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THE RELATIVE EFFECTS ON MATH PERFORMANCE OF SINGLE- VERSUS MULTIPLE-RATIO SCHEDULES: A CASE STUDY[1]

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This series of four experiments sought to assess the comparative effects of multiple- *versus* single-ratio schedules on a pupil's responding to mathematics materials. Experiment I, which alternated between single- and multiple-ratio contingencies, revealed that during the latter phase the subject responded at a higher rate. Similar findings were revealed by Exp. II. The third experiment, which manipulated frequency of reinforcement rather than multiple ratios, revealed that the alteration had a minimal effect on the subject's response rate. A final experiment, conducted to assess further the effects of multiple ratios, provided data similar to those of Exp. I and II.

In several recently reported studies, experimental analysis procedures were applied to classroom situations in an attempt to discover the effects of certain variables on different behaviors. They have: (a) described a behavior directly; (b) measured the occurrence of this behavior for an extended period of time; and (c) systematically manipulated a variable in order to analyze its effect.

The majority of these experimental analyses emanating from classrooms have been concerned with managerial behaviors such as inappropriate talking, disruptive, and out-of-seat behavior (Becker, Madsen, Arnold, and Thomas, 1967; Thomas, Nielson, Kuypers, and Becker, 1968). Other reports have described the manipulation of a variable when an academic behavior was the dependent variable (Lovitt and Curtiss, 1969). These studies are representative of current field investigations in that, generally, there is more concern given to the identification of the affecting variables than of the effects of the variables when they are intermittently scheduled.

Studies of contingencies or schedules of reinforcement involving children have been rare. Staats (1965), however, investigated the reading responses of children under several reinforcement schedules and reported that, generally, higher response rates were produced under intermittent schedules. He added that: "Even the child under the variable-ratio and variable-interval schedule responded at a greater rate than the continuously reinforced children . . . [Staats, 1965, p. 45]."

Staats' evidence would tend to corroborate the remarks of Morse (1966), who stated that contingencies of reinforcement are as influential in generating and maintaining behavioral patterns as the reinforcers themselves. Morse also noted that "powerful control of behavior by discriminative stimuli and by reinforcers such as food and water actually develops because they are favorably scheduled events [Morse, 1966, p. 59]."

The present study, which was composed of a series of experiments, was prompted by a boy who responded academically at a very low rate. A previous attempt to accelerate the subject's response rate involved the manipulation of reinforcers by changing the consequences of his academic behavior from contingent time with games and crafts to social time with an adult male. This manipulation did not seem to affect significantly the dependent variable, academic rate.

The study sought to analyze the effects of contingencies of reinforcement on academic performance. To be precise, the purpose of this investigation was to compare performance rate when one reinforcement contingency was scheduled and when several reinforcement schedules were simultaneously available.

The dependent variables were correct and error performance rates on mathematics problems. The consequences or reinforcers for all

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studies were the same—points that were redeemable for minutes of free time. The independent variable was schedules of reinforcement.

During certain phases of these experiments, only one ratio was available—so many points contingent on correct math responses. In other phases, several ratios or contingency bands were available. During these latter phases, the subject was paid off from one or another ratio, contingent on his rate of responding. If his responses fell below a certain rate he received nothing. However, responses within a higher rate range were reinforced. Moreover, if he responded at a rate within the next higher band, he was paid off at a still higher rate. As the subject's response rate accelerated from one contingency range to the next, he was paid off with increasingly richer ratios.

EXPERIMENT I

Method

The subject was a 12-yr-old boy enrolled in a class for children with behavioral disorders at the Experimental Education Unit of the University of Washington. The material used was the subject's regular mathematics material *Sets and Numbers* (Suppes and Suppes, 1968).

During the 15-day baseline phase, data were obtained 1 hr daily on the subject's rate of responding to the math material. At this time the subject was on a 20:1 reinforcement schedule—1 min of free time in the "high-interest" room (Haring and Lovitt, 1967) contingent on 20 correct mathematics responses.

During the second phase (33 trials), four reinforcement bands were arranged. These new specifications were derived on the basis of the subject's performance during the first (20:1) phase. In order to receive any payoff during Phase 2 (multiple-ratio condition), the subject had to respond beyond his Phase 1 correct rate median of about one per minute.

Response rates higher than one per minute were reinforced at adjusted ratio schedules. The four ratio bands were:

(1) No points if fewer than 60 responses were emitted.
(2) Three points for 60 to 89 responses.
(3) Nine points for 90 to 119 responses.
(4) Fifteen points for more than 120 responses.

The sixtieth, ninetieth, and one-hundred-twentieth responses were marked on the subject's math sheet. These marks served as indicators to the subject only when all of his responses were correct. For example, if the subject passed the sixtieth problem, yet had answered four problems incorrectly, his point accumulation would be derived only from the 56 correct responses.

The ratio of points to responses was "richer" from one ratio band to the next. Within these bands, however, the ratios of reinforcement actually became leaner as the subject approached the next band. For example, as the subject passed into the second band, his 60 responses earned him three points, or a ratio of 20:1. Within the same band, his 89 responses still earned him three points, but now the ratio was 30:1.

The ratio conditions, either single or multiple, were explained to the subject each day. Table 1 describes the four ratio bands in terms of response requirements, rate equivalent, points earned, and the response-per-point or ratio equivalent that were in effect during the multiple-ratio phase.

Table 1

Multiple Rate Contingencies, Experiment I

Responses	*Rate/Minute*	*Points Earned*	*Ratio Equivalent*
0-60	<1	0	0
60-89	1-1.48	3	20:1-30:1
90-119	1.5-1.98	9	10:1-13:1
120-240*	2-4.00**	15	8:1-16:1

*Subject's highest number of correct responses throughout Exp. I.
**Subject's highest rate throughout Exp. I.

In Phase 3, extending over seven trials, the initial contract was reinstated—1 point or 1 min per 20 correct mathematics responses. Throughout the experiment, the teacher calculated the subject's rate immediately after each session. Then, dependent on his rate of correct responses, he received a correspondent number of points that could be redeemed for minutes of free time.

Results

During the first phase, the subject's median response rate was 0.8 per min, in a range from 0.0 to 2.9. His median correct response rate during the multiple ratio stage was 1.7. His range of responding throughout this period was 3.8, extending from 0.2 to 4.0 responses per minute. A median response rate of 0.6 was calculated for the seven-day period when there was a return to initial, single-ratio conditions. The subject's range during this period was 1.3, extending from 0.2 to 1.5 problems per minute. Figure 1 presents the daily response rates throughout the experimental sessions.

Discussion

Although performance appeared to be sensitive to the experimental manipulation of the variable multiple ratios, two procedural matters could have spuriously influenced the findings. First, although the subject's overall response rate increased when multiple ratio bands were in effect and decreased after the variable was removed, the median difference from condition to condition was not great and the subject's response rate during all experimental phases fluctuated widely. The experimenters believed that this variability in response was partly because the math problems were not always sequentially arranged according to difficulty. The subject worked straight through his Suppes text where the types of problems varied from page to page. For ex-

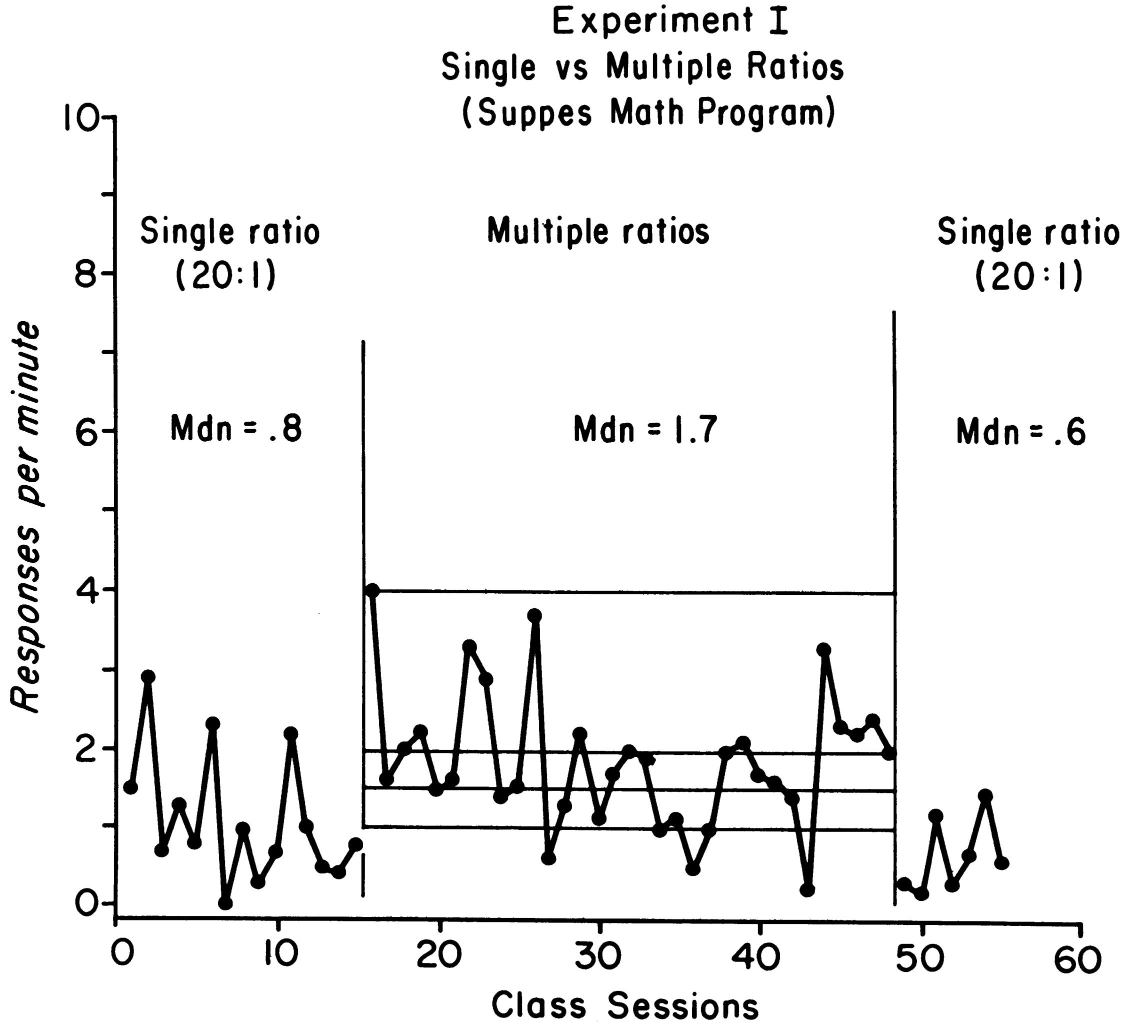

Fig. 1. Correct mathematics response rate throughout Exp. I where the Suppes Math Program was used and where single and multiple ratios were manipulated. The horizontal lines through the multiple-ratio phase indicate the four contingency bands.

ample, on one page, problems such as $63 \div 7 = \square$ might appear, and on the next page narrative problems might appear. The subject's response rate was obviously affected by the type of problem.

Second, no error rate data were kept for this experiment. Since only correct rate of responding was recorded, it was impossible to determine whether the multiple ratios had any effect on the quality of the performance. Although the subject's correct rate was higher throughout the middle phase than in the first or last phases, the quality of responses (ratio of correct and error responses) was unknown. Because of these procedural concerns, the experimenters decided to conduct a second, more carefully controlled study.

EXPERIMENT II

Method

Since the major concern of this investigation was to assess the variable, multiple-ratio contingencies, and the subject's acquisition of mathematics responses was of secondary importance, the academic material was altered. Rather than require the subject to respond to mathematics material from the Suppes program, as in Exp. I, the subject was now given mathematics problems of the class $49 + 23 =$ ____, where the sum was $\leqq 198$. Mathematics problems of this class were already in the subject's repertoire (Easy Math Program). It was hypothesized that material that was not only within his capabilities, but comparable from problem to problem, would be more sensitive to the experimental variable. It was also decided that error rate, as well as correct rate data, should be gathered.

During Phases 1 and 2, the subject's response-per-point requirement was 20:1 (the same ratio that prevailed during Phases 1 and 3 of Exp. I). In Phases 2 and 4, multiple-ratio bands were imposed. As in Exp. I, the four ratio bands were calculated on the basis of the subject's median performance in the first phase of the experiment. Since the subject's median rate was about three responses per minute during the initial phase of Exp. II, his responses had to exceed that rate to receive points during the multiple-ratio phases. Response rates of fewer than three per minute were not reinforced but rates over three were reinforced with successively richer ratios. For the four ratio bands the following adjusted rate requirements were specified:

(1) No points for 0 to 44 responses.
(2) Three points for 45 to 59 responses.
(3) Six points for 60 to 74 responses.
(4) Fifteen points for more than 75 responses.

Table 2 presents information concerning the multiple ratios, responses required, rate equivalent, points earned, and ratio equivalent.

Table 2

Multiple Rate Contingencies, Experiment II

Responses	*Rate/Minute*	*Points Earned*	*Ratio Equivalent*
0-44	<3	0	0
45-59	3-3.93	3	15:1-20:1
60-74	4-4.93	6	10:1-13:1
75-126*	5-8.4**	15	5:1-8:1

*Subject's highest number of correct responses throughout Exp. II.
**Subject's highest rate throughout Exp. II.

If the subject responded at a rate of three problems per minute, his payoff would be at a ratio of 15:1, decreasing to 20:1 as his response rate approached four correct problems per minute. Then, if his rate of responding reached four per minute, the ratio would be 10:1.

Each session in Exp. II lasted for 15 min, and, as in Exp. I, the single- and multiple-ratio conditions were explained daily to the subject. Throughout the multiple-ratio phases, the forty-fifth, sixtieth, and seventy-fifth mathematics problems were marked on the subject's worksheet.

Results

During the first phase, the subject's median rate of correct responses was 3.1, ranging from 2.0 to 4.5. A median rate of 5.35 correct responses per minute was obtained in the second phase, varying from 4.0 to 7.3 responses per minute. A median correct response rate of 3.9 was calculated for the third phase with responses ranging from 1.7 to 4.4. A median correct rate of 6.4 was obtained for the final multiple-ratio phase. The subject's response rate throughout this last phase varied from 5.5 to 8.4. The data from the four phases are presented in Fig. 2. The ranges of correct

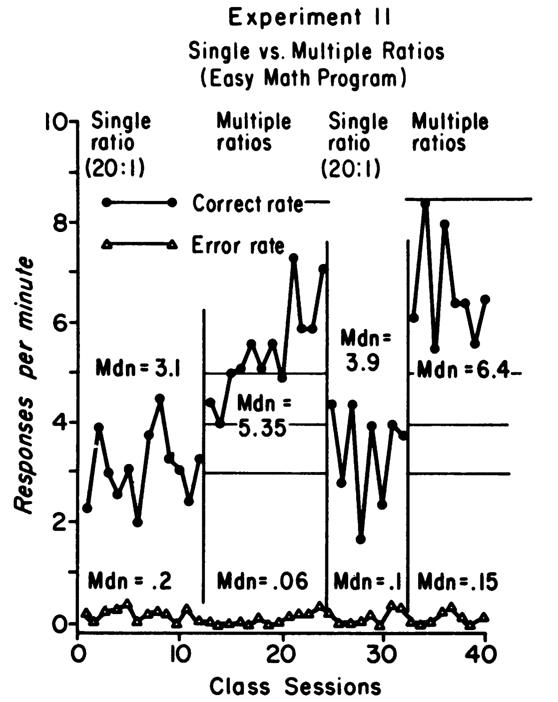

Fig. 2. Correct and error mathematics response rates throughout Exp. II where Easy Math problems were used and where single and multiple ratios were manipulated.

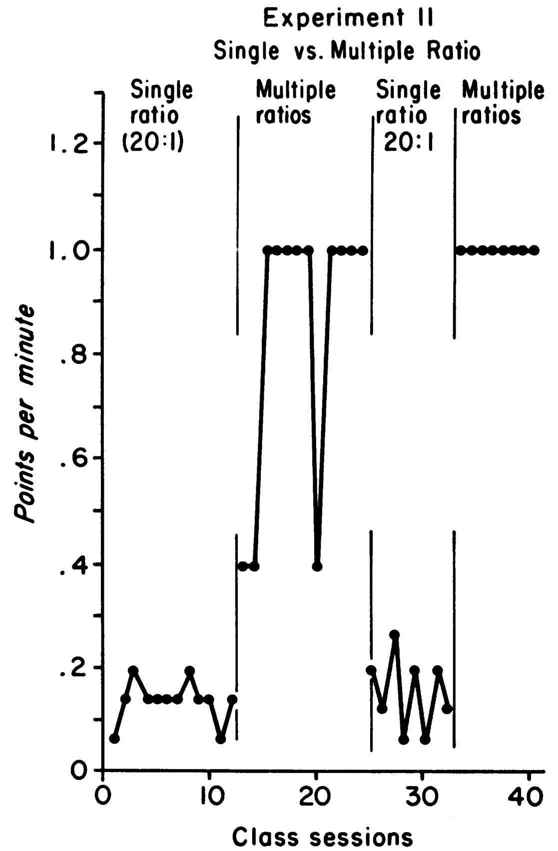

Fig. 3. Rate of points received per minute by the subject during the four phases of Exp. II.

responses for the four experimental conditions were 2.5, 3.3, 2.7, and 2.9. This variability was virtually the same as that reported for Exp. I. The error-rate medians for the four phases were 0.2, 0.06, 0.1, and 0.15.

Discussion

It appears that the multiple ratios of reinforcement served to increase the rate of correct responses. It is also evident that no corresponding rise in error rate occurred. In fact, error rate variance was slight throughout the experiment.

The mathematics items throughout the second experiment were more uniform than those in Exp. I. The altered response rate from condition to condition could therefore be attributed more to the manipulated variable than to an irregular curriculum.

Although the variable—multiple-reinforcement ratios—apparently was effective in altering the subject's rate of mathematics responding, the possibility existed that sheer frequency of reinforcement was at least partially responsible for the performance increase. Figure 3 shows that the subject received much more reinforcement in terms of amount of points during the multiple-ratio phases of Exp. II than during the single ratio phases of the study. In fact, when a comparison is made between the subject's response rate and the rate at which points were dispensed during the second experiment, the patterns were very similar; *i.e.,* when responses per minute were high, number of points received was also high (see Fig. 2 and 3).

To determine whether the multiple-ratio condition or frequency of reinforcement was the crucial variable in affecting response-rate differences, a third experiment was conducted in which frequency of reinforcement was the only variable manipulated.

EXPERIMENT III

Method

The first and third phases used the same base ratio as the first two experiments; for 20 correct responses the subject received 1 min of free time. A 5:1 ratio, the highest possible during previous multiple-ratio phases, was scheduled during the second phase of the study. The arithmetic materials were the same as those used in the second experiment (Easy Math Program).

Results

The results of Exp. III, illustrated in Fig. 4, reveal that frequency of reinforcement was apparently only a minimally affecting variable. His median correct rates were 5.65 during Phase 1, 5.9 during Phase 2, and 5.5 during Phase 3. The error-rate medians during the three phases were 0.06, 0.06, and 0.03. The subject's correct rate ranges were 3.2 (4.3 to 7.5), 2.7 (4.7 to 7.4), and 1.3 (5.2 to 6.5) during the first, second, and third phases respectively.

Discussion

As indicated by the data in Fig. 4, the subject's correct rate of responding was but slightly affected by the variable, frequency of reinforcement. Although "easy math problems" were used in both Exp. II and III and the 5:1 ratio was the richest ratio scheduled in both studies, the subject's performance in Exp. II was quite different from his effort in Exp. III. In Exp. II, his median correct rates were much higher in the manipulation phases (2 and 4) than during the control phases; this was not the case in Exp. III.

This difference in response rate between Exp. II and III could be attributed to the fact that during Exp. II, multiple-ratio bands were scheduled, whereas during Exp. III only one

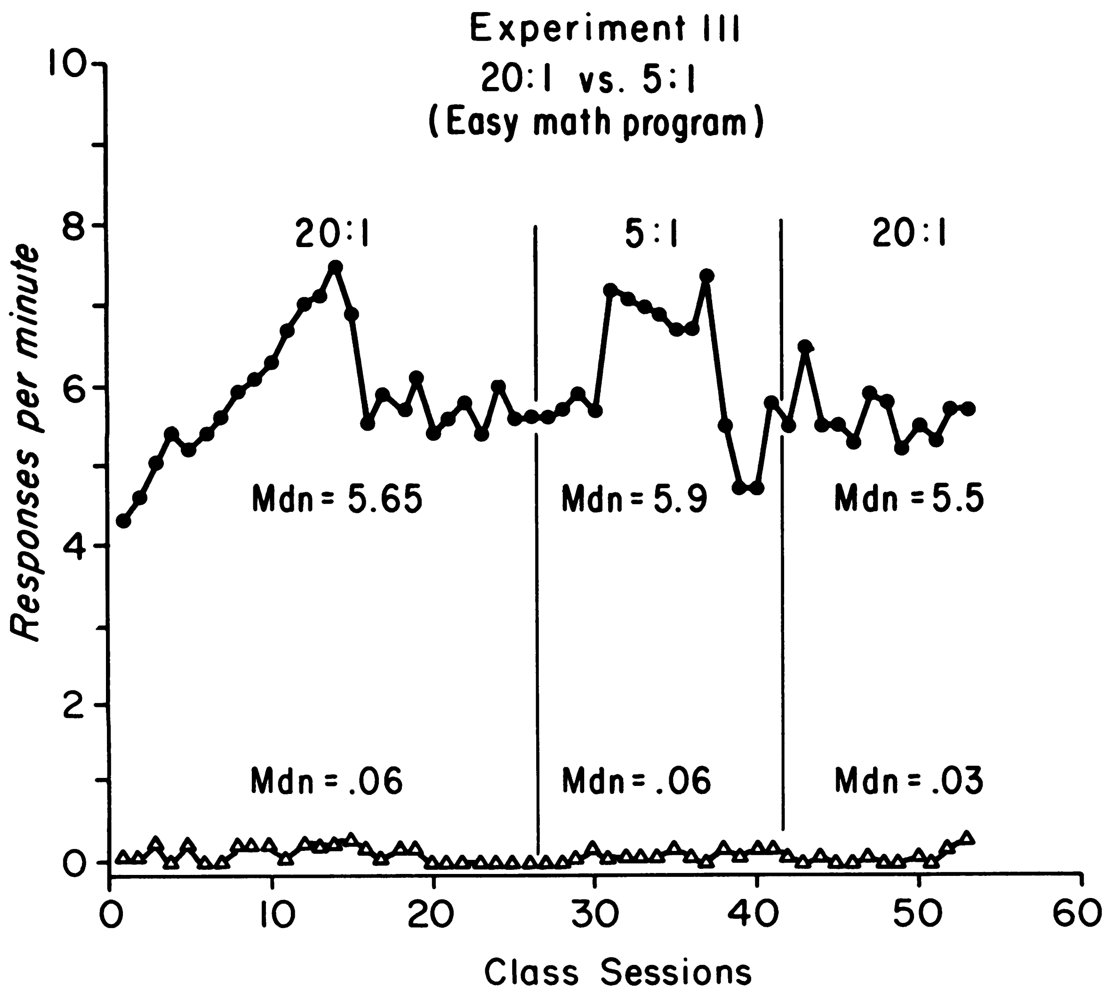

Fig. 4. Correct and error mathematics response rates during Exp. III where frequency of reinforcement was manipulated.

ratio was scheduled. It is also possible, however, that this performance difference was the result of "marking". During Exp. II, certain problems were marked, thus informing the subject that he had passed from one ratio band to another (if all his answers were correct). It is possible that marking served as a stimulus for accelerated performance. A further experiment was conducted to investigate this possibility.

EXPERIMENT IV

Method

The reason for conducting the fourth experiment was to determine whether marking certain problems to indicate multiple ratios was of itself accountable for the subject's rate increase.

During the multiple-ratio phases of Exp. II, the forty-fifth, sixtieth, and seventy-fifth responses were marked on the subject's math sheets to indicate which schedule of reinforcement would prevail. These marks were included throughout all phases of Exp. IV.

The procedures were the same as those of Exp. II. Responses were reinforced on a 20:1 ratio during Phases 1 and 3, while multiple ratios were in effect in the second and fourth phases. The type of mathematics problems and the length of each experimental session were also the same as before: "easy" materials and 15-min sessions. The ratio conditions, either single or multiple, were explained daily to the subject.

The multiple ratios employed in Phases 2 and 4 were derived in the same way as in Exp. I and II. These rates were based on the subject's average response rate during the initial 20:1 phase, which during Exp. IV, was six responses per minute.[3] In a 15-min session the subject was expected to emit 90 responses (15 × 6). Therefore, the four differential rate ratios were:

(1) No points for 0 to 90 responses.
(2) Six points for 90 to 99 responses.
(3) Eight points for 100 to 119 responses.
(4) Twelve points for more than 120 responses.

Table 3 presents information concerning the multiple ratios.

Table 3

Multiple Rate Contingencies, Experiment IV

Responses	*Rate/Minute*	*Points Earned*	*Ratio Equivalent*
0-90	<6	0	0
90-99	6-6.6	6	15:1-16.5:1
100-119	6.7-7.9	8	12.5:1-14.9:1
120-144*	8-9.6**	12	10:1-12:1

*Subject's highest number of correct responses throughout Exp. IV.
**Subject's highest rate throughout Exp. IV.

Results

During the first phase (Fig. 5), the single-ratio phase, the subject's response rate ranged from 3.9 to 7.4; a median response rate of 6.1. Throughout the 15 sessions of Phase 2, his median rate of responding was 8.1, ranging from 7.5 to 9.6.

When conditions were reversed, the subject's response rate ranged from 5.5 to 7.8. His median rate throughout this phase was 6.8. The fourth phase of Exp. IV, the return to multiple-ratio bands, was characterized by a response range of 1.9 (from 7.6 to 9.5) and a median rate of responding of 8.4. The error-rate medians during the four phases of the study were 0.0, 0.0, 0.0, and 0.06.

Discussion

Apparently, the cue marks used in Exp. II did not influence response rate; for even though the forty-fifth, sixtieth, and seventy-fifth responses were marked throughout the single-ratio phases, his correct rates, during those phases, were lower than during the multiple-ratio conditions. Furthermore, the forty-fifth, sixtieth, and seventy-fifth responses were marked throughout the multiple-ratio phases, when in fact the ratio bands corresponded to the ninetieth, one-hundredth, and one-hundred-twentieth responses.[4] Yet the

[3]In Exp. I, II, and IV the first ratio bands were similarly derived. The lowest rate of the first band was comparable to the subject's median rate in the first phase (single ratio) of the experiment. Subsequent ratio bands were rather arbitrarily established.

[4]In Exp. I and II, the multiple ratios were derived from the subject's median response rate in the first, single-ratio phase. Since in Exp. IV marks were used in the first phase, before any knowledge of his performance, the same marks were used in the second phase. Therefore the marks in this experiment were not derived from the subject's median rate in the first phase and, correspondingly, did not describe the contingency bands that were in effect during multiple-ratio conditions.

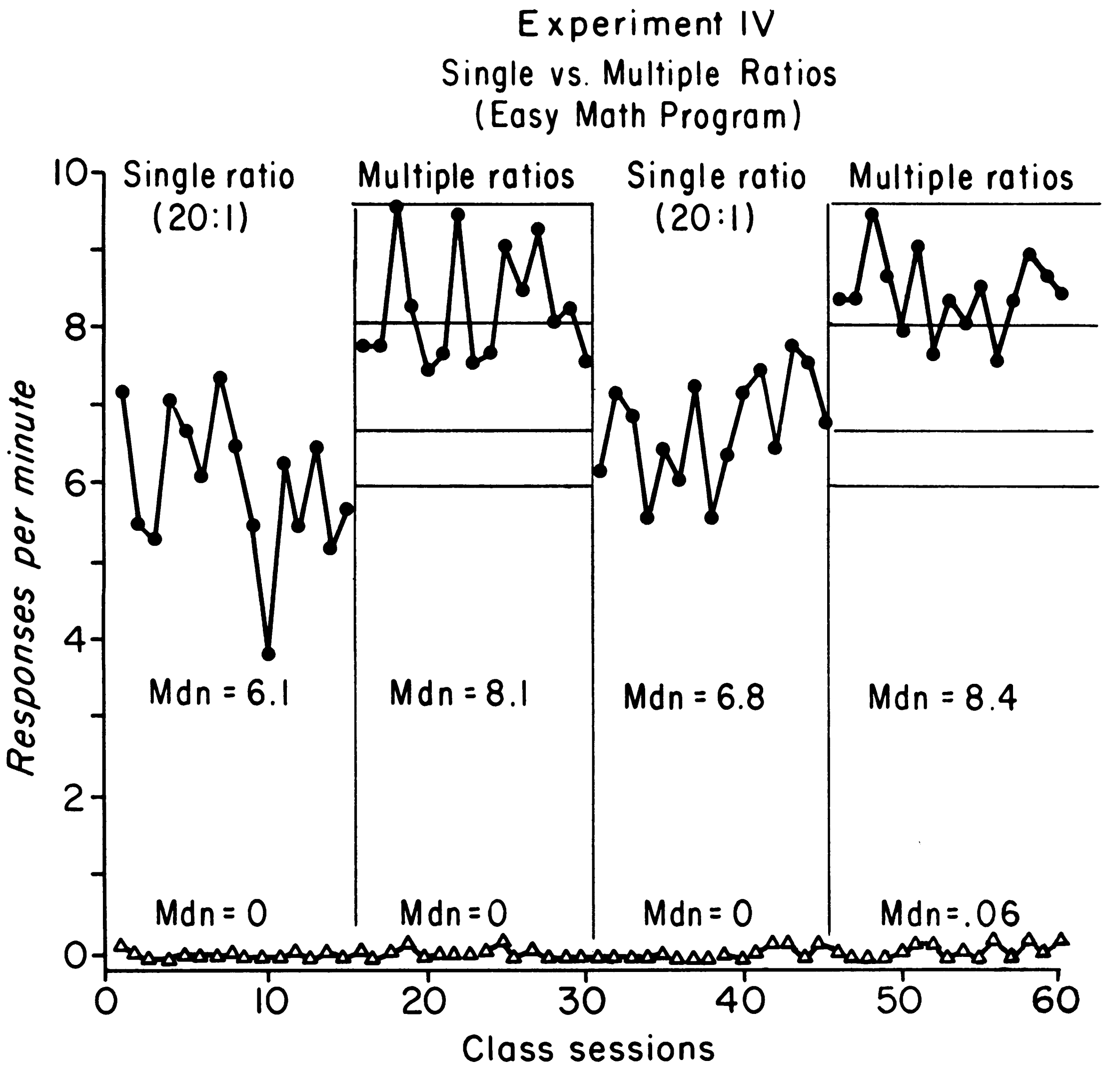

Fig. 5. Correct and error mathematics response rates during Exp. IV where Easy Math problems were scheduled and where single and multiple ratios were manipulated.

subject's correct response rate was higher during these phases than when a single ratio was scheduled. It would appear then, that the marks on the pupil's paper, whether they corresponded to ratio changes or not, were totally nonfunctional.

Less variation was observed between the correct-rate medians of Phases 1 and 2, and 3 and 4 of Exp. IV than between the same phases of Exp. II. The differences between the correct medians of adjacent phases in Exp. II were 2.2 and 2.5. The differences in Exp. IV were 2.0 and 1.6. These data could indicate that the subject was perhaps reaching a performance ceiling. As noted earlier, the same materials were used in both experiments. Therefore, the more familiar the subject became with the materials, rate differences between experimental conditions would become increasingly more difficult to obtain.

The subject's gradual increase in response rate may be noted throughout Exp. II, III, and IV by analyzing the data in the single or 20:1 ratio phases. The correct-rate medians during these phases throughout the three experiments were 3.1, 3.9, 5.65, 5.5, 6.1, and 6.8. This acceleration across experiments may also be pointed out by presenting the data from the multiple-ratio phases of Exp. II and IV. The correct-rate medians during multiple-ratio phases through the two experiments were 5.3, 6.4, 8.1, and 8.4.

GENERAL DISCUSSION

The independent variable throughout this study, multiple-ratio contingencies, was a series of ratio bands. This arrangement of ratios was similar to a series of DRH schedules, where successively more rapid response rates are reinforced by correspondingly richer payoffs. However, the similarity between the independent variable in this study and traditional efforts to reinforce high response rates differentially is appropriate for only the lowest portion of each reinforcement band. Since each contingency band represented a range of ratios, the higher the response rate within a band, the higher the reinforcement ratio. It can be argued that it would be most economical, in terms of work expended for points received, for the subject to perform in the lower portion of each contingency band where the schedule is richer. In this series of experiments, the subject did not always behave in such a manner.

As may be noted in Phase 2 of Exp. I, of the 15 times the subject's rate was in the highest payoff band (over two responses per minute) his rates during 10 sessions were no higher than 2.5 responses per minute. It might be said, then, that in this experiment his behavior was very efficient. During Exp. II, Phase 2, the subject responded within 0.5 of the third payoff band twice and within 0.5 of the fourth band three times. Only once in Phase 4 was his response rate within 0.5 of the lower limit of any band. In Exp. IV, Phase 2, when the subject's rates fell within the third ratio band, they were invariably at the top of the band. When his rates fell in the highest band, he responded within 0.5 of the bottom of the band four of the eight times. During the final phase of the experiment the subject's rates, when in the highest payoff band, were within 0.5 of the lower limit six of the 12 times.

When the data from the first multiple-ratio phase of Exp. I, II, and IV were analyzed, it was noted that higher ratio bands generated more pronounced behavioral effects than lower bands. When the subject's responses were analyzed during the four bands of the multiple-ratio phases it was discovered that the subject was paid off more often from the highest rate band than from any of the others. During Phase 2 of Exp. I, the subject's response rate fell three times within the no-payoff band, seven times in the next higher, eight in the next to highest, and 15 in the highest. During Phase 2 of Exp. II, his rates fell three times in the next-to-highest and nine times in the highest band, while never falling in the no-payoff or next higher ratio bands. In Exp. IV, Phase 2, the subject was also paid off from only the top two bands—seven times from the next-to-highest and eight from the highest.

Numerous academic, social, and economic situations come to mind that are based on the rather complicated ratios investigated in this report. Circumstances where several reinforcement ratios are available and where the subject must exert more and more effort as he approaches the next ratio are common.

In social organizations like scouting, where several steps or ranks are sequentially arranged, this type of ratio is in operation. When the rank of Life Scout is reached, the scout does not have to increase his behavioral repertoire to retain the rank. But later, as he attempts to pass the skills required of an Eagle, he must first master the easiest tests, then the more difficult. As he approaches the next level of reinforcement, his rate of behavior must increase, although while it is increasing he is still recognized as a Life Scout and is paid off from that level.

A schedule of this type is noted in certain businesses. Civil service employees are also assigned ratings and are paid accordingly. If they wish to advance from one level to the next, they must become more competent, pass tests, or in some way increase their rates of behavior. While these rates are in the process of increasing, however, they are paid off from the initial reinforcement level. Thus, until the next reinforcement band is reached, the civil servant must do more work or more complicated work for the same reinforcement. Only when he is promoted does his reinforcement match his work efforts. And then the process begins all over again.

Rarely in the "real" social and economic worlds are reinforcement levels or promotions linearly related to behavior (too often promotions have no relationship to behavior). These promotions usually occur when a person has greatly accelerated his performance. Once elevated, however, the person's behavioral rate generally stabilizes (post-reinforcement pause).

On the basis of this series of studies it appears that multiple-ratio conditions should be considered an effective variable when the objective is to accelerate academic response rate. Teachers should, however, exercise some caution in scheduling multiple contingencies, as in this study, to accelerate performance. Such contingencies, if associated with reading or arithmetic, when the acquisition of new information is of prime concern, could indeed accelerate responding. However, although the response rate increases, the quality of performance is not necessarily improved; for as correct rate increases, so might error rate. Teachers, therefore, when measuring academic performance, must monitor error rate as well as correct rate and should, in some instances, to influence high-quality performance, associate some contingency with errors.

This study, besides exploring a condition that could serve to accelerate academic performance, also demonstrates a technique for the investigation of other independent variables. Educators, particularly educational researchers, have at least two responsibilities; (a) to arrange circumstances so that pupils acquire new behaviors, and (b) to discover what effects various environmental variables have on behavior.

In setting up experiments, the researcher must consider his objective; is he concerned with the pupil's acquisition of behaviors, or with the discovery of environmental relationships? These objectives are not necessarily the same. If his concern is for the former, measures of the pupil's performance before, during, and after training should be taken to determine the effects of teaching. If the training was successful (the pupil's correct rate increased and error rate decreased), the pupil's behavior is probably irreversible; a reversal condition would therefore serve no purpose.

In such instances, where learning occurs and where an independent variable such as points or tokens is also being manipulated, and if the rate of the measured behavior is altered, the reason for those effects would not be known. If the performance improved, it could be the function of the acquisition of additional skills, the manipulated variable, or some interaction.

However, if the researcher's objective is to ascertain the effects of some environmental condition—arrange situations where the variable is alternately available—he should arrange the setting so that possible effects of that variable can be detected. One way of arranging such conditions was the tactic employed throughout most of the present study—the use of easy or known materials. When the math or reading materials scheduled for a pupil are within his repertory and if a wide rate range of response is possible, the effects of an environmental manipulation on response rate can be isolated from the effects of learning. Such experiments may initially appear as too expensive for the classroom teacher who must be concerned with assisting pupils to acquire dozens of skills. However, unless educational researchers, either in classrooms, laboratories, or clinics, begin to explore the circumstances that may affect learning, the practice of teaching will continue to be nonempirically based.

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