EXPERIMENTAL ANALYSIS OF CHILDHOOD PSYCHOPATHOLOGY: A LABORATORY MATCHING ANALYSIS OF THE BEHAVIOR OF CHILDREN DIAGNOSED WITH ATTENTION-DEFICIT HYPERACTIVITY DISORDER (ADHD)

SCOTT H. KOLLINS, SCOTT D. LANE, and STEVEN K. SHAPIRO
Auburn University

The behavior of children diagnosed with Attention-Deficit Hyperactivity Disorder (ADHD) has been hypothesized to involve differential sensitivity to parameters of reward and punishment. However, support for these theories has been limited because, in part, of the methods used to investigate them. The current study examined the behavior of six ADHD children and six comparison children on a computer task designed to present different parameters of reinforcement by using concurrent reinforcement schedules. A quantitative analysis of the sensitivity to changing contingencies of reinforcement was conducted by examining the performance of the children across five experimental conditions. Results suggest that although there may have been several mediating variables, children diagnosed with ADHD may show less sensitivity to changing parameters of reinforcement rate as measured by response ratios and time allocation to two concurrently available alternatives. Implications of these results are discussed in terms of the utility of such experimental methods in the study of childhood behavior disorders.

Attention-Deficit Hyperactivity Disorder (ADHD) is one of the most commonly diagnosed behavior disorders among preadolescent children in the United States (Barkley, 1991). Accordingly, much effort has been devoted to understanding the etiology and subsequent course of this disorder. Traditionally, ADHD has been characterized by a number of behavioral constructs, the most general of which are developmentally inappropriate levels of hyperactivity, attentional deficits, and impulsivity (American Psychiatric Association, 1987, 1994). It is often suggested
that these behavioral patterns observed in children diagnosed with ADHD are the result of differential sensitivity to the consequences of their behavior as compared to normal, undiagnosed children (e.g., Barkley, 1988; Haenlein & Caul, 1987, Quay, 1987).

Quay (1987) suggests that the behavior of children diagnosed with ADHD does not decrease in rate or probability in the expected manner following exposure to either punishment or extinction. Such behavior, according to Quay, is demonstrated by higher rates of responding under fixed-interval (FI), fixed-ratio (FR), and differential reinforcement for low rates of responding (DRL) schedules of reinforcement as compared to their normal peers.

In a similar manner, Haenlein and Caul (1987) have proposed that children diagnosed with ADHD are less sensitive to reinforcement than typical children. Haenlein and Caul propose that a greater level of reinforcement is needed to control the same level of behavior in children with ADHD than in normal children. Both of these models share the notion that the behavioral differences between children diagnosed with ADHD and normal children are the result of differential sensitivity to the consequences of their behavior. Additionally, Barkley (1989, 1990) has outlined a theory of ADHD that explains the behavior of such children in terms of a lack of proper stimulus control and a deficit in rule-governed behavior.

Two major approaches have been utilized to examine empirically the idea that ADHD children differ from normal children in their behavioral sensitivity to reinforcement and punishment. One group of studies has examined the behavior of ADHD and typical children under DRL schedules of reinforcement (Gordon, 1979; McClure & Gordon, 1984; Solanto, 1990). Collectively, these studies suggest that although ADHD children may receive the same overall amount of reinforcement, they generally make more responses to do so. Conclusions from these studies characterize the behavior of ADHD children as less efficient than the behavior of normal children in terms of response allocation per reinforcer. These conclusions support the idea that the behavioral sensitivity of ADHD children differs from normal children under conditions which reinforce low rates of behavior.

Another series of studies has investigated how continuous versus intermittent reinforcement differentially affects the behavior of ADHD children. In this paradigm, children perform some task and are rewarded either after every correct response (continuous reinforcement, CRF) or after some predetermined number of correct responses (intermittent or partial reinforcement, PRF). Several of these studies reported no differences in the performance of ADHD versus normal children under both conditions of CRF and PRF on tasks of general cognitive skill (Cunningham & Knights, 1978; Pelham, Milich, & Walker, 1986). Other studies have shown that ADHD children performed with less accuracy than normal children under both CRF and PRF conditions (Douglas & Parry, 1983; Parry & Douglas, 1983) and yet another study has shown that ADHD children perform worse than normal children under conditions
of PRF but not under CRF conditions (Barber & Milich, 1989). All these studies compared the behavior of ADHD and normal children under different conditions of reinforcement but yielded different results. Because these studies employed a wide range of methods, differential outcomes are difficult to interpret. As a result, the possibility cannot be ruled out that the differential outcomes are caused, at least in part, by the methods employed rather than behavioral characteristics of the two groups.

Several other variables have been investigated to highlight the relationship between reinforcement and the behavior of ADHD children compared to normal children. One study reported that the reaction times of hyperactive children did not differ significantly under conditions of reward and punishment (Firestone & Douglas, 1975) and studies examining the effects of positive and negative verbal feedback on the behavior of ADHD and normal children have reported conflicting results. One study reported that ADHD children perform worse than normals under conditions of negative feedback (Rosenbaum & Baker, 1984) and another reported no differences between the two groups under conditions of both positive and negative verbal feedback (Worland, 1976).

Collectively, findings regarding the differential sensitivity of ADHD children to reinforcement and punishment are clearly equivocal. Some of these inconsistent results may be accounted for by the different response classes used across studies, including button presses (Gordon, 1979; McClure & Gordon, 1984; Solanto, 1990; Sonuga-Barke, Taylor, Sembi, & Smith, 1992); motor coordination with respect to auditory stimuli (Douglas & Parry, 1983; Firestone & Douglas, 1975); the completion of spelling tasks (Barber & Mitich, 1989; Pelham et al., 1986; Worland, 1976); concept-formation tasks (Cunningham & Knights, 1978; Parry & Douglas, 1983; Rosenbaum & Baker, 1984); and other measures of cognitive ability (Rapport et al., 1986; Worland, 1976).

The use of varying experimental preparations may also have contributed to the inconsistent findings noted above. Variations included changing experimental conditions based upon number of trials (e.g., Firestone & Douglas, 1975), predetermined time periods (e.g., Solanto, 1990), or response-based criteria (e.g., Pelham et al., 1986). Subject characteristics have also varied widely across studies, with some studies using only hyperactive children, some using only children with insufficient attention, and some using children with both. The differences in subject characteristics may have resulted in different clinical groups of children being compared as if they were the same. Despite these methodological inconsistencies, all of the studies are similar in that they demonstrate potential differences in the behavior of normal and hyperactive children under different conditions of reinforcement and punishment.

We reasoned that an alternative approach, based on a well established literature from experimental psychology, would contribute to the current literature which suggests that children diagnosed with ADHD may be differentially sensitive to reinforcement compared to normal children. Herrnstein (1970) proposed a mathematical
relationship between behavior rate and reinforcement rate. Known commonly as the matching law, this relationship states that the proportion of behavior allocated to a particular alternative is a function of the rate at which reinforcement is obtained from that alternative. The most common way of evaluating this relationship has been through the use of concurrent schedules of reinforcement which operate independently for two possible response alternatives (Davison & McCarthy, 1988). In such a preparation, the ratio of response rates for the two alternatives is a function of the ratio of reinforcement rates obtained from those alternatives. Equation 1 illustrates this situation, said to be strict matching:

\[
\frac{b_1}{b_2} = \frac{r_1}{r_2}
\]  

(1)

In this equation, \( b \) and \( r \) represent the rates of behavior and reinforcement, respectively, and the subscripts refer to the response alternatives. Baum (1974) described a method for evaluating deviations from strict matching by fitting the following linear equation to data obtained from a similar experimental preparation,

\[
\log \left( \frac{b_1}{b_2} \right) = a \log \left( \frac{r_1}{r_2} \right) + \log k
\]  

(2)

where the parameter \( a \) is the slope of the linear fit and hypothetically represents sensitivity to reinforcement by the organism under study. The parameter \( k \) is the intercept of the line and is said to represent bias for one of the response alternatives which is caused by extra-experimental reinforcement contingencies. This analytical technique has been used to provide a precise and quantitative description of the relationship between behavior and its consequences under a range of environmental conditions in humans (Kollins, 1995; Pierce & Epling, 1983) and nonhuman species (Baum, 1979; Davison & McCarthy, 1988).

If there exist differences between normal and ADHD children with respect to how their behavior is affected by consequences, the analysis of response allocation under concurrent schedules of reinforcement using the matching equation may provide a more objective description of the differences than has previously been offered. Therefore, the purpose of the present study was twofold. First, we sought to examine possible differences between the behavior of normal and ADHD-diagnosed children in terms of their sensitivity to environmental consequences. Second, the viability of the matching law as a tool for understanding the behavior of clinically defined populations was investigated. We hypothesized that if children diagnosed with ADHD are differentially sensitive to reinforcement contingencies, then their performance on an experimental task designed to quantify this sensitivity would be different from that of normal children.
Method

Subjects
Subjects consisted of 6 children diagnosed with ADHD and 6 control children matched on the basis of age, gender, and ethnic background. ADHD children were recruited from a community-oriented, university-based training clinic, and other local resources. Control children were recruited through local school systems and university programs. Inclusionary criteria for participation of all subjects were a score of above 80 (Low Average Range) on a short-form of the Wechsler Intelligence Scale for Children, Third Edition (WISC-III); and the absence of any sensory or motor handicaps (no subjects were excluded from the study on this basis). For inclusion in the ADHD group, children must have received a prior diagnosis of ADHD, must have had at least eight items endorsed at or above a "2" on the ADHD Rating Scale (ADHDRS; DuPaul, 1990) and a T-score of greater than 65 on the Attentional Problems Subscale of the Child Behavior Checklist (CBCL, Achenbach, 1991). Normal children were required to have no diagnostic history, a score not meeting the above criteria on the ADHDRS, and a CBCL Attentional Problems T-score of less than 65. Individual scores on these instruments for both groups and other relevant subject characteristics are shown in Table 1. In addition to Table 1, probands received a significantly higher rate of endorsement than controls with regard to total

Table 1

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender</th>
<th>Age</th>
<th>WISC-III short form</th>
<th>ADHDRS score</th>
<th>CBCL Attentional Problems score</th>
<th>Medication Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>M</td>
<td>12-7</td>
<td>106</td>
<td>12</td>
<td>65</td>
<td>none</td>
</tr>
<tr>
<td>S2</td>
<td>M</td>
<td>9-8</td>
<td>94</td>
<td>14</td>
<td>86</td>
<td>methylphenidate</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4 of 5 days*</td>
</tr>
<tr>
<td>S3</td>
<td>F</td>
<td>8-2</td>
<td>83</td>
<td>10</td>
<td>82</td>
<td>none</td>
</tr>
<tr>
<td>S4</td>
<td>M</td>
<td>10-4</td>
<td>106</td>
<td>9</td>
<td>63*</td>
<td>imipramine</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 of 5 days*</td>
</tr>
<tr>
<td>S5</td>
<td>F</td>
<td>10-7</td>
<td>97</td>
<td>4*</td>
<td>74</td>
<td>none</td>
</tr>
<tr>
<td>S6</td>
<td>F</td>
<td>10-7</td>
<td>123</td>
<td>12</td>
<td>71</td>
<td>none</td>
</tr>
<tr>
<td>S7</td>
<td>M</td>
<td>11-8</td>
<td>94</td>
<td>1</td>
<td>62</td>
<td>none</td>
</tr>
<tr>
<td>S8</td>
<td>F</td>
<td>11-10</td>
<td>120</td>
<td>0</td>
<td>50</td>
<td>none</td>
</tr>
<tr>
<td>S9</td>
<td>M</td>
<td>9-5</td>
<td>106</td>
<td>5</td>
<td>60</td>
<td>none</td>
</tr>
<tr>
<td>S10</td>
<td>M</td>
<td>11-4</td>
<td>109</td>
<td>0</td>
<td>54</td>
<td>none</td>
</tr>
<tr>
<td>S11</td>
<td>F</td>
<td>8-3</td>
<td>141</td>
<td>2</td>
<td>50</td>
<td>none</td>
</tr>
<tr>
<td>S12</td>
<td>F</td>
<td>9-7</td>
<td>103</td>
<td>2</td>
<td>58</td>
<td>none</td>
</tr>
</tbody>
</table>

MEAN (SD) VALUES

<table>
<thead>
<tr>
<th></th>
<th>ADHD</th>
<th>NORMAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>10.4 (1.4)</td>
<td>10.4 (1.4)</td>
</tr>
<tr>
<td>WISC-III short form</td>
<td>101.5 (13.6)</td>
<td>112.2 (16.5)</td>
</tr>
<tr>
<td>ADHDRS score</td>
<td>10.2 (3.5)</td>
<td>1.7 (1.9)</td>
</tr>
<tr>
<td>CBCL Attentional Problems score</td>
<td>73.5 (9.1)</td>
<td>55.7 (5.1)</td>
</tr>
</tbody>
</table>

Five experimental sessions were conducted with each child.

*See text for explanation.

Note. ADHD subjects indicated in boldface.
score on the ADHD Rating Scale as measured by standard deviation units from the mean for the appropriate normative group (+1.71 SD vs. -0.08 SD; \( t = 4.63, p < .002 \)). Also, two-thirds of the ADHD subjects were receiving ongoing special education services (as a Learning Disabled and/or Emotionally Conflicted child), and one control subject (S11) was identified as academically gifted.

With regard to medication status, all ADHD subjects were prescribed medication during the school year and all but one were on a summer drug holiday for at least 1 month prior to experimental sessions (see Table 1). S4's mother reported that her responses on the CBCL were based upon S4's behavior while on Imipramine and that his behavior was otherwise much more maladaptive. For this reason, S4 was not excluded on the basis of his below criterion score on the Attention Problems dimension of the CBCL. In addition, although S5's score on the ADHD Rating Scale was lower than the criterion of 8, other measures and available clinical information provided strong evidence for the appropriateness of her inclusion in the ADHD group.

**Experimental Apparatus**

The apparatus used for the study consisted of an IBM-compatible personal computer, a 14" SVGA color monitor, and a standard keyboard on which all but two keys were covered with cardboard. The experimental sessions took place in a quiet laboratory room. A partition separated the computer console from a 19" color television which was connected to a Super Nintendo video game system.

**Procedure**

Following parent and child consent, the questionnaires and interview were administered. Subjects subsequently participated in five experimental sessions, lasting approximately 1 hour each. All but one subject completed the study in 14 days or less. For reasons unrelated to the study, S8 was unable to complete the final 4 experimental days until 6 weeks after her initial experimental day. Parents were reimbursed five dollars for each experimental session in which their child participated. Parents of ADHD children were also offered clinical services as compensation for their participation. In addition to playing the video games (described below), children were allowed to select a small toy at the end of each experimental session and a larger prize (e.g., movie passes, gift certificates) at the end of their participation in the study.

At the beginning of the first experimental session, subjects were read the following instructions by the experimenter:

> Please sit down over here [subjects were seated in front of the computer console]. Today, you are going to play a couple of different games. In the first game, you will be
Figure 1. Representation of concurrent VI-VI computer task used across all experimental segments. Subjects fired "shots" at the "aliens" by pressing right and left arrow keys (top panel). Aliens were "destroyed" according to VI schedule programmed for that side (bottom panel).
working on this computer. You will use these two keys [pointing to the visible arrow keys] to fire shots at the ugly aliens on the sides of the screen. Your job is to try to destroy them. Sometimes when you hit them with the laser beams, they will blow up. After you blow up enough aliens, you will be able to go to the other side of the room to play Nintendo. After you play Nintendo a little while, we will come back to this game and keep switching back and forth. At the end of today, you will get to pick a special prize from the drawer you saw earlier. Also at the end of all your days, you will get a bigger prize to show how much I appreciate you helping me.

When you are playing this computer game, do not press any buttons except these two [pointing to the left and right arrow buttons]. No other buttons will help to blow up the aliens. Also, do not hold the buttons down. You must press them each time you want to fire at the aliens. Have fun and remember to press only these two buttons. Once we start, I won’t be able to answer any questions. Do you have any questions before starting?

Each experimental session was divided into approximately twelve segments lasting between 2 and 5 minutes per segment. Subjects had the opportunity to play the Nintendo game of their choice between segments. During each experimental segment, the computer screen presented the arrangement shown in the top panel of Figure 1. Shots were fired from the “guns” in the center of the screen by pressing the right and left arrow keys which produced a red line extending to the “alien.” The aliens could be destroyed (bottom panel, Figure 1) according to two independent variable-interval (VI) schedules of reinforcement operating on both sides of the screen. Any button press following the programmed time interval for one side of the screen produced a shot that destroyed the alien. Each segment required the subject to destroy 20 aliens before being allowed to play a selected Nintendo game for 2 minutes.

To establish a reinforcement history for both left and right responses, subjects were exposed to a VI 3-second schedule on either the left or right side of the screen at the beginning of the first experimental session. The subjects were exposed once each to the right and left sides under this condition. Subjects were exposed to the VI schedules for both sides of the screen during all subsequent experimental segments. Values for the concurrent schedules remained constant during each day but were varied across the five experimental sessions. A 2-second changeover delay (COD) was employed across all concurrent conditions. The specific sequence of concurrent VI-VI schedule values was identical for all subjects and is presented in Table 2.
### Table 2

Sequence of VI-VI Schedule Values (in seconds) Used for All Subjects

<table>
<thead>
<tr>
<th>Day</th>
<th>Right Key</th>
<th>Left Key</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>24</td>
</tr>
</tbody>
</table>

Note. A COD of 2 seconds was used in all conditions for all subjects.

### Data Analysis

In the present experiment, the data from all subjects was analyzed in the following way. From each segment completed across the five sessions (approximately 60 segments in all for each subject), the ratio of right-to-left responding was determined and plotted (in logarithmic coordinates) as a function of the ratio of reinforcers obtained on the right side to reinforcers obtained on the left side. Also, the ratio of time allocated to the right versus left sides was plotted as a function of the ratio of reinforcement earned on both sides. The best fitting line (using the least squares method) was used to fit the data for both the response matching analysis and the time matching analysis mentioned above. From these lines, estimates of $a$ and $k$ were obtained as described in Equation (2). The analyses described above are similar to those used in other matching studies of choice with humans as subjects (see Pierce & Epling, 1983).

### Results

#### Group Comparisons

Data from individual subjects in both ADHD and normal groups were averaged together for measures of total responses, segment length, responses within changeover delay, number of changeovers, and response rates. A series of two-factor mixed ANOVAs (between groups with repeated measures across days) were used to compare groups. Table 3 illustrates $F$ values for all ANOVAs for GROUP main effect, DAY

### Table 3

Summary of $F$-Values for 2-Factor Mixed ANOVA

<table>
<thead>
<tr>
<th>Variable</th>
<th>Group $(df=1, 10)$</th>
<th>Day $(df=4, 40)$</th>
<th>Group x Day $(df=4, 40)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Responses</td>
<td>0.17</td>
<td>10.65*</td>
<td>0.30</td>
</tr>
<tr>
<td>Segment Length</td>
<td>0.00</td>
<td>11.97*</td>
<td>0.41</td>
</tr>
<tr>
<td>Responses Within</td>
<td>0.10</td>
<td>1.09</td>
<td>0.17</td>
</tr>
<tr>
<td>Changeover Delay</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Changeovers</td>
<td>0.07</td>
<td>0.43</td>
<td>0.21</td>
</tr>
<tr>
<td>Response Rate</td>
<td>0.05</td>
<td>4.52*</td>
<td>0.02</td>
</tr>
</tbody>
</table>

*p < .01
main effect, and GROUP X DAY interaction effect. No main effects between groups were found for any of the variables, indicating that the behavior of ADHD and normal subjects as measured by these variables, was not significantly different. Variables for which a main effect was revealed were segment length, total responses, and response rate. These analyses indicate that as experimental days progressed, segment

Figure 2 is continued on next page.
Figure 2. Ratio of responding on right and left keys as a function of the ratio of reinforcement obtained on right and left keys plotted in logarithmic coordinates. Each data point represents a different experimental day. The equation of the fitted line, including slope, intercept, and variance accounted for appears in each graph panel. Left column represents ADHD subjects and right column represents normal subjects. Subjects in both groups are rank-ordered according to slope from highest to lowest.
length, total number of responses, and overall response rates increased for both groups. No main or interaction effects were revealed for number of changeovers or total changeover responses.

Post hoc stability analyses for session length and response rates were conducted in the following manner. The difference between the mean of the last two trials for each experimental day and the mean of the first two trials of each day was divided by the grand mean for all four of the trials involved. The analysis revealed that out of 60 experimental days (12 subjects x 5 experimental days each), none of the days showed changes in session length of more than 30% from beginning to end.

**Linear Regression Functions**

Data from the last five sessions of each day were averaged together to obtain the values used in linear regression analysis. Matching functions were obtained for each subject for both response ratios and time allocation and are illustrated in Figures 2 and 3, respectively. In these figures, left columns illustrate ADHD subjects while right columns represent normal subjects. For ease of visual comparison, slopes for response allocation and time allocation were rank ordered for both groups of subjects and are arranged so that the functions with the highest slopes for both groups are placed next to one another. The second highest slopes for both groups are arranged next to one another and so on.

A comparison of slopes across groups indicates that the highest slopes for normal subjects (S7, S10, S9) tended to be greater than those for the highest ADHD subjects (S1, S2, S3). Normal subjects with the lowest slopes, however, did not tend to differ from the ADHD subjects and S12, a normal subject, actually showed the most negative slope of all subjects. For both response ratio and time allocation, half of the normal subjects obtained matching function slopes of greater than .4 whereas none of the subjects in the ADHD group exhibited slopes higher than .36 for response ratios and .25 for time allocation. In fact, the highest slope for ADHD subjects for both responses (a=.36) and time allocation (a=.25) would have been rank-ordered 4th in the normal group and the second highest slope in the ADHD group for time allocation would have been rank-ordered 5th in the normal group. It is relevant to note that in the normal group, the three highest obtained slopes for both time allocation and response ratio were male subjects. For the ADHD group, this trend was also true, with the exception of S4 (male) whose slope values were 4th highest rather than 3rd.

A comparison of functions in Figures 2 and 3 indicates that slopes for time allocation and response ratios differed in a systematic way. For those subjects whose response ratio slopes were greater than .2 (S1, S7, S8, S9, S11), slopes for time allocation tended to be shallower than those for response ratio. For those subjects whose response ratio slopes were between +.2 and -.2, time allocation slopes tended to be the same as slopes for responses. Subjects whose response ratio slopes were less than -.2 tended to have time allocation slopes which were greater,
or less negative, than response ratio slopes. For all subjects, time allocation slopes were closer to zero than slopes from their respective response ratio functions. However, the tendency for time allocation slopes to differ from response functions did not have any effect upon the rank ordering of subjects based upon slope. That is, all subjects retained their ordinal position of slope value from the response ratio function.

**ADHD SUBJECTS**

<table>
<thead>
<tr>
<th>S1</th>
<th>S2</th>
<th>S3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y = 0.25x - 0.02$</td>
<td>$y = 0.09x + 0.07$</td>
<td>$y = 0.05x + 0.20$</td>
</tr>
<tr>
<td>$R^2 = 0.43$</td>
<td>$R^2 = 0.11$</td>
<td>$R^2 = 0.09$</td>
</tr>
</tbody>
</table>

**NORMAL SUBJECTS**

<table>
<thead>
<tr>
<th>S7</th>
<th>S10</th>
<th>S9</th>
</tr>
</thead>
<tbody>
<tr>
<td>$y = 0.63x - 0.04$</td>
<td>$y = 0.48x - 0.07$</td>
<td>$y = 0.43x - 0.06$</td>
</tr>
<tr>
<td>$R^2 = 0.56$</td>
<td>$R^2 = 0.91$</td>
<td>$R^2 = 0.35$</td>
</tr>
</tbody>
</table>

*Figure 3 is continued on next page.*
Measures of bias not accounted for by the independent variables, as measured by the intercept of the matching function, were also compared across subjects and are shown in Figures 2 and 3. Values for the $y$-intercept of the fitted function were observed to depart from 0 for response matching for Subject 3 ($b=.25$), Subject 5 ($b=.27$), and Subject...
ANALYSIS OF CHILDHOOD PSYCHOPATHOLOGY

6 (b= -.35) in the ADHD group and for Subject 11 (b=.12) and Subject 8 (b= -.34) in the normal group; all of whom were females. For all other subjects, values for the intercept of the fitted line were less than .10. For time allocation, Subject 3 (b=.20) and Subject 6 (b= -.29) in the ADHD group and Subject 11 (b=.11) and Subject 8 (b= -.18) in the normal group were observed to have y-intercept values above .10. Again, these subjects were exclusively female.

The degree to which the linear functions used were able to describe the obtained data is represented by the R² value for each function. For responses in the ADHD group, these values ranged from .02 to .78 (median=0.40). The corresponding values for the normal subjects ranged from nearly 0 (S12) to .94 (median=0.33) Thus, although there may have been a trend for the linear function to better describe the data obtained from ADHD subjects, this was not significant (t=0.16, NS) and variation existed in both groups in the degree to which the fitted function could approximate the data. The functions obtained for time allocation showed a similar trend with ADHD values of R² ranging from .09 to .74 (median=0.48), and normal values ranging from .30 to .91 (median= 0.36). The difference between these values was also nonsignificant (t=0.11, NS).

Discussion

The purpose of the present study was to examine the behavioral sensitivity to changing consequences in ADHD and normal children under concurrent VI schedules of reinforcement. Results of this investigation suggest that, under these experimental conditions, the behavior of children diagnosed with ADHD was less likely than that of normal children to change in a manner consistent with changing rates of reinforcement.

For ADHD subjects, 3 of the 6 subjects (S4, S5, S6) exhibited negative slopes, whereas only one normal subject exhibited such a function (S8) for time matching. For response matching, 2 normal subjects exhibited negative slopes (S8, S12), although the slope for S12 was very close to 0 and not as negative as all three of the ADHD subjects.

There appeared to be a clear gender difference across both ADHD and normal subjects in the slope of the obtained matching functions. Of the six lowest slopes, five were those of female subjects (S5, S6 in the ADHD group; S8, S11, S12 in the normal group). It is possible that the lower, and in some cases negative, slopes obtained by these subjects was because the reinforcer used (video games) was not as salient as it was for the male subjects in both groups. The y-intercept for the female subjects was also much more likely to deviate from 0 (5 out of 6 females) than for male subjects, indicating that for these subjects, one side was systematically favored for reasons other than the reinforcement rates delivered on that side. Anecdotal reports from the children indicated that none of the six female subjects owned a Nintendo game system at home, whereas all six of the male subjects had Nintendo or similar
games at home. Several conclusions may be drawn based upon the differences noted between male and female subjects.

First, differences between ADHD and normal subjects are more evident if only male subjects are considered. Not only were the normal male subjects' slopes higher than the male ADHD subjects' slopes, the variance accounted for by the linear function was higher for the normal boys than for the ADHD boys. Second, based upon the similarities between female subjects in both groups as well as the amount of unaccounted bias (as indicated by the intercept of the function), it is possible that differences between these two groups may be obscured by the present method. Future research involving comparisons between normal and ADHD girls should make efforts to identify salient reinforcers to determine whether the apparent lack of sensitivity to reinforcement contingencies is a function of experimental method or a function of gender. The present data do suggest, however, that for males, normal subjects tended to be more sensitive to the changing reinforcement contingencies than the ADHD subjects.

Such an hypothesis has been suggested before, albeit in somewhat different terms (e.g. Barkley, 1991; Hanlein & Caul, 1987). These hypotheses propose that a higher density of reinforcement is required to control equal amounts of behavior in ADHD versus normal children. Support for these approaches has been limited, perhaps as a result of the methods used to study them. Based in part on results from the present study, we suggest that an accurate characterization of ADHD may be established through a precise quantification of behavior allocated between two concurrently available alternatives. This approach demonstrates the coalescence of two relatively well-established areas in psychology: behavior analysis and child clinical psychology. The union of these two fields has shown promise in the past, such as the investigation of self-control behavior in children described as hyperactive (Sonuga-Barke & Lea, 1989; Sonuga-Barke, Lea, & Wembley, 1989; Sonuga-Barke et al., 1992). However, to date, there have been only isolated attempts to apply established methods from the experimental analysis of behavior to answer questions regarding the nature of childhood behavior disorders.

There are a number of important limitations to the present study which need to be addressed before any firm conclusions may be reached. Perhaps the biggest caveat involves the heterogeneity of the ADHD group with respect to reported behavior problems. Although all ADHD subjects had received a diagnosis using clinical and research diagnostic criteria, there was considerable variability in the number of parent-reported behavior problems pertaining to attentional problems. The number of diagnostic items endorsed on the ADHDRS by parents ranged from 4 to 14. It is an established finding that children diagnosed with ADHD may differ in the extent to which they exhibit the defining characteristics of this syndrome (Lahey, Schaughency, Hynd, Carlson & Nieves, 1987). In addition, there is evidence to suggest that children who are comorbid for ADHD and other behavior disorders may not exhibit the
same patterns of behavior as children diagnosed only with ADHD (McBurnett et al., 1991). Future research in this area would be well served to address the issue of comorbidity in subject selection, as these confounds may hinder a clear understanding of how behavior associated specifically with ADHD and other disorders is related to differential effects of reinforcement. A more homogenous subject pool is necessary to determine more specifically how behavioral differences are attributable to subject characteristics.

Another limitation in the present study was the failure to accurately determine the efficacy of the reinforcer used. Although normal children, especially male subjects, tended to show more sensitivity to reinforcement contingencies as measured by the slope of the matching function, the behavior of all subjects could be described as undermatching. Such performance in human subjects has been noted previously under laboratory conditions (see Pierce & Epling, 1983, for a review) and may be related to the type of reinforcer used (Kollins, 1995). In future studies, it will be critical to identify reinforcers that exert strong control over behavior to determine with greater precision how experimentally arranged schedules of reinforcement control different levels of behavior in ADHD versus normal children. Ideally, reinforcers that engender performance that more closely approximates matching, as measured by a slope of 1, would be used to determine the extent to which different clinical populations deviate from normal subjects. In addition, particular care should be taken in selecting appropriate reinforcers if both genders are included in the same study.

Another difficulty with the present study involves the amount of exposure subjects received to the various experimental contingencies. The variability in response allocation in all subjects (as indicated by the wide range of $R^2$ values) may be a result of limited exposure to each pair of VI schedule values. Future work that seeks to quantify sensitivity to reinforcement contingencies should establish a priori criteria for changing experimental conditions to ensure that the matching functions obtained reflect steady-state behavior. The importance of studying behavior under steady-state conditions has been outlined in detail previously (Johnston & Pennypacker, 1992). It is possible that more extensive exposure to each pair of concurrent VI-VI schedule values would result in behavior more in line with predictions from Equations 1 and 2 for both normal and ADHD-diagnosed children.

The range of VI-VI schedule values used in the present study may have also contributed to the undermatching observed in all subjects and possibly the differences noted between children diagnosed with ADHD and nondiagnosed children. Matching research involving human subjects has typically used VI-VI schedule values that are proportionally greater and that encompass a broader range than the values used presently. For example, Horne and Lowe (1993) used concurrent schedule values that ranged from VI 50s-VI 50s to VI 50s-VI 720s. The latter of these schedules represents a 14:1 ratio between the programmed rates of
reinforcement on the two schedules. This ratio is compared with the greatest value of 8:1 (VI 3s-VI 24s) used in the current study. The absolute differences between schedule values in the current study is also quite restrictive (3s, 6s, 9s, 15s, & 24s) as compared with other matching studies with humans (e.g., Horne & Lowe, 1993; 10s, 20s, 175s, 500s, & 720s). It is possible that the differences in the programmed rates of reinforcement in the current research were not discriminable enough to engender behavior consistent with matching and may have thus obscured more reliable differences in behavior between ADHD-diagnosed and normal children.

Replication under different schedule values and different stimulus conditions will also be important to determine whether the behavior of children diagnosed with ADHD is differentially sensitive to consequences as compared to normal children. Replication will be important in both laboratory and, perhaps more importantly, in applied settings. The behavior of other clinical populations has been investigated through the use of matching analyses to help characterize such behavior problems. Examples include, but are not limited to, developmentally delayed adolescents (Martens & Houk, 1989) and self-injurious children (McDowell, 1981).

Overall, there is preliminary evidence to suggest that normal children are more sensitive to changing schedules of reinforcement than are ADHD children. Future work in this area, however, will be well served to address the important limitations noted above. The use of salient reinforcers, adequate exposure to experimental contingencies, and a broader range of schedule values are all methodological issues to be improved upon to more reliably determine the extent to which children diagnosed with ADHD differ from normal children with respect to sensitivity to reinforcement contingencies. The likely utility of the present study, however, lies not in the conclusions which can be drawn from the data, but rather on the experimental model of ADHD it suggests. The investigation of behavioral differences through the use of a well established behavior analytic method may help to generate a better understanding of behavioral disorders in more objective, operational, and clinically useful terms.

References


