Methylphenidate Effects on the Learning and Performance of Four Hyper Active Children

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METHYLPHENIDATE EFFECTS ON THE LEARNING AND PERFORMANCE
OF FOUR HYPERACTIVE CHILDREN

by

Paul James Yoder

A Dissertation
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
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Western Michigan University
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METHYLPHENIDATE EFFECTS ON THE LEARNING AND PERFORMANCE OF FOUR HYPERACTIVE CHILDREN

Paul James Yoder, Ph.D.
Western Michigan University, 1984

The effects of methylphenidate hydrochloride (Ritalin) on the learning and performance of four hyperactive children were evaluated using a repeated acquisition procedure with both learning and performance components. Three dosages of methylphenidate plus a placebo were evaluated under double-blind experimental conditions. Dosages tested included each subject's therapeutic dosage, a dosage 5 milligrams higher, and a dosage 5 milligrams lower. Methylphenidate produced no effect on either the number of errors per session or on the rate of responding across the range of dosages tested suggesting that the medication neither facilitated nor impaired learning or performance. Data were also collected on social behavior in the classroom using the abbreviated Conners Teacher Rating Scale (CTRS) and on daily math scores for two of the four subjects. Scores on the abbreviated CTRS generally decreased (less "hyperactive") as medications were increased. Math scores were variable both within and across conditions, but generally higher during the placebo condition.
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Paul James Yoder
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INTRODUCTION

Hyperactivity, now referred to as Attention Deficit Disorder (ADD) with or without hyperactivity (American Psychiatric Association, 1980), is the behavioral disorder most often encountered by pediatricians and the treatment of choice is most often stimulant medication, usually methylphenidate hydrochloride (Ritalin) (Julien, 1975; Rapport, Murphy, & Bailey, 1982; Ray, 1978; Swanson, Kinsbourne, Roberts, & Zucker; 1978; Werry, Aman, & Diamond, 1980). Stimulant medications have been used to treat hyperactivity since 1937 (Walker, 1982), but their use has shown a marked increase in the past 20 years (O'Leary, 1980). Methylphenidate has been shown consistently to improve social behavior in the classroom, and vigilance, persistence, and attentional behavior in laboratory situations (Julien, 1975; O'Leary, 1980; Ray, 1978; Thurston, Solbol, Swanson, & Kinsbourne, 1979; Walker, 1982; Werry, 1978; Werry et al., 1980). However, long-term improvements in academic achievement may not occur (Barkley & Cunningham, 1978; O'Leary, 1980; Rie & Rie, 1977; Walker, 1982; Whalen & Henker, 1976; Wolraich, 1977). The reasons for this apparent discrepancy between the effects of stimulants on social behavior and academic measures are not clear. However, several possible explanations may be suggested.

Different target behaviors improve at different dosages and memory and learning may actually be impaired at commonly administered...
dosages (Brown & Sleator, 1979; Rapport et al., 1982; Sprague & Sleator, 1977; Walker, 1982). In one study (Sprague & Sleator, 1977), improvement on a short-term memory task was maximal at a dosage of 0.3 mg/kg, while social behavior, as rated by teachers, was maximally improved at a dosage of 1.0 mg/kg. Performance on a short-term memory task at the higher, more typical therapeutic dosage was lower than performance under placebo. In another study (Rapport et al., 1982), the highest dose of methylphenidate tested resulted in a high level of "on task" behavior, but "problems completed" decreased for one of two subjects at that dosage. These studies suggest that the failure to find long term improvements in academic achievement may have been due to the use of medication dosages adjusted on the basis of social behavior in the classroom rather than on the basis of learning and academic measures.

There have been few attempts to directly study the effects of methylphenidate on learning with school-aged children. Studies of "cognition" have generally used performance measures involving recall or application of material previously mastered (e.g., short-term memory, number of problems completed, achievement test scores, etc.) rather than learning measures that assess the rate or ease with which new material is mastered (Walker, 1982). The studies of stimulant medication effects on learning have produced mixed results. Two studies found no effects of medication on the learning of a series of paired word associations (Aman & Sprague, 1974; Conners, 1966), while others have reported that medication enhanced learning on the same
task in 45% to 70% of the children tested, with learning unaffected or impaired in the remaining subjects (Swanson et al., 1978; Swanson, Sandman, Deutsch, & Baren, 1983). Factors responsible for the mixed results across and within experiments were not identified although standardized dosages (mg/kg) were not reported leaving open the possibility that between subject dosage differences may have contributed to the mixed results.

Given that learning difficulties and poor academic performance are major problems associated with ADD, it is surprising that more research has not been done in this area (Gadow, 1983; Walker, 1982). However, studying learning poses a number of methodological problems because the task difficulty must be equated across repeated measures of learning for within subject experimental designs. Intersubject experimental designs are faced not only with the problem of task equivalence when using repeated measures such as in pre/post test designs, but also with the traditional problems of group designs such as individual subject differences, reliance upon statistical analysis, etc., (Baer, 1977; Sidman, 1960). A combination of a within subject experimental design and a repeated acquisition procedure solves most of these methodological problems (Boren, 1963; Thompson, 1973). With repeated acquisition, subjects learn a new sequence or chain of responses each session. At each component of the chain, subjects select one of three possible options (e.g., left, right, or center response key), only one of which is correct. Since the response options remain constant from trial to trial, new chains
of roughly equivalent difficulty can be generated by randomly altering the correct response location at each link in the chain. Repeated measures using such sequences reveal a relatively stable rate of learning as measured by the reduction in errors across repeated exposures to a given sequence and the total number of errors across different response sequences. Effects of an independent variable on learning can be assessed by looking at changes in the number and/or distribution of errors across conditions. This paradigm also allows one to simultaneously distinguish between effects on learning and effects on performance by utilizing both a learning component, as described above, and an additional component in which the behavioral chain remains constant from session to session for measurement of effects on performance.

Using this procedure with pigeons resulted in learning being impaired at low doses of methylphenidate while performance was unaffected by the same dose. Performance was impaired only by the highest dose tested, suggesting different dose response relationships for learning and performance measures (Thompson, 1976).

In the only study which has attempted to directly evaluate the effects of methylphenidate on learning in hyperactive children using the repeated acquisition procedure (Walker, 1982), children learned a six component chain with three animal pictures (cat, dog, and rabbit) as discriminative stimuli. Completion of five (FR-5) of the six component sequences earned one point exchangeable for toys at the end of the session. Doses of 0.3 mg/kg, 0.7 mg/kg, and a placebo
resulted in a drug-induced facilitation of learning (i.e., reduction in errors per session) which was maximal at the larger dose. These data would appear to be inconsistent with prior experiments showing 0.3 mg/kg to be the optimal dose for enhancing short-term memory. Two potential explanations for this seeming discrepancy are readily apparent. First, the 0.7 mg/kg dose falls between doses tested previously, hence, it is not clear that the data are actually in conflict. Secondly, different cognitive measures, such as short-term memory (a performance measure) and learning, may show different dose-response curves with respect to methylphenidate. However, the data which suggest that methylphenidate may enhance learning on the repeated acquisition task, are in contrast to the earlier data which suggested that methylphenidate impaired learning in pigeons using a similar procedure (Thompson, 1976). While species or dosage differences may account for this discrepancy, potential deleterious effects of stimulant medication on learning processes should be investigated further in children being treated with stimulant medication.

In light of the research suggesting different dose-response curves for different behaviors, direct comparison of a range of methylphenidate dosages on both learning and performance with hyperactive children is needed. The current research extends previous work by replicating the repeated acquisition procedure with humans and allowing a direct comparison of the effects of methylphenidate on both learning and performance. In addition, data
were collected on several additional "naturalistic" target behaviors in order to assess the relevance of the laboratory measures for the classroom situation. These included daily scores on academic tasks, where possible, and teachers' ratings of "hyperactivity" or social behavior based on the abbreviated Conners Teacher Rating Scale (CTRS) (Conners, 1973).
METHODS

Subjects and Settings

Potential subjects who had been diagnosed ADD and were being treated with methylphenidate were referred by a community based pediatrician. The purposes of the research project were explained to the parents of each child and informed consent was obtained prior to their inclusion in the study. Four children, three males (Michael, Greg, Scott) and one female (Brandy), ages 11, 11, 10, & 6 respectively, participated in this study. All had histories of attentional and behavioral problems in school and were being treated (successfully per teacher report) with methylphenidate prior to the study. Michael, Greg, and Scott were all enrolled in normal fourth grade classrooms at different schools and all had been on Ritalin at least one prior school year. Brandy was enrolled in a regular first grade classroom at the same school Scott attended and had been taking Ritalin for three to four months prior to the start of the study.

Sessions were conducted at each subject’s school in a room which was equipped with a minimum of one table and two chairs. Other data were collected by subjects’ teachers in the classroom setting.

Apparatus

The repeated acquisition apparatus consisted of an array of 18 poker chips arranged into six groups of three chips per group on a
board (constructed out of six layers of posterboard) measuring 9 cm deep by 89 cm long. Groups of chips were separated by 1.9 cm and chips within each group were 0.6 cm apart. A row of 36 map tacks (2 per chip) were located 2.5 cm from the back of the board. Chips could be easily pushed/pulled against these tacks to return them quickly to their original position after being displaced. A different color of tacks was used for each group of chips to increase the discriminability between groups. A hinged flap 9 cm by 89 cm constructed out of two layers of posterboard was attached to the front of the board and could be flipped up to cover the array of chips. On the back vertical edge of the panel (visible only to trainer) each chip location was numbered from 1 through 18 from right to left to facilitate recording of errors. Poker chips were either red or blue (depending upon the component in effect) and contained a white circular label sticker 1.9 cm in diameter on the bottom side. In addition, one chip in each group of three had a gold star superimposed on the white label designating it as the correct choice. A 2.5 cm by 11.4 cm bar functioned as a discriminative stimulus and was used to signal which of the six groups of chips was appropriate for a response. A stopwatch was used to time the sessions and two counters (31 day digital desk top calendars) were used to deliver points and to keep track of the trials.
Procedure

Sessions were conducted at the same time each school day—immediately prior to the start of classes for Scott, Greg, and Brandy and during the morning recess for Michael. All sessions occurred not less than one nor more than three hours following ingestion of medication to insure maximal therapeutic effects (Swanson et al., 1978).

Subjects were seated across the table from the trainer with the repeated acquisition apparatus on the table between them. A counter to the subject's right faced the subject and was used to deliver points contingent upon each completion of the response sequence. An identical counter to the trainer's right faced the trainer and was used to keep track of the current response sequence.

The subjects' task was to select the correct chip in each group of three. One chip (i.e., either the left (L), center (C), or right (R)) in each group contained a gold star on the underside. Picking up and replacing each starred chip in the correct sequence from left to right resulted in delivery of one point simply for completing the chain regardless of the number of errors. An additional point could be earned by an errorless completion of the chain. Picking up non-starred chips (as well as picking up starred chips out of sequence) were counted as errors and resulted in a 5 second timeout during which time the array was covered with the hinged flap and the trainer recorded the error. Following a timeout, the subject was returned to the same link in the chain. The discriminative stimulus
bar was placed behind the group of chips to be selected from and was
moved to the next group to the subject's right following each correct
response. Upon completion of the chain, the trainer incremented the
reinforcement counter by one or two points (depending on whether or
not an error was made during that trial), returned the bar to the
group at the far left, and incremented the trial counter by one.

Each session consisted of a learning (acquisition) component
followed by a performance (maintenance) component. Each component
ran for a maximum of 10 minutes or 20 completions of the response
sequence. Either red or blue poker chips were always used for the
learning component for a given subject, with the remaining color
always used for the performance component. For the learning
component a new response sequence was generated each session.
Sequences were generated randomly with the following restrictions:
(1) a given position (i.e. L, R, or C) could not be repeated more
than twice consecutively within a chain, (2) for a given link of the
six link chain, the same position could not be designated as correct
for more than two consecutive sessions (thus if the second link in
the chain happened to be R for sessions one and two, it had to be L
or C for session three), and (3) a given two link sequence (i.e.,
L-R) could not appear more than twice consecutively within a single
chain. Following the learning component, the red (or blue) chips
were removed and the blue (or red) chips were arranged (behind the
hinged flap) for the performance component. The correct responses
for the performance component sequence remained the same during each session of the experiment.

Points earned on the subject's counter were exchangeable for a choice of video arcade tokens or dimes. Each time the counter accumulated 31 points (the maximum number on the counter since it was a calendar) a token or dime was delivered by the trainer. Points accumulated at the end of a session were carried over to the next day.

Instructions plus reverse chaining were used to train subjects on the experimental task. Initially a point was earned for correctly turning over the starred chip in the last link of the chain, then last two links, etc. until the entire chain was being completed. Pre-experimental sessions continued until the response sequence for the performance component had been learned and the number of errors per session in the learning component appeared relatively stable based on visual inspection.

Independent Variable

The independent variable consisted of the subject's morning dosage of methylphenidate (Ritalin). Subjects continued to receive their normal noontime medication dosage throughout the experiment. Dosages tested were individualized for each subject based upon their previously determined therapeutic dosage, i.e., the dosage being received at the start of the study became the baseline dosage. Other dosages tested were: 5 milligrams above the baseline dosage.
(higher), 5 milligrams less than the baseline dosage (lower), and a placebo.

Experimental Design

Initial training was conducted under the baseline dosage of medication. The general order of administration was then as follows: (1) baseline, (2) higher, (3) lower, (4) placebo, and (5) baseline. Following these five administrations, several dosage reversals were conducted as time permitted at the end of the school year. For Scott and Brandy this consisted of two one-day alternations between placebo and baseline dosages. For Michael this consisted of two days at the higher dosage, one day at placebo, and one day at the baseline dosage. For Greg this consisted of a full week at placebo and a full week at the baseline dosage. Michael also experienced a one day reversal to the baseline dosage during the placebo condition. This occurred at the mother's request after the teacher reported Michael to have been extremely disruptive in the classroom on the second day of placebo administration. Only the mother and the experimenter were aware of this change. With the exception of the reversals near the end of the study, each dosage was administered for a minimum of one week (Scott and Brandy received two dosages for two weeks) with dosage changes occurring over the weekends. Dosages were prepared in look-alike capsules and administered in a double-blind fashion. The experimenter delivered the medication in sealed, dated envelopes to the parents each weekend. Parents, teachers, subjects and the
trainers were aware that dosage changes, if they occurred, would occur over the weekends, but they were uninformed of the medication levels given at any time.

**Dependent Variables**

Data were collected on both the number of errors and the rate of responding for both the learning and performance components each session. The trainer recorded trial number and position (1-18) for each error so that error patterns could be examined. Rate measures were calculated by dividing the total number of responses (both correct and incorrect) by the total component time minus timeouts.

The effects of the medication on "hyperactivity" in the classroom was measured using the abbreviated CTRS (Conners, 1973). Teachers were asked to complete the scale at the end of each week based on the subject's behavior during the first half of each day. Daily math scores were also obtained for Greg and Michael. Similar measures were not available for Scott and Brandy because there were no recurring academic tasks each morning.

Interobserver agreement data were collected by the experimenter (not blind) on at least 20 percent of the sessions. The experimenter sat to the right of the trainer and recorded the trial and position number of each error. Reliability for the occurrence of errors was calculated by dividing the number of agreements on the occurrence of an error by the number of agreements plus the number of disagreements. Mean occurrence agreement scores averaged 97% for all
subjects and ranged from 89% to 100% for individual subjects.
Reliability data were not available for measures (e.g., math scores)
provided by the teachers.
RESULTS

Figure 1 shows the number of errors per session for each of the subjects in both the learning and performance components. The absolute number of errors and trends within phases showed no stable changes with dosage changes. On several occasions, initial changes in the number of errors per session proved to be transitory. For example, with the first dosage increase above baseline levels, Michael initially showed a dramatic increase in errors in the learning component which declined to baseline levels within four sessions. This transient effect was not replicated when the higher dosage was repeated later. Another apparently dramatic change occurred on the day that Michael received the baseline dose during the placebo week. On that occasion he made the fewest errors of any session. However, when returning to the baseline dose at the beginning of the next week, he made the most errors of any session. In general, variability was as great within as across dosages during both the learning and performance components for each of the subjects.

Figure 2 shows the mean number of learning and performance errors per session averaged across all sessions under each dosage of methylphenidate for each of the subjects. Subjects uniformly made few errors during the performance component. The number of errors during the learning component consistently exceeded the number of
Figure 1. Number of errors per session in both learning and performance components. Medication dosages are in mg/kg. Placebo is indicated by PL.
Figure 2. Mean number of errors per session in both learning and performance components averaged across all administrations of a given dosage. Brackets represent one standard deviation.
performance errors at each dosage level. The learning measures are characterized by high levels of variability (brackets represent one standard deviation) and relatively small differences between dosage levels suggesting an absence of robust dose-related effects on learning. However, it is of interest to note some similarity in the shapes of the curves. The mean number of errors in the learning component under the placebo and higher dosages was higher than for the baseline and lower dosages for three of the four subjects. While not necessarily significant, these U-shaped curves are similar to dose-response effects of methylphenidate on short-term memory (Sprague & Sleator, 1977) and problems completed (Rapport et al., 1982).

Response rate was higher in the performance component than in the learning component for all subjects. Scott, Greg, and Michael showed an increasing trend in performance rate which cut across dosage changes and appeared to be independent of medication changes. Brandy showed a higher rate of responding under all drug dosages than under placebo in both components.

Figure 3 shows the classroom data provided by teachers. In each case "hyperactivity" as measured by the abbreviated CTRS was greatest in the placebo condition. Michael and Brandy showed a dose dependent decrease in hyperactivity as might be expected. Greg never scored in the hyperactive range (a score of 15 or greater) on the scale under any dosage. Scott’s data are less clear since data were unavailable.
Figure 7. Mean scores on the abbreviated CTRS and mean math scores (Greg and Michael) averaged across all administrations of a given dosage. Horizontal line indicates two standard deviations above the mean on the CTRS and brackets represent one standard deviation. Data unavailable for Scott at .32 mg/kg.
the week of the lower dosage and the score for the higher dosage was the mean of one low and one high weekly score.

Figure 3 also shows the mean daily math scores for Greg and Michael at each dosage (brackets again represent one standard deviation). Both subjects had the highest mean math scores in the placebo condition. Not only did Greg have the highest average scores in the placebo condition, his scores were also more consistent (less variable) than under any of the methylphenidate conditions. In addition, Greg's data show a dose dependent increase in variability while mean scores remain relatively constant across all three dosages of methylphenidate. In contrast, Michael's scores were most consistent at the higher dosage.
DISCUSSION

The results of the present study suggest that methylphenidate neither facilitates nor impairs learning in hyperactive children. However, these results should be interpreted cautiously given the small number of subjects and generally high levels of variability obtained. Nevertheless, these results are inconsistent with prior methylphenidate research using either nonhuman subjects (Thompson, 1976) or human subjects (Walker, 1982). The former suggested that low doses of methylphenidate would have little effect on either learning or performance, but that higher doses would disrupt learning while continuing to have little or no effect on performance. The latter suggested that methylphenidate would enhance learning in a dose dependent fashion. Neither was substantiated. This failure to replicate the earlier findings could have resulted from a number of factors such as species differences with respect to the former, and subject and/or procedural differences with respect to the latter. Prior human research utilized an intersubject design which compared averaged scores across groups. Whether similar results would have been attained using within subject comparisons at different dosages is problematic. In addition, a number of procedural variations may be significant, such as the differences in stimulus presentations (one vs. six components visible at any given time) and differences in
reinforcement schedules. Whether these differences account for the discrepant results between experiments is ultimately an experimental question.

Despite substantial variability in error rates and overlap between dosage levels in the current study, similarities between the dose-response curves in Figure 2 and those presented previously using short-term memory measures (Sprague & Sleator, 1977) are noteworthy. The lower dosage condition for all subjects has fewer mean errors per session than either the placebo condition or a subsequent higher dosage. Brandy and Scott's data show this U-shaped pattern most clearly, but it is also evident in Michael's data as well as in Greg's data with the exception of the highest dosage condition. Taken together with previous research (Rapport et al., 1982; Sprague & Sleator, 1977), these data suggest that an optimal methylphenidate dosage may exist for "cognitive" measures (which may differ from an optimal dosage based on social measures) and that increases or decreases from the optimal dosage may have an adverse impact on the cognitive measures.

Variability within a phase and overlap in error rates across dosage levels were pronounced in the current study despite testing conditions that match or exceed the stability of naturalistic settings in which methylphenidate might be prescribed to alter socially relevant behavior. The factors responsible for the variability observed in the results of the current study are unclear,
but the lack of stable data across repeated measures calls into question the validity of classifying ADD subjects as favorable or adverse responders to stimulant medication on the basis of one or two data points as has been done by previous investigators using the paired-associate learning procedure (Swanson et al., 1978, Swanson et al., 1983). Research is needed to determine whether or not learning, as measured by the paired-associate learning task, is stable over multiple sessions under a given condition.

Stimulant medication is often said to have a paradoxical effect on hyperactive children in that activity level is generally reduced (Ray, 1978). While it is not clear that the response rate measure of the current study and activity level are equivalent, it is interesting to note that the only clear medication effect during the repeated acquisition sessions was the decrement in response rate for Brandy in the learning and performance components under the placebo condition. In this case, it appeared that the methylphenidate was having a direct stimulating effect. If so, one might expect dose dependent increases in response rate. However, response rate was constant across all doses tested suggesting that the rate increase reached asymptote at the lowest dose tested.

The current research again demonstrates that different target behaviors are differentially affected by medication dosage (Rapport et al., 1982, Sprague & Sleator, 1977). While repeated acquisition measures were unaffected by dosage changes, subjects generally were scored as less hyperactive on the abbreviated CTRS as dosage
increased, and all subjects scored better under drug than placebo conditions. The same was not true, however, for academic performance. Both Greg and Michael had their highest mean math scores under placebo conditions. For Greg this included the least amount of variability as well. Why math scores would be affected and not the performance component of the repeated acquisition procedure is not clear. However, these data must be interpreted cautiously because the abbreviated CTRS involves a subjective rating of questionable reliability and validity. Additionally, the difficulty of the math assignments and other motivational variables which could affect studying were not held constant.

Future research utilizing the repeated acquisition procedure is needed in several areas. First, attempts should be made to assess the correlation between repeated acquisition measures and more academic measures of learning and performance. If the correlation is high, the repeated acquisition procedure could provide a convenient, well controlled baseline against which the effects of various medications on learning could be assessed. Secondly, research is needed on the interaction between medication effects and the level of difficulty of the repeated acquisition task. Error rates were generally low and response rates were generally high in the current experiment. Whether similar results would have been attained using repeated acquisition tasks or other cognitive measures of greater difficulty is an empirical question. Perhaps the medication had no
effect because there simply was no room for improvement. Taken as a whole, these results suggest that, at the dosages tested, methylphenidate neither facilitates nor disrupts learning or performance as measured by the repeated acquisition task. However, dosages tested were associated with improvements in teacher ratings of social behavior (hyperactivity) as well as decrements in academic performance. Thus decisions regarding the use of stimulant therapy in the treatment of hyperactivity should be based on a careful assessment of therapeutic and deleterious changes across a range of social and academic behaviors.
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