compared the time productions of hyperactive and normal children. In one study, children ages 7 to 10 years were asked to produce intervals of 15, 30, and 60 s. The hyperactive children were selected on the basis of teacher ratings, a history of medical diagnosis, and placement in special education. They were found to make larger discrepancies in their time productions than the control children. Both groups showed an increase in the inaccuracy of their productions as length of the interval increased but this increase in errors with increasing durations was greater in the hyperactive than control children. In a second study using substantially larger samples, children ages 8 to 12 years were required to produce intervals of 7, 15, and 30 s duration. The results were similar to those of the first study showing that hyperactive children were less accurate than control children and made increasingly larger errors of production as duration increased than did the control children. Although the children in the Cappella et al. study were not clinically diagnosed as ADHD by current standards, these findings, nonetheless, are in keeping with the earlier predicted association between hyperactive–impulsive behavior, or ADHD, and an impairment in sense of time. Thus, it is proper that we consider these studies to have precedence over our own in this area and so the results of the Cappella et al. (1972) studies will serve as the basis for comparison with our own results.

Study I provided further evidence, consistent with the earlier research of Cappella et al. (1977), that the capacity to reproduce temporal durations is impaired in children with ADHD. The ability of ADHD children to accurately reproduce temporal durations appeared to be partly a function of the duration to be reproduced, as well as the presence of distracting events. Study I found that the absolute magnitude of error in time reproductions in children with ADHD was a function of both of these variables. Children with ADHD displayed an increasing magnitude of errors as duration increased. This same effect occurred in the control children, but children with ADHD were significantly less accurate in these reproductions relative to controls.

The effect of distraction on time reproductions was significant but only for the ADHD group, particularly at intervals of 12 to 36 s. When the direction of errors (under- *vs*. overreproductions) was examined similar effects were noted. These results suggested that children with ADHD may provide overreproductions of the shorter intervals but progressively move in the direction of providing underreproductions as the duration of the sample intervals increased. The effect of distraction was to increase the likelihood of overreproducing the time interval relative to the reproductions of that interval given in the nondistraction condition, particularly at the 12- to 36-s intervals.

In the studies conducted by Cappella et al. (1977), inaccuracy of the hyperactive children's time productions increased more than that seen in the control children as interval duration increased, resulting in a significant group by duration interaction. This was not the case here in Study I. It is difficult to account for this difference in findings, given that children of similar ages were employed in the present study and the earlier ones. Cappella et al. (1977) also used a comparable range of time durations to be reproduced (7- to 60-s range) but used a time production task rather than the *re*-production paradigm used here. Perhaps this difference or others dealing with the manner in which subjects were identified (clinic *vs*. school identified, respectively) and defined as having a disorder (ADHD *vs*. hyperactivity, respectively) contributed to these different outcomes between the present study and that of Cappella et al. (1977). Also, the different instructions and materials employed to assess sense of time may have been another contributing factor. Even minor procedural differences, as Zakay (1992) has shown, may influence children's time estimations in significant ways. Also, larger samples of ADHD subjects were used in the studies by Cappella et al. (1977) suggesting that such sample sizes may need to be employed to detect this interaction as statistically significant.

Besides the greater inaccuracy of time productions found in ADHD children relative to control children, two other

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features of the pattern of responding in ADHD children in Study I were noteworthy and possibly atypical. First, the ADHD group appeared to be adversely affected by the distraction condition, especially at the 12- to 36-s intervals, while the control children seemed to show no such exacerbation at any of the interval durations (12–60 s). This had the effect of increasing the absolute magnitude of the errors made by the ADHD group in the direction of a longer (over-) reproduction relative to their reproductions in the nondistraction condition for that interval. In Zakay's research (1992) on normal children's time reproduction, a similar method of distraction was employed but it produced two effects not seen in the present study. First, it resulted in greater inaccuracy in reproducing the time intervals (6 and 10 s) of the normal children. Only the ADHD children in the present study were affected by the distraction, and mainly at the 12- and 36-s durations. And second, the effect of distraction was generally opposite to that found by Zakay (1992), increasing the time reproductions of the ADHD group at these durations rather than shortening them as had occurred in the Zakay (1992) study.

Why the control children in the present study should be unaffected by the distraction while the normal children in the study by Zakay (1992) would be is difficult to explain. Similar methods of testing time reproductions were used in all of these studies. However, Zakay's study employed much shorter time intervals. This might imply that distractions primarily affect control or normal children only at relatively short intervals (below 10 s) while affecting ADHD children across larger durations of time.

The second atypical finding in the pattern of results for the ADHD children was observed in the direction of the errors of reproduction they made. These errors appeared to reverse direction with increasing durations of time intervals to be reproduced. To appreciate this pattern, the results found for the absolute magnitude of the errors (absolute discrepancy scores) made by the groups must be contrasted with their coefficients of accuracy which reflected the average direction of these errors (under- *vs*. overreproductions). Comparing Figure 1 with Figure 2 shows that while the absolute magnitude of reproduction errors was generally increasing as the duration to be reproduced increased, these errors were in the direction of overreproductions (coefficients above 1.00) for the shortest intervals (12 and 24 s) but moved toward the opposite direction of errors, or underreproductions (coefficients less than 1.00) as the durations increased. Thus, while the ADHD group appeared to produce less accurate and more variable time reproductions, the direction of these errors tends to reverse itself from more overreproductions to more underreproductions as the length of time interval to be reproduced increases. If one were to look only at the accuracy coefficients (Figure 2), it would suggest a rather startling finding: Children with ADHD are as accurate as control children in their time reproductions at the 36- and 48-s intervals, and the effect of distraction is to *increase* the accuracy of these reproductions at the 36-, 48-, and 60-s durations! Inspection of the results for the absolute magnitude of the errors, which disregards the direction of error (Figure 1) shows that this is not the case. ADHD children, like control children, generally increased the magnitude of their errors as duration increased and the effect of distraction was to increase further the size of these reproduction errors, especially for the 12- and 36-s intervals. To summarize, children with ADHD appear to be making larger reproduction errors in both directions around the sample duration to be reproduced than are control children. However, the direction of their errors is quite variable. The proportion of error types (under- *vs*. overreproductions) is changing as duration increases. This pattern of increasing underreproductions of the intervals with increasing duration is evident in the control children as well but shows no reversal of error type (direction), as these children tend to slightly underreproduce even the shortest durations tested here.

The failure to find an effect of medication on the time reproductions of ADHD children in Study II was somewhat surprising. Stimulant medication tends to reduce deviations from norms on cognitive measures on which ADHD children have been found to be deficient (Rapport & Kelly, 1993). In particular, MPH has been shown to improve the working memory of ADHD children, at least those who are not anxious (Tannock et al., 1995a). If the accurate reproduction of temporal durations is dependent on working memory, as hypothesized earlier, then improvements in working memory should be associated with more accurate temporal reproductions. Yet no improvement in temporal reproduction was found here. Measures of working memory were not taken here to directly evaluate this relationship, however, so it remains conjectural. The inability to detect MPH effects in this study is unlikely to be related to the range of doses used here, as these ranges were quite comparable to those used in other studies noting cognitive improvements. That these children were responding to medication was quite evident in significant changes in the parent and teacher ratings of ADHD symptoms collected during the active medication and placebo conditions. This lack of significant drug effects may simply have resulted from the relatively small sample size for the ADHD group and, hence, the limited statistical power to detect small to moderate effect sizes of medication on the time reproductions of these children. Thus, studies of MPH effects on time reproduction in ADHD children using larger samples are to be encouraged. It is also possible that the time of testing the ADHD participants may not have been during the peak effect of their medication dose each week. Although parents were encouraged to delay giving the most recent dose of medication on the day of testing until 1 hr prior to the testing appointment (usually in the late afternoon) and reported doing so, this does not guarantee that such was the case. But it may also be that sense of time is a domain that remains unaffected by stimulant medication treatment in children with ADHD.

A number of methodological problems affect any straightforward interpretation of the results of these studies. In

Study I, a major limitation may rest in the use of the scores of the ADHD group from the placebo condition for comparison with the scores for the control participants. As noted above, half of the ADHD subjects had their placebo condition as the last week of their 4-week trial and thus had been tested three times in this same procedure before this placebo condition. Three other subjects received this placebo condition on the 2nd or 3rd week of testing. And so, 75% of these participants had at least one or more testing experiences with the apparatus before their placebo condition, raising the potential for practice or boredom effects to exist in these placebo scores. If the effect of practice, on the one hand, is to improve the accuracy of the ADHD children in this procedure, then it serves as a conservative corrective influence on these data, decreasing the likelihood of finding differences from the control group. Yet, such differences were found. On the other hand, if the effect of such practice or boredom is to worsen the performance of ADHD children, then it could well have contributed to the group differences noted here. Arguing against any practice or boredom effects of repeat administrations were the absence of significant main effects for trial in both Zakay's (1992) initial study with normal children and the present study. This would seem to maximize the likelihood of finding such effects in comparison to a weekly retesting procedure, as was also used here.

In both Studies I and II, the use of a standard sequence of presenting the differing time durations and distracting conditions across all participants could be problematic. Order effects may well exist in such sequences that could contribute to some of the significant interactions (i.e., Duration $\times$ Distraction) found here. For instance, the first trial of the 12-s duration (without distraction) occurred after a 36-s (no distraction) and then a 60-s (with distraction) trial. The presentation of longer durations before the shortest one in this sequence might serve to bias the reproduction of the shorter duration in the direction of overreproducing it (as occurred here with the ADHD children). The alternative, however, of randomizing participants to all possible sequences in such a paradigm is highly impractical, given the potential variations of the sequence of 20 trials used here. The present study also did not find an interaction of trial with any of the other factors in the design or their combinations, making such order effects within these results less likely, although not completely so. The studies by Cappella et al. (1977) used such a randomization procedure but did not examine order effects in their analyses of their data. Future studies should be encouraged to do so.

A further methodological limitation was the testing of some control children in their homes in Study I while others as well as all ADHD participants were tested in playrooms at the same clinic. This may have introduced greater variation into the results of the control group. Children's time reproductions are extraordinarily sensitive to even small shifts in methodology, such as seemingly minor factors like the size and burning intensity of the light bulb used to present the time duration (Zakay, 1992). It therefore is conceivable that even small differences in the context of the testing session might affect the results of such studies. Even so, the use of different testing locations in this study would most likely have created a conservative effect upon finding group differences, tending to increase the variability within the control group relative to the ADHD group and thus decreasing the sensitivity of the study to potential differences between these groups. The fact that such differences emerged despite this difference in methods could be construed as attesting to the robustness of the results.

A final limitation may have been the confounding of problems with motor control and impersistence in children with ADHD with the method used to assess their time reproductions. ADHD children have been found previously to have difficulties with motor coordination compared to normal children (Barkley, 1997; Carte et al., 1996; Denckla & Rudel, 1978; Denckla et al., 1985). They may also have difficulties with the persistence of motor acts (Voeller & Heilman, 1988). Children in this study were required to press and hold the activation button of the flashlight in reproducing each interval. In essence, then, longer durations to be reproduced in the present study might have required more motor persistence in the children. This could lead to a finding of greater errors in time reproductions with increasing duration to be reproduced; specifically, children with ADHD should persist less than control subjects, and this impersistence should become increasingly evident as duration increases. Several findings argue against this possibility of motor impersistence difficulties accounting for the findings for the ADHD group. First, at the short intervals, the ADHD children actually created longer reproductions than the normal participants, only moving toward shorter reproductions as the intervals reached the 48- and 60-s durations. Second, the most telling feature of the reproductions of the ADHD children was their variability in both directions of error (under- and overreproductions). While the proportion of these error types changed significantly with increasing duration, at all durations ADHD children made significant over- as well as underreproductions. Such variability, especially toward overreproductions on some trials, is less easily explained by simply motor impersistence in the ADHD group. Finally, the pattern of increasing magnitude of errors with increasing duration has been found in various procedures for testing time estimation in normal children, where a motor component may not be required for the task (Brown, 1985; Zakay, 1990), suggesting that this phenomenon is not due entirely to issues related to motor persistence. The opposite line of reasoning is also worth considering, and that is whether problems with motor impersistence in ADHD might be due to a disturbance in sense of time. This inverse argument has been made by others who have found that a disruption in the psychological sense of time may produce effects on motor speed, reaction time, and persistence (Pastor et al., 1992). In a study of time estimation and reproduction in Parkinson's patients, Pastor et al. (1992) found significant correlations between tapping speed, simple reaction time, and movement time and the results of their time estimation *and* reproduction tasks. Following this line of reasoning, it is possible that the impairment in sense of time in those with ADHD may actually contribute to their problems with motor control and persistence rather than *vice versa*.

With these limitations in mind, the present preliminary studies, along with the earlier studies of Cappella et al., 1977, suggest that ADHD may create an impairment in the capacity to accurately reproduce temporal durations relative to control children. Most striking in our results is that these reproduction inaccuracies are quite variable, occurring as both under- and overreproductions. Such inaccuracies may be exacerbated by the presence of distractions, at least at some time durations, as well as by longer durations to be reproduced. Distractions do not seem to affect the accuracy of time reproductions by control children at the longer durations used here (12–60 s). Both ADHD and control children become increasingly inaccurate in their time reproductions as durations increase, with both groups increasingly erring in the direction of proportionally more underproductions as duration increases. However, unlike the control children, ADHD children appeared to produce proportionally more overreproductions at the shortest time durations, yet shifting toward proportionally more underreproductions as duration increased. Stimulant medication was not found to improve these errors in sense of time in the ADHD group. These preliminary studies clearly indicate that larger, more rigorous investigations of temporal reproductions in children with ADHD should proceed and are likely to be worthwhile in further elaborating the manner in which ADHD interferes with sense of time.

Future studies could further clarify the nature of this potential impairment in time sense by assessing working memory, behavioral inhibition, and motor persistence along with time reproductions in the ADHD and normal children. Evaluating the relationships among these various measures might then show whether deficits in these other neuropsychological functions are the basis for, or are at least associated with, the impairment in sense of time apparently occurring in ADHD. Using such a battery of measures with a larger sample of ADHD children undergoing a stimulant medication trial, such as that attempted here, would also help to clarify whether stimulants improve the sense of time in ADHD children considering that previous studies have found these drugs to improve the deficits in behavioral inhibition, motor persistence, and working memory in children with ADHD (Rapport & Kelly, 1993; Tannock et al., 1995a; Tannock et al., 1995b).

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