Schedules of Reinforcement

Key Terms

adjunctive behaviors
alternative schedule (alt)
chained schedule of reinforcement (chain)
compound schedule of reinforcement
concurrent schedule (conc)
conjunctive schedule (conj)
continuous reinforcement (CRF)
differential reinforcement of diminishing rates (DRD)
differential reinforcement of high rates (DRH)
differential reinforcement of low rates (DRL)
fixed interval (FI)
fixed ratio (FR)
intermittent schedule of reinforcement (INT)
limited hold
matching law
mixed schedule (mix)
multiple schedule (mult)
postreinforcement pause
progressive schedule of reinforcement
ratio strain
schedule of reinforcement
schedule thinning
tandem schedule (tand)
variable interval (VI)
variable ratio (VR)

Behavior Analyst Certification Board® BCBA® & BCABA® Behavior Analyst Task List©, Third Edition

Content Area 9: Behavior Change Procedures	
9-2 (b)	Use appropriate parameters and schedules of reinforcement.
9-6	Use differential reinforcement.
9-24	Use the matching law and recognize factors influencing choice.

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A **schedule of reinforcement** is a rule that describes a contingency of reinforcement, those environmental arrangements that determine conditions by which behaviors will produce reinforcement. Continuous reinforcement and extinction provide the boundaries for all other schedules of reinforcement. A schedule of **continuous reinforcement (CRF)** provides reinforcement for each occurrence of behavior. For example, a teacher using a continuous schedule of reinforcement would praise a student each time she identified a sight word correctly. Examples of behaviors that tend to produce continuous reinforcement include turning on a water faucet (water comes out), answering a telephone after it rings (a voice is heard), and putting money into a vending machine (a product is obtained). During extinction (EXT), no occurrence of the behavior produces reinforcement.

Intermittent Reinforcement

Between continuous reinforcement and extinction many **intermittent schedules of reinforcement (INT)** are possible in which some, but not all, occurrences of the behavior are reinforced. Only selected occurrences of behavior produce reinforcement with an intermittent schedule of reinforcement. CRF is used to strengthen behavior, primarily during the initial stages of learning new behaviors. Applied behavior analysts use intermittent reinforcement to maintain established behaviors.

Maintenance of Behavior

Maintenance of behavior refers to a lasting change in behavior. Regardless of the type of behavior change technique employed or the degree of success during treatment, applied behavior analysts must be concerned with sustaining gains after terminating a treatment program. For example, Mary is in the seventh grade and taking French, her first foreign language class. After a few weeks, the teacher informs Mary's parents that she is failing the course. The teacher believes that Mary's problems in French have resulted from lack of daily language practice and study. The parents and teacher decide that Mary will record a tally on a chart kept on the family bulletin board each evening that she studies French for 30 minutes. Mary's parents praise her practice and study accomplishments and offer encouragement. During a follow-up meeting 3 weeks later, the parents and teacher decide that Mary has done so well that the tally procedure can be stopped. Unfortunately, a few days later Mary is once again falling behind in French.

A successful program was developed to establish daily French language practice. However, gains did not maintain after removing the tally procedure. The parents and the teacher did not establish intermittent reinforcement procedures. Let us review what happened and what could have happened. Continuous reinforcement was used correctly to develop daily study behavior. However, after the study behavior was established and the tally procedure removed, the parents should have continued to praise and encourage daily practice and gradually offer fewer encouragements. The parents could have praised Mary's accomplishments after every second day of daily practice, then every fourth day, then once per week, and so on. With the intermittent praise, Mary might have continued daily practice after removing the tally procedure.

Progression to Naturally Occurring Reinforcement

A major goal of most behavior change programs is the development of naturally occurring activities, stimuli, or events to function as reinforcement. It is more desirable for people to read because they like to read, rather than to obtain contrived reinforcement from a teacher or parent; to engage in athletics for the enjoyment of the activity, rather than for a grade or because of a physician's directive; to help around the house for the personal satisfaction it brings, rather than to earn an allowance. Intermittent reinforcement is usually necessary for the progression to naturally occurring reinforcement. Even though some individuals spend hours each day practicing a musical instrument because they enjoy the activity, chances are good that this persistent behavior developed gradually. At first the beginning music student needs a great deal of reinforcement to continue the activity: "You really practiced well today," "I can't believe how well you played," "Your mother told me you received a first place in the contest—that's super!" These social consequences are paired with other consequences from teachers, family members, and peers. As the student develops more proficiency in music, the outside consequences occur less frequently, intermittently. Eventually, the student spends long periods making music without receiving reinforcement from others because making music has itself become a reinforcer for doing that activity.

Some might explain the transition of our music student from an "externally reinforced person" to a "self-reinforced musician" as the development of intrinsic motivation, which seems to imply that something inside the person is responsible for maintaining the behavior. This view is incorrect from a behavioral standpoint. Applied behavior analysts describe intrinsic motivation as reinforcement that is received by manipulating the

physical environment. Some individuals ride bicycles, go backpacking, read, write, or help others because manipulations of the environment provide reinforcement for engaging in those activities.

Defining Basic Intermittent Schedules of Reinforcement

Ratio and Interval Schedules

Applied behavior analysts directly or indirectly embed ratio and interval intermittent schedules of reinforcement in most treatment programs, especially ratio schedules (Lattal & Neef, 1996). Ratio schedules require a number of responses before one response produces reinforcement. If the ratio requirement for a behavior is 10 correct responses, only the 10th correct response produces reinforcement. Interval schedules require an elapse of time before a response produces reinforcement. If the interval requirement is 5 minutes, reinforcement is provided contingent on the first correct response that occurs after 5 minutes has elapsed since the last reinforced response.

Ratio schedules require a number of responses to be emitted for reinforcement; an elapse of time does not change the number contingency. The participant's response rate, however, determines the rate of reinforcement. The more quickly the person completes the ratio requirement, the sooner reinforcement will occur. Conversely, interval schedules require an elapse of time before a single response produces reinforcement. The total number of responses emitted on an interval schedule is irrelevant to when and how often the reinforcer will be delivered. Emitting a high rate of response during an interval schedule does not increase the rate of reinforcement. Reinforcement is contingent only on the occurrence of one response after the required time has elapsed. The availability of reinforcement is time-controlled with interval schedules, and rate of reinforcement is "self-controlled" with ratio schedules, meaning that the more quickly the individual completes the ratio requirement, the sooner reinforcement will occur.

Fixed and Variable Schedules

Applied behavior analysts can arrange ratio and interval schedules to deliver reinforcement as a fixed or a variable contingency. With a fixed schedule, the response ratio or the time requirement remains constant. With a variable schedule, the response ratio or the time requirement can change from one reinforced response to another. The combinations of ratio or interval and fixed or variable contingencies define the four basic schedules of intermittent reinforcement: fixed ratio, variable ratio, fixed interval, and variable interval.

The following sections define the four basic schedules of intermittent reinforcement, provide examples of each schedule, and present some well-established schedule effects derived from basic research.

Fixed Ratio Defined

A **fixed ratio (FR)** schedule of reinforcement requires the completion of a number of responses to produce a reinforcer. For example, every fourth correct (or target) response produces reinforcement on an FR 4 schedule. An FR 15 schedule means that 15 responses are required to produce reinforcement. Skinner (1938) conceptualized each ratio requirement as a response unit. Accordingly, the response unit produces the reinforcer, not just the last response of the ratio.

Some business and industrial tasks are paid on an FR schedule (e.g., piecework). A worker might receive a pay credit after completing a specified number of tasks (e.g., assembling 15 pieces of equipment or picking a box of oranges). A student might receive either a happy face after learning 5 new sight words or a certain number of points after completing 10 math problems.

De Luca and Holborn (1990) reported a comparison of obese and nonobese children's rate of pedaling an exercise bicycle under baseline and FR schedules of reinforcement. The baseline and FR conditions used the same duration of exercise. After establishing a stable rate of pedaling during baseline, De Luca and Holborn introduced an FR schedule that matched the rate of reinforcement produced during baseline. All participants increased their rate of pedaling with the introduction of the FR schedule.

Fixed Ratio Schedule Effects

Consistency of Performance

FR schedules produce a typical pattern of responding: (a) After the first response of the ratio requirement, the participant completes the required responses with little hesitation between responses; and (b) a **postreinforcement pause** follows reinforcement (i.e., the participant does not respond for a period of time following reinforcement). The size of the ratio influences the duration of the postreinforcement pause: Large ratio

requirements produce long pauses; small ratios produce short pauses.

Rate of Response

FR schedules often produce high rates of response. Quick responding on FR schedules maximizes the delivery of reinforcement because the quicker the rate of response, the greater the rate of reinforcement. People work rapidly with a fixed ratio because they receive reinforcement with the completion of the ratio requirements. Computer keyboarders (typists) who contract their services usually work on an FR schedule. They receive a specified amount for the work contracted. A typist with a 25-page manuscript to complete is likely to type at the maximum rate. The sooner the manuscript is typed, the sooner payment is received, and the more work the typist can complete in a day.

The size of the ratio can influence the rate of response on FR schedules. To a degree, the larger the ratio requirement, the higher the rate of response. A teacher could reinforce every third correct answer to arithmetic facts. With this ratio requirement, the student might complete 12 problems within the specified time, producing reinforcement four times. The student might complete more problems in less time if the teacher arranged reinforcement contingent on 12 correct answers rather than 3. The higher ratio is likely to produce a higher rate of response. The rate of response decreases, however, if the ratio requirements are too large. The maximum ratio is determined in part by the participant's past FR history of reinforcement, motivating operations, the quality of the reinforcer, and the procedures that change the ratio requirements. For example, if ratio requirements are raised gradually over an extended period of time, extremely high ratio requirements can be reached.

Figure 1 summarizes the schedule effects typically produced by FR schedules of reinforcement.

Variable Ratio Defined

A **variable ratio (VR)** schedule of reinforcement requires the completion of a variable number of responses to produce a reinforcer. A number representing the average (e.g., mean) number of responses required for reinforcement identifies the VR schedule. For example, with a VR 10 schedule every tenth correct response on the average produces reinforcement. Reinforcement can come after 1 response, 20 responses, 3 responses, 13 responses, or n responses, but the average number of responses required for reinforcement is 10 (e.g., 1 + 20 + 3 + 13 + 18 = 55; 55/5 = 10).

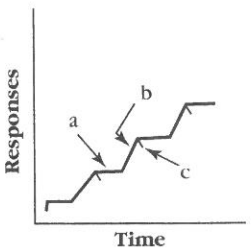
The operation of a slot machine, the one-armed bandit, provides a good example of a VR schedule. These machines are programmed to pay off only a certain proportion of the times they are played. A player cannot predict when the next operation of the machine will pay off. The player might win 2 or 3 times in succession and then not win again for 20 or more plays.

De Luca and Holborn (1992) examined the effects of a VR schedule on three obese and three nonobese children's rate of pedaling an exercise bicycle. The children could use the exercise bicycle Monday to Friday during each week of the analysis, but received no encouragement to do so. The participants received the instruction to "exercise as long as you like" to initiate the baseline condition. De Luca and Holborn introduced the VR schedule of reinforcement after establishing a stable baseline rate of pedaling. They calculated the baseline mean number of pedal revolutions per minute and programmed the first VR contingency at approximately 15% faster pedaling than the baseline mean. The children received points on

Definition: Reinforcement delivered contingent on emission of a specified number of responses.

Schedule Effects: After reinforcement a postreinforcement pause occurs. After the pause the ratio requirement is completed with a high rate of response and very little hesitation between responses. The size of the ratio influences both the pause and the rate.

Stylized Graphic Curve of Cumulative Responses:



a = postreinforcement pause
b = high rate of response "run"
c = reinforcer delivered upon emission of n^{th} response

Figure 1 Summary of FR schedule effects during ongoing reinforcement.

the VR schedule to exchange for backup reinforcers. De Luca and Holborn increased the VR schedule in two additional increments by approximately 15% per increment. All participants had systematic increases in their rate of pedaling with each VR value, meaning that the larger the variable ratio, the higher the rate of response. De Luca and Holborn reported that the VR schedule produced higher rates of response than did the FR schedule in their previous study (De Luca & Holborn, 1990).

Figure 2 presents the participants' performances under baseline and VR (i.e., VR ranges 70 to 85, 90 to 115, 100 to 130) conditions.

Student behaviors usually produce reinforcement following the completion of variable ratios. Usually a student cannot predict when the teacher will call on him to give an answer, and receive reinforcement. Good grades, awards, promotions—all may come after an unpredictable number of responses. And in checking

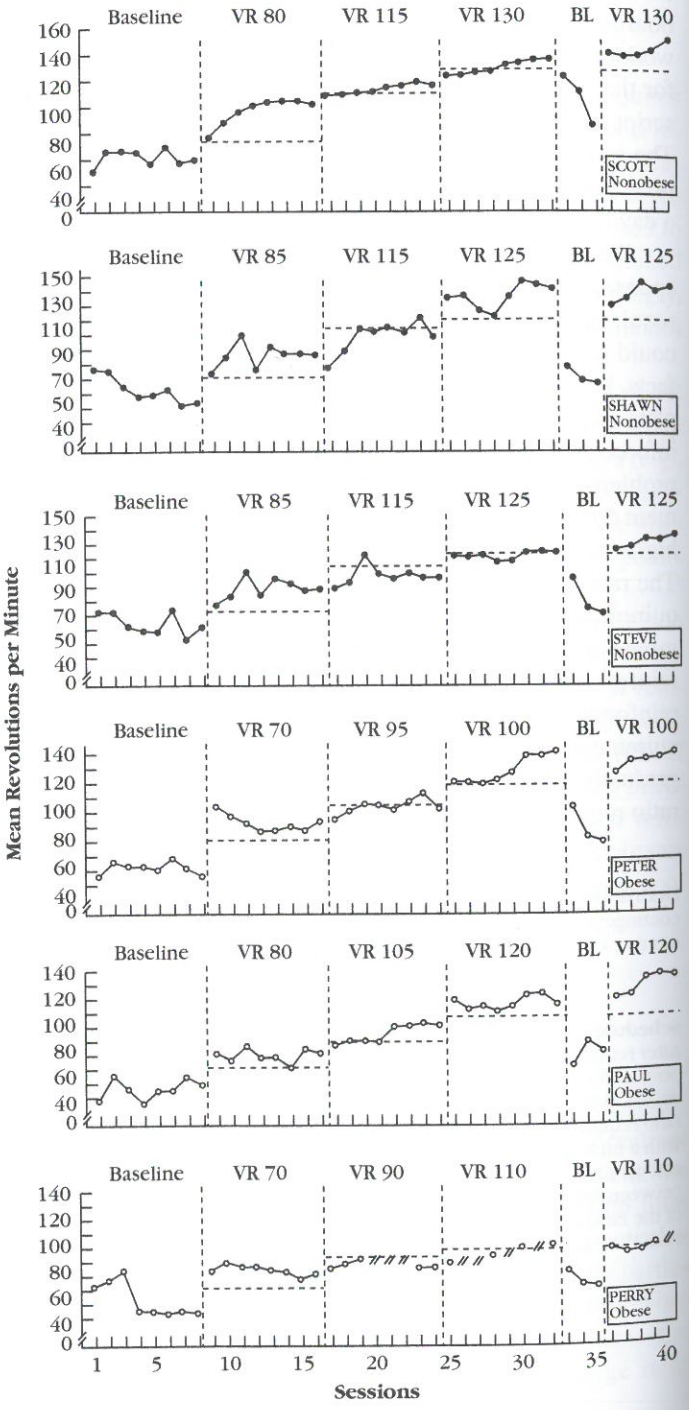


Figure 2 Mean revolutions per minute during baseline, VR 1 (VR range, 70 to 85), VR 2 (VR range 90 to 115), VR 3 (VR range 100 to 130), return to baseline, and return to VR 3 phases for obese and nonobese subjects.

From "Effects of a Variable-Ratio Reinforcement Schedule with Changing Criteria on Exercise in Obese and Nonobese Boys" by R. V. De Luca and S. W. Holborn, 1992, *Journal of Applied Behavior Analysis, 25* p. 674. Copyright 1992 by the Society for the Experimental Analysis of Behavior, Inc. Reprinted by permission.

seatwork, the teacher might reinforce a student's work after the completion of 10 tasks, another student's work after 3 tasks, and so on.

Variable Ratio Schedule Effects

Consistency of Performance

VR schedules produce consistent, steady rates of response. They typically do not produce a postreinforcement pause, as do FR schedules. Perhaps the absence of pauses in responding is due to the absence of information about when the next response will produce reinforcement. Responding remains steady because the next response may produce reinforcement.

Rate of Response

Like the FR schedule, the VR schedule tends to produce a quick rate of response. Also similar to the FR schedule, the size of the ratio influences the rate of response. To a degree, the larger the ratio requirement, the higher the rate of response. Again like FR schedules, when variable ratio requirements are thinned gradually over an extended period of time, participants will respond to extremely high ratio requirements. Figure 3 summarizes the schedule effects typically produced by VR schedules of reinforcement.

Variable Ratio Schedules in Applied Settings

Basic researchers use computers to select and program VR schedules of reinforcement. VR schedules used in applied settings are seldom implemented with a planned and systematic approach. In other words, the reinforcer is delivered by chance, hit or miss in most interventions. This nonsystematic delivery of reinforcement is not an effective use of VR schedules. Teachers can select and preplan VR schedules that approximate the VR schedules used in basic research. For example, teachers can plan variable ratios by (a) selecting a maximum ratio for a given activity (e.g., 15 responses) and (b) using a table of random numbers to produce the specific variable ratios for the schedule of reinforcement. A table of random numbers might produce the following sequence of ratios: 8, 1, 1, 14, 3, 10, 14, 15, and 6, producing a VR 8 schedule of reinforcement (on the average each 8th response produces the reinforcer) with the ratios ranging from 1 to 15 responses.

Teachers can apply the following VR procedures as individual or group contingencies of reinforcement for academic or social behavior:

Tic-Tac-Toe VR Procedure

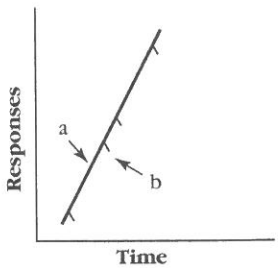
1. The teacher establishes a maximum number for the individual student or group. The larger the maximum number selected, the greater the odds against meeting the contingency. For example, 1 chance out of 100 has less chance of being selected than 1 chance out of 20.
2. The teacher gives the individual or group a tic-tac-toe grid.
3. Students fill in each square of the grid with a number no greater than the maximum number. For example, if the maximum number is 30, the score sheet might look like this:

1	20	13
3	5	30
7	11	6

Definition: Reinforcer is delivered after the emission of a variable number of responses.

Schedule Effects: Ratio requirements are completed with a very high rate of response and little hesitation between responses. Postreinforcement pauses are not a characteristic of the VR schedule. Rate of response is influenced by the size of the ratio requirements.

Stylized Graphic Curve of Cumulative Responses:



a = high, steady rate of responding
b = reinforcement delivered after a varying number of required responses are emitted

Figure 3 Summary of VR schedule effects during ongoing reinforcement.

4. The teacher fills a box or some other type of container with numbered slips of paper (with numbers no higher than the maximum number). Each number should be included several times; for example, five 1s, five 2s, five 3s.
5. Contingent on the occurrence of the target behavior, students withdraw one slip of paper from the box. If the number on the paper corresponds with a number on the tic-tac-toe sheet, the students mark out that number on the grid.
6. The reinforcer is delivered when students have marked out three numbers in a row—horizontally, vertically, or diagonally.

For example, a student might withdraw one slip of paper for each homework assignment completed. Selecting an activity from the class job board (e.g., teacher's helper, collecting milk money, running the projector) could serve as the consequence for marking out three numbers in a row.

Classroom Lottery VR Procedure

1. Students write their names on index cards after successfully completing assigned tasks.
2. Students put signature cards into a box located on the teacher's desk.
3. After an established interval of time (e.g., 1 week), the teacher draws a signature card from the box and declares that student the winner. The lottery can have first, second, and third place, or any number of winners. The more cards students earn, the greater is the chance that one of their cards will be picked.

Teachers have used classroom lotteries with a variety of student accomplishments, such as nonassigned book reading. For example, for each book read, students write their names and the titles of the book they have read on a card. Every 2 weeks the teacher picks one card from the box and gives the winning student a new book. To make the book an especially desirable consequence, the teacher lets students earn the privilege of returning the book to the school, inscribed with the student's name, class, and date (e.g., *Brian Lee, fifth grade, donated this book to the High Street Elementary School Library on May 22, 2007*).

Desk Calendar VR Procedure

1. Students receive desk calendars with loose-leaf date pages secured to the calendar base.
2. The teacher removes the loose-leaf date pages from the calendar base.
3. The teacher establishes a maximum ratio for the students.
4. The teacher numbers index cards consecutively from 1 to the maximum ratio. Multiple cards are included for each number (e.g., five 1s, five 2s). If a large average ratio is desired, the teacher includes more large numbers; for small average ratios, the teacher uses smaller numbers.
5. The teacher uses a paper punch to punch holes in the index cards for attaching the cards to the calendar base.
6. The teacher or student shuffles the index cards to quasi-randomize the order and attaches the index cards to a calendar base face down.
7. Students produce their own VR schedules by turning over one index card at a time. After meeting that ratio requirement, students flip the second card to produce the next ratio, and so on.

Students can use the desk calendar base to program VR schedules for most curriculum area (e.g., arithmetic facts). For example, after receiving an arithmetic worksheet, the student flips the first card. It has a 5 written on it. After completing five problems, she holds up her hand to signal her teacher that she has completed the ratio requirement. The teacher checks the student's answers, provides feedback, and presents the consequence for correct problems. The student flips the second card; the ratio requirement is 1. After completing that single problem, she receives another consequence and flips the third card. This time the ratio is 14. The cycle continues until all of the cards in the stack are used. New cards can then be added or old cards reshuffled to create a new sequence of numbers. The average of the numbers does not change in the reshuffling.

Fixed Interval Schedules

A **fixed interval (FI)** schedule of reinforcement provides reinforcement for the first response following a fixed duration of time. With an FI 3-minute schedule, the first response following the elapse of 3 minutes produces the reinforcer. A common procedural misunderstanding with the FI schedule is to assume that the elapse of time alone is sufficient for the delivery of a reinforcer, assuming that the reinforcer is delivered at the end of each fixed interval of time. However, more time than the fixed interval can elapse between reinforced responses. The reinforcer is available after the fixed time interval has elapsed, and it remains available until the first response. When the first response occurs sometime after the elapse of a fixed interval, that response is immediately reinforced, and the timing of another fixed interval is usually started with the delivery of the reinforcer. This FI cycle is repeated until the end of the session.

Actual examples of FI schedules in everyday life are difficult to find. However, some situations do approximate and in reality function as FI schedules. For

example, mail is often delivered close to a fixed time each day. An individual can make many trips to the mailbox to look for mail, but only the first trip to the mailbox following the mail delivery will produce reinforcement. Many textbook examples of FI schedules, such as the mail example, do not meet the definition of an FI schedule; but the examples do appear similar to an FI schedule. For example, receiving a paycheck as wages for work by the hour, day, week, or month is contingent on the first response on payday that produces the paycheck. Of course, receiving the paycheck requires many responses during the interval that eventually lead to receiving the paycheck. In a true FI schedule, responses during the interval do not influence reinforcement.

FI schedules are relatively easy to use in applied settings. A teacher could make reinforcement available on an FI 2-minute schedule for correct answers on an arithmetic worksheet. The teacher or student could use an electronic timer with a countdown function to signal the elapse of the 2-minute interval. The student's first correct answer following the interval produces reinforcement, and then the teacher resets the timer for another 2-minute interval. Similarly, the teacher could use small timing instruments such as the Gentle Reminder (dan@gentlereminder.com) and MotivAiders (www.habitchange.com) that vibrate to signal the elapse of an interval.

Fixed Interval Schedule Effects

Consistency of Performance

FI schedules typically produce a postreinforcement pause in responding during the early part of the interval. An initially slow but accelerating rate of response is evident toward the end of the interval, usually reaching a maximum rate just before delivery of the reinforcer. This gradually accelerating rate of response toward the end of the interval is called an *FI scallop* because of the rounded curves that are shown on a cumulative graph (see Figure 4).

FI postreinforcement pause and scallop effects can be seen in many everyday situations. When college students are assigned a term paper, they typically do not rush to the library and start to work on the paper immediately. More often they wait a few days or weeks before starting to work. However, as the due date approaches, their work on the assignment increases in an accelerating fashion, and many are typing the final draft just before class. Cramming for a midterm or final examination is another example of the FI scallop effect.

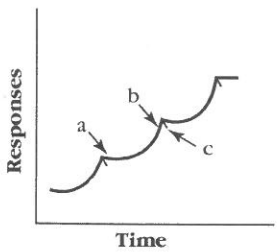
These examples with the reinforcement pause and scallop effects appear to be produced by FI schedules of reinforcement. They are not, however, because like the paycheck example, college students must complete many responses during the interval to produce the term paper or a good grade on the examinations, and the term paper and examinations have deadlines. With FI schedules, responses during the interval are irrelevant, and FI schedules have no deadlines for the response.

Why does an FI schedule produce a characteristic pause and scallop effect? After adjustment to an FI schedule, participants learn (a) to discriminate the elapse of time and (b) that responses emitted right after a reinforced response are never reinforced. Therefore, extinction during the early part of the interval might account for the postreinforcement pause. The effects of FI and FR schedules of reinforcement are similar in that both schedules produce postreinforcement pauses. However, it is important to recognize the different characteristics of behavior that emerge under each schedule. Responses under

Definition: The first correct response after a designated and constant amount of time produces the reinforcer.

Schedule Effects: FI schedules generate slow to moderate rates of responding with a pause in responding following reinforcement. Responding begins to accelerate toward the end of the interval.

Stylized Graphic Curve of Cumulative Responses:



a = postreinforcement pause
b = increase in response rates as interval progresses and reinforcer becomes available
c = reinforcer delivered contingent on first correct response after interval

Figure 4 Summary of FI schedule effects during ongoing reinforcement.

an FR schedule are emitted at a consistent rate until completing the ratio requirement, whereas responses under an FI schedule begin at a slow rate and accelerate toward the end of each interval.

Rate of Responding

Overall, FI schedules tend to produce a slow to moderate rates of response. The duration of the time interval influences the postreinforcement pause and the rate of response; to a degree, the larger the fixed interval requirement, the longer the postreinforcement pause and the lower the overall rate of response.

Variable Interval Schedules

A **variable interval (VI)** schedule of reinforcement provides reinforcement for the first correct response following the elapse of variable durations of time. The distinguishing feature of VI schedules is that "the intervals between reinforcement vary in a random or nearly random order" (Ferster & Skinner, 1957, p. 326). Behavior analysts use the average (i.e., mean) interval of time before the opportunity for reinforcement to describe VI schedules. For example, in a VI 5-minute schedule the average duration of the time intervals between reinforcement and the opportunity for subsequent reinforcement is 5 minutes. The actual time intervals in a VI 5-minute schedule might be 2 minutes, 5 minutes, 3 minutes, 10 minutes, or *n* minutes (or seconds).

An example of VI reinforcement in everyday situations occurs when one person telephones another person whose line is busy. This is a VI schedule because a variable interval of time is necessary for the second person to conclude the telephone conversation and hang up so that another call can be connected. After that interval the first dialing of the second person's number will probably produce an answer (the reinforcer). The number of responses (attempts) does not influence the availability of reinforcement in a VI schedule; no matter how many times the busy number is dialed, the call will not be completed until the line is free. And the time interval is unpredictable in a VI schedule: The busy signal may last for a short or long time.

Variable Interval Schedule Effects

Consistency of Performance

A VI schedule of reinforcement tends to produce a constant, stable rate of response. The slope of the VI schedule on a cumulative graph appears uniform with few pauses in responding (see Figure 5). A VI schedule typically produces few hesitations between responses. For example, pop quizzes at unpredictable times tend to occasion more consistent study behavior from students than do quizzes scheduled at fixed intervals of time. Furthermore, students are less apt to engage in competing off-task behaviors during instructional and study periods when a pop quiz is likely. The pop quiz is used often as an example of a VI schedule because the performance effect is similar to a VI performance. The pop quiz does not represent a true VI schedule, however, because of the required responses during the interval, and the deadline for receiving reinforcement.

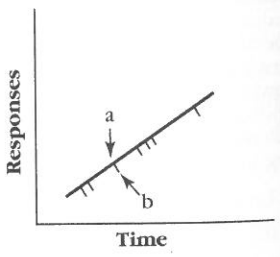
Rate of Responding

VI schedules of reinforcement tend to produce low to moderate rates of response. Like the FI schedule, the average duration of the time intervals on VI schedules influences the rate of response; to a degree, the larger the average interval, the lower the overall rate of response. Figure 5 summarizes the schedule effects typically produced by VI schedules during ongoing reinforcement.

Definition: The first correct response following varying intervals of time produces the reinforcer.

Schedule Effects: A VI schedule generates a slow to moderate response rate that is constant and stable. There are few, if any, postreinforcement pauses with VI schedules.

Stylized Graphic Curve of Cumulative Responses:



a = steady response rate; few, if any, postreinforcement pauses
b = reinforcer delivered

Figure 5 Summary of VI schedule effects during ongoing reinforcement.

Variable Interval Schedules in Applied Settings

Basic researchers use computers to select and program VI schedules of reinforcement, as they do with VR schedules. Teachers seldom apply VI schedules in a planned and systematic way. For example, a teacher might set an electronic countdown timer with varied intervals of time ranging from 1 minute to 10 minutes without any prior plan as to which intervals or which order will be used. This set-them-as-you-go selection of intervals approximates the basic requirements for a VI schedule; however, it is not the most effective way of delivering reinforcement on a VI schedule. A planned, systematic application of varied intervals of time should increase the effectiveness of a VI schedule.

For example, applied behavior analysts can select the maximum time interval, whether in seconds or minutes, that will maintain performance and still be appropriate for the situation. Preferably, applied behavior analysts will use data from a direct assessment to guide the selection of the maximum VI interval, or at the least clinical judgment based on direct observation. Analysts can use a table of random numbers to select the varied intervals between 1 and the maximum interval, and then identify the VI schedule by calculating an average value for the VI schedule. The VI schedule may need adjustments following the selection of time intervals. For example, if a larger average interval of time appears reasonable, the teacher can replace some of the smaller intervals with larger ones. Conversely, if the average appears too large, the teachers can replace some of the higher intervals with smaller ones.

Interval Schedules with a Limited Hold

When a **limited hold** is added to an interval schedule, reinforcement remains available for a finite time following the elapse of the FI or VI interval. The participant will miss the opportunity to receive reinforcement if a targeted response does not occur within the time limit. For example, on an FI 5-minute schedule with a limited hold of 30 seconds, the first correct response following the elapse of 5 minutes is reinforced, but only if the response occurs within 30 seconds after the end of the 5-minute interval. If no response occurs within 30 seconds, the opportunity for reinforcement has been lost and a new interval begins. The abbreviation LH identifies interval schedules using a limited hold (e.g., FI 5-minute LH 30-second, VI 3-minute LH 1-minute). Limited holds with interval schedules typically do not change the overall response characteristics of FI and VI schedules beyond a possible increase in rate of response.

Martens, Lochner, and Kelly (1992) used a VI schedule of social reinforcement to increase the academic engagement of two 8-year-old boys in a third-grade classroom. The classroom teacher reported that the boys had serious off-task behaviors. The experimenter wore an earphone connected to a microcassette recorder containing a 20-second fixed-time cueing tape. The cueing tape was programmed for a VI schedule of reinforcement in which only some of the 20-second intervals provided the opportunity for reinforcement in the form of verbal praise for academic engagement. If the boys were not academically engaged when the VI interval timed out, they lost that opportunity for reinforcement until the next cue. Thus, this VI schedule entailed a very short limited hold for the availability of reinforcement. Following baseline, the experimenter delivered contingent praise on a VI 5-minute or VI 2-minute schedule that alternated daily on a quasi-random basis. Both boys' academic engagement on the VI 5-minute schedule resembled their baseline engagement. Both students had a higher percentage of academic engagement on the VI 2-minute schedule than they had during baseline and VI 5-minute conditions. Figure 6 presents percentages of academic engagement across baseline and VI conditions.

Thinning Intermittent Reinforcement

Applied behavior analysts often use one of two procedures for **schedule thinning.** First, they thin an existing schedule by gradually increasing the response ratio or the duration of the time interval. If a student has answered addition facts effectively and responded well to a CRF schedule for two or three sessions, the teacher might thin the reinforcement contingency slowly from one correct addition fact (CRF) to a VR 2 or VR 3 schedule. The student's performance should guide the progression from a dense schedule (i.e., responses produce frequent reinforcement) to a thin schedule (i.e., responses produce less frequent reinforcement). Applied behavior analysts should use small increments of schedule changes during thinning and ongoing evaluation of the learner's performance to adjust the thinning process and avoid the loss of previous improvements.

Second, teachers often use instructions to clearly communicate the schedule of reinforcement, facilitating a smooth transition during the thinning process. Instructions include rules, directions, and signs. Participants do not require an awareness of environmental contingencies for effective intermittent reinforcement, but instructions may enhance the effectiveness of interventions when participants are told what performances produce reinforcement.

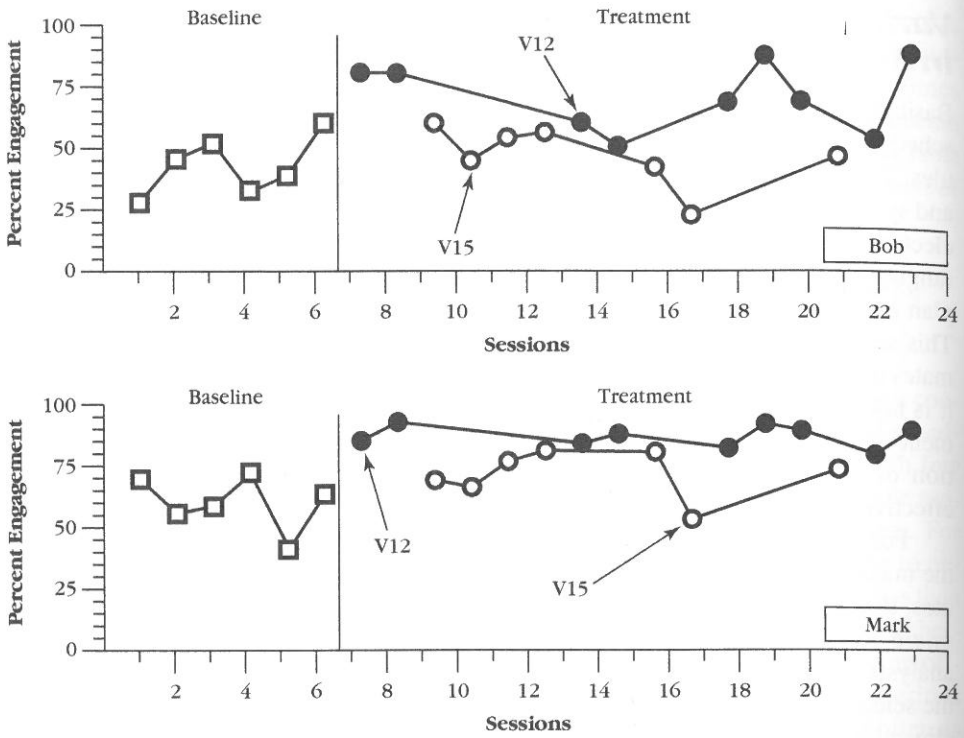


Figure 6 Percentage of academic engagement for each child across all conditions in Experiment 2.

From "The Effects of Variable-Interval Reinforcement on Academic Engagement: A Demonstration of Matching Theory" by B. K. Martens, D. G. Lochner, and S. Q. Kelly, 1992, *Journal of Applied Behavior Analysis, 25*, p. 149. Copyright 1992 by the Society for the Experimental Analysis of Behavior, Inc. Reprinted by permission.

Ratio strain can result from abrupt increases in ratio requirements when moving from denser to thinner reinforcement schedules. Common behavioral characteristics associated with ratio strain include avoidance, aggression, and unpredictable pauses in responding. Applied behavior analysts should reduce the ratio requirement when ratio strain is evident. The analyst can again gradually thin ratio requirements after recovering the behavior. Small and gradual increases in ratio requirements help to avoid the development of ratio strain. Ratio strain will occur also when the ratio becomes so large that the reinforcement cannot maintain the response level or the response requirement exceeds the participant's physiological capabilities.

Variations on Basic Intermittent Schedules of Reinforcement

Schedules of Differential Reinforcement of Rates of Responding

Applied behavior analysts frequently encounter behavior problems that result from the rate that people perform certain behaviors. Responding too infrequently, or too often, may be detrimental to social interactions or academic learning. Differential reinforcement provides an intervention for behavior problems associated with rate of response. Differential reinforcement of particular rates of behavior is a variation of ratio schedules. Delivery of the reinforcer is contingent on responses occurring at a rate either higher than or lower than some predetermined criterion. The reinforcement of responses higher than a predetermined criterion is called **differential reinforcement of high rates (DRH).** When responses are reinforced only when they are lower than the criterion, the schedule provides **differential reinforcement of low rates (DRL).** DRH schedules produce a higher rate of responding. DRL schedules produce a lower rate of responding.

Applied behavior analysts use three definitions of DRH and DRL schedules. The first definition states that reinforcement is available only for responses that are separated by a given duration of time. This first definition is sometimes called spaced-responding DRH or spaced-responding DRL. An interresponse time (IRT) identifies the duration of time that occurs between two responses. IRT and rate of response are functionally related. Long IRTs produce low rates of responding; short IRTs produce high rates of responding. Responding on a DRH schedule produces reinforcement whenever a response occurs before a time criterion has elapsed. If the time criterion is 30 seconds, the participant's response produces reinforcement only when the IRT is 30 seconds or less.

Under the DRL schedule, a response produces reinforcement when it occurs after a time criterion has elapsed. If the stated DRL time criterion is again 30 seconds, a response produces reinforcement only when the IRT is 30 seconds or greater.

This first definition of DRH and DRL as IRT schedules of reinforcement has been used almost exclusively in laboratory settings. There are two apparent reasons for its lack of application in applied settings: (a) Most applied settings do not have sufficient automated equipment to measure IRT and to deliver reinforcement using an IRT criterion; and (b) reinforcement is delivered usually, but not necessarily, following each response that meets the IRT criterion. Such frequent reinforcement would disrupt student activity in most instructional settings. However, with increased use of computers for tutorial and academic response practice, opportunities increasingly should become available for using IRT-based schedules of reinforcement to accelerate or decelerate academic responding. Computers can monitor the pauses between academic responses and provide consequences for each response meeting the IRT criterion, with little disruption in instructional activity.

Based on the laboratory procedures for programming DRL schedules presented previously, Deitz (1977) labeled and described two additional procedures for using differential reinforcement of rates of responding in applied settings: full-session DRH or DRL and interval DRH or DRL. Deitz initially used the full-session and interval procedures as a DRL intervention for problem behaviors. The full-session and interval procedures, however, apply also for DRH.

A DRH full-session schedule provides reinforcement if the total number of responses during the session meets or exceeds a number criterion. If the participant emits fewer than the specified number of responses during the session, the behavior is not reinforced. The DRL full-session schedule is procedurally the same as the DRH schedule, except reinforcement is provided for responding at or below the criterion limit. If the participant emits more than the specified number of responses during the session, reinforcement is not delivered.

The interval definition for DRH and DRL schedules states that reinforcement is available only for responses that occur at a minimum or better rate of response over short durations of time during the session. To apply an interval DRH schedule, the applied behavior analyst organizes the instructional session into equal intervals of time and dispenses a reinforcer at the end of each interval when the student emits a number of responses equal to, or greater than, a number criterion. The interval DRL schedule is procedurally like the DRH interval schedule, except that reinforcement is provided for responding at or below the criterion limit.

The **differential reinforcement of diminishing rates (DRD)** schedule provides reinforcement at the end of a predetermined time interval when the number of responses is less than a criterion that is gradually decreased across time intervals based on the individual's performance (e.g., fewer than five responses per 5 minutes, fewer than four responses per 5 minutes, fewer than three responses per 5 minutes, etc.). Deitz and Repp (1973) used a group DRD contingency to reduce off-task talking of 15 high school senior girls. They set the first DRD criterion limit at five or fewer occurrences of off-task talking during each 50-minute class session. The DRL criterion limits were then gradually reduced to three or fewer, one or fewer, and finally no responses. The students earned a free Friday class when they kept off-task talking at or below the DRD limit Monday through Thursday.

The previous example of a DRD schedule used an identical procedure as described for the full-session DRL. DRD is also a procedural variation on interval DRL schedules described by Deitz (1977) and Deitz and Repp (1983). The typical procedure for using an interval DRL as an intervention for problem behavior provided reinforcement contingent on emitting one or no responses per brief interval. After the problem behavior stabilizes at the initial criterion, the applied behavior analyst maintains the maximum criterion of one or no responses per interval, but increases the duration of the session intervals to further diminish the behavior. Increasing the duration of session intervals continues gradually until the problem behavior achieves a terminal low rate of responding.

Later Deitz and Repp (1983) programmed the interval DRL with a criterion greater than one response per interval, then gradually diminished the maximum number of responses per interval while the duration of the interval remained constant (e.g., fewer than five responses per 5 minutes, fewer than four responses per 5 minutes, fewer than three responses per 5 minutes, etc.). The DRD schedule and the interval DRL schedule that use a maximum number criterion greater than one per interval are different terms for the same procedure. Full-session and interval DRL have a long history of application in applied behavior analysis. DRD offers applied behavior analysts a new, and perhaps improved, label for the interval DRL procedure.

Progressive Schedules of Reinforcement

A **progressive schedule of reinforcement** systematically thins each successive reinforcement opportunity independent of the participant's behavior. Progressive ratio

(PR) and progressive interval (PI) schedules of reinforcement change schedule requirements using (a) arithmetic progressions to add a constant amount to each successive ratio or interval or (b) geometric progressions to add successively a constant proportion of the preceding ratio or interval (Lattal & Neef, 1996). Progressive schedules of reinforcement are often used for reinforcer assessment and behavioral intervention as described in the following sections.

Using Progressive Schedules for Reinforcer Assessment

Applied behavior analysts typically use a dense schedule of reinforcement (e.g., CRF) during reinforcer assessment while presenting preferred stimuli to increase or maintain existing behavior. However, Roane, Lerman, and Vorndran (2001) cautioned that "reinforcement effects obtained during typical reinforcer assessments may have limited generality to treatment efficacy when schedule thinning and other complex reinforcement arrangements are used" (p. 146). They made an important clinical point by showing that two reinforcers could be equally effective for dense schedules of reinforcement, but differentially effective when the schedule of reinforcement requires more responses per reinforcement. Progressive schedules of reinforcement provide an assessment procedure for identifying reinforcers that will maintain treatment effects across increasing schedule requirements. During the session, progressive schedules are typically thinned to the "breaking point," when the participant stops responding. Comparing the breaking points and corresponding number of responses associated with each reinforcer can identify relative reinforcement effects.

Using Progressive Schedules for Intervention

Applied behavior analysts have used progressive schedules to develop self-control (e.g., Binder, Dixon, & Ghezzi, 2000; Dixon & Cummins, 2001). For example, Dixon and Holcomb (2000) used a progressive schedule to develop cooperative work behaviors and self-control of six adults dually diagnosed with mental retardation and psychiatric disorders. The adults participated in two groups comprised of three men in Group 1 and three women in Group 2. During a natural baseline condition, the groups received instruction to exchange or share cards to complete a cooperative task of sorting playing cards into piles by categories (i.e., hearts with hearts, etc.). Dixon and Holcomb terminated a natural baseline session for the group when one of the adults quit sorting cards.

The groups received points for working on the card-sorting task during the choice baseline condition and the self-control training condition. Groups exchanged their points earned for items such as soda pop or cassette players, ranging in values from 3 points to 100 points.

During the choice baseline conditions, the group's participants could choose an immediate 3 points before doing the card sorting or a delayed 6 points after sorting the cards. Both groups chose the immediate smaller number of points rather than the larger amount following a delay to reinforcement.

During self-control training, the participants were asked while working on a cooperative task, "Do you want 3 points now, or would you like 6 points after sorting the cards for Z minutes and seconds?" (pp. 612–613). The delay was initially 0 seconds for both groups. The progressive delay to reinforcement ranged from an increase of 60 seconds to 90 seconds following each session that the group performance met the exact criterion for number of seconds of task engagement. The terminal goals for the delay to reinforcement were 490 seconds for Group 1 and 772 seconds for Group 2. Both groups achieved these delay-to-reinforcement goals. Following the introduction of the progressive delay procedure, both groups improved their cooperative work engagement and the self-control necessary to select progressively larger delays to reinforcement that resulted in more points earned. Figure 7 shows the performance of both groups of adults during natural baselines, choice baselines, and self-control training conditions.

Compound Schedules of Reinforcement

Applied behavior analysts combine the elements of continuous reinforcement (CRF), the four intermittent schedules of reinforcement (FR, VR, FI, VI), differential reinforcement of various rates of responding (DRH, DRL), and extinction (EXT) to form **compound schedules** of reinforcement. Elements from these basic schedules can occur

- successively or simultaneously;
- with or without discriminative stimuli; and
- as a reinforcement contingency for each element independently, or a contingency formed by the combination of all elements (Ferster & Skinner, 1957).

Concurrent Schedules

A **concurrent schedule (conc)** of reinforcement occurs when (a) two or more contingencies of reinforcement (b) operate independently and simultaneously (c) for two

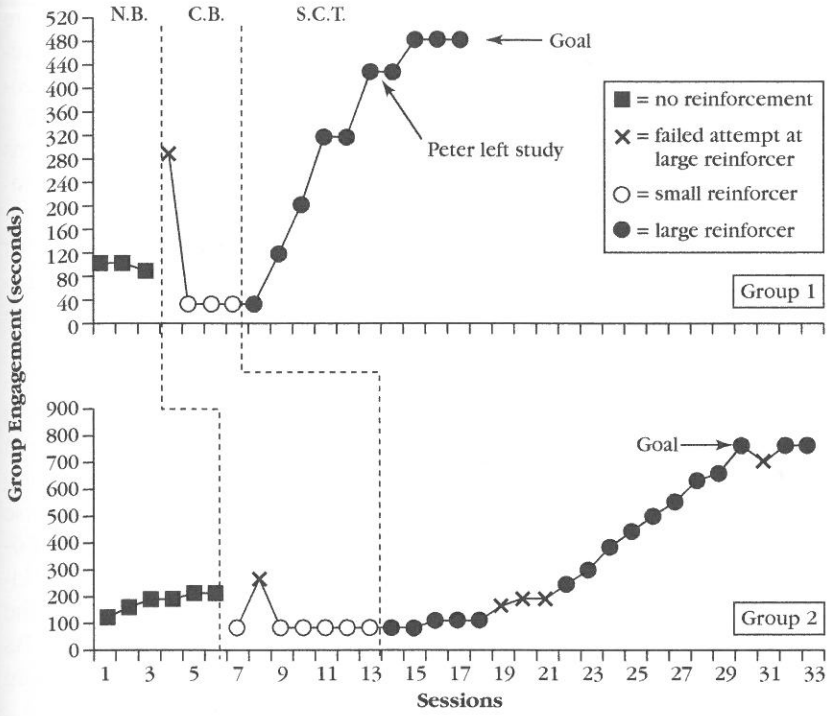


Figure 7 Number of seconds of engagement in the concurrent delay activity of cooperative card sorting during natural baseline (N.B.), choice baseline (C.B.), and self-control training (S.C.T.) for each group of participants. Filled circles represent performance at exactly the criterion level, and X data points represent the number of seconds of engagement below the criterion.

From "Teaching Self-Control to Small Groups of Dually Diagnosed Adults" by M. R. Dixon and S. Holcomb, 2000, *Journal of Applied Behavior Analysis, 33*, p. 613. Copyright 1992 by the Society for the Experimental Analysis of Behavior Inc. Reprinted by permission.

or more behaviors. People in the natural environment have opportunities for making choices among concurrently available events. For example, Sharon receives a weekly allowance from her parents contingent on doing daily homework and cello practice. After school she can choose when to do homework and when to practice the cello, and she can distribute her responses between these two simultaneously available schedules of reinforcement. Applied behavior analysts use concurrent schedules for reinforcer assessment and for behavioral interventions.

Using Concurrent Schedules for Reinforcer Assessment

Applied behavior analysts have used concurrent schedules extensively to provide choices during the assessment of consequence preferences and the assessment of response quantities (e.g., force, amplitude) and reinforcer quantities (e.g., rate, duration, immediacy, amount). Responding to concurrent schedules provides a desirable assessment procedure because (a) the participant makes choices, (b) making choices during assessment approximates the natural environment, (c) the schedule is effective in producing hypotheses about potential reinforcers operating in the participant's environment, and (d) these assessments require the participant to choose between stimuli rather than indicating a preference for a given stimulus (Adelinis, Piazza, & Goh, 2001; Neef, Bicard, & Endo, 2001; Piazza et al., 1999).

Roane, Vollmer, Ringdahl, and Marcus (1998) presented 10 items to a participant, 2 items at a time. The participant had 5 seconds to select 1 item by using a reaching response to touch the selected item. As a consequence for the selection, the participant received the item for 20 seconds. The analyst verbally prompted a response if the participant did not respond within 5 seconds, waiting another 5 seconds for the occurrence of a prompted response. Items were eliminated from the assessment (a) if they were not chosen during the first five presentations or (b) if they were chosen two or fewer times during the first seven presentations. The participant made a total of 10 choices among the remaining items. The number of selections out of the 10 opportunities served as a preference index.

Using Concurrent Schedules for Intervention

Applied behavior analysts have used concurrent schedules extensively for improving vocational, academic, and social skills in applied settings (e.g., Cuvo, Lerch, Leurquin, Gaffaney, & Poppen, 1998; Reid, Parsons, Green, & Browning, 2001; Romaniuk et al., 2002). For example, Hoch, McComas, Johnson, Faranda, and Guenther (2002) arranged two concurrent response alternatives for three boys with autism. The boys could play in one setting with a peer or sibling, or play alone in another area. Hoch and colleagues manipulated the duration of access to toys (i.e., reinforcer magnitude) and preference (i.e., reinforcer quality). In one condition, the magnitude and quality of the reinforcer was equal in both settings. In the other condition, the magnitude and quality of the reinforcer was greater for play in the setting

with a peer or sibling than in the play-alone setting. With the introduction of the condition with greater magnitude and quality of the reinforcer, the boys allocated more play responses to the setting with the peer or sibling, rather than playing alone. The magnitude and quality of the reinforcer influenced choices made by the three boys. Figure 8 reports the percentage of responses allocated to the concurrent play areas.

Concurrent Performances: Formalizing the Matching Law

Cuvo and colleagues (1998) reported that concurrent schedules typically produce two response patterns. With concurrent interval schedules (conc VI VI, conc FI FI), participants "typically do not allocate all of their responses exclusively to the richer schedule [i.e., the schedule producing the higher rate of reinforcement]; rather, they distribute their responding between the two schedules to match or approximate the proportion of reinforcement that is actually obtained on each independent schedule" (p. 43). Conversely, with concurrent ratio schedules (conc VR VR, conc FR FR), participants are sensitive to the ratio schedules and tend to maximize reinforcement by responding primarily to the ratio that produces the higher rate of reinforcement.

Williams (1973) identified three types of interactions found with concurrent schedules. First, when similar reinforcement is scheduled for each of the concurrent responses, the response receiving the higher frequency of reinforcement will increase in rate whereas a corresponding decrease will occur in the response rate of the other behavior. Second, when one response produces reinforcement and the other produces punishment, responses associated with punishment will decrease in occurrence. That decrease may produce a higher rate of response for the behavior producing reinforcement. Third, with a concurrent schedule programmed for one response to produce reinforcement and the other response to produce avoidance of an aversive stimulus, the rate of avoidance responding will accelerate with an increase in the intensity or the frequency of the aversive stimulus. As avoidance responding accelerates, typically responding on the reinforcement schedule will then decrease.

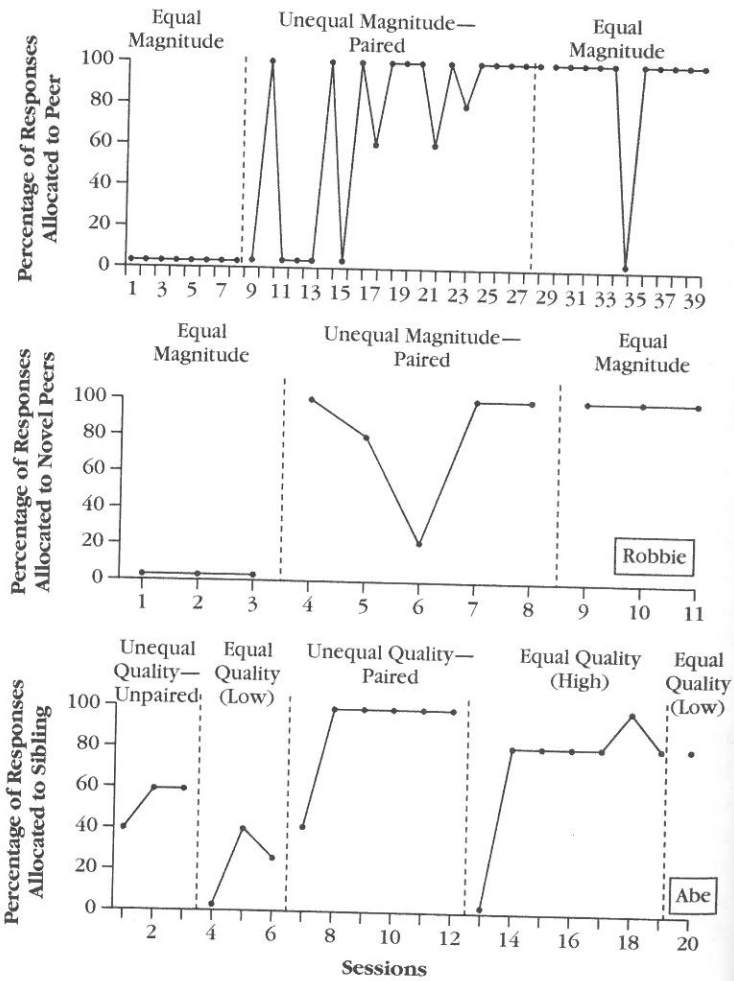


Figure 8 Percentage of responses allocated to the play area with the peer across experimental sessions (top panel) and in natural-setting probes with different peers in the classroom (middle panel) for the analysis of magnitude of reinforcement with Robbie, and the percentage of responses allocated to the play area with the sibling across experimental sessions for the analysis of quality of reinforcement with Abe (bottom panel).

From "The Effects of Magnitude and Quality of Reinforcement on Choice Responding During Play Activities" by H. Hoch, J. J. McComas, L. Johnson, N. Faranda, and S. L. Guenther, 2002, *Journal of Applied Behavior Analysis, 35*, p. 177. Copyright 1992 by the Society for the Experimental Analysis of Behavior Inc. Reprinted by permission.

The characteristics of performance on concurrent schedules as detailed previously by Cuvo and colleagues and Williams are consistent with the relationships formalized by Herrnstein (1961, 1970) as the **matching law.** The matching law addresses response allocation to choices available with concurrent schedules of reinforcement. Basically, the rate of responding typically is proportional to the rate of reinforcement received from each choice alternative.

Discriminative Schedules of Reinforcement

Multiple Schedules

A **multiple schedule (mult)** presents two or more basic schedules of reinforcement in an alternating, usually random, sequence. The basic schedules within the multiple schedule occur successively and independently. A discriminative stimulus is correlated with each basic schedule, and that stimulus is present as long as the schedule is in effect.

Academic behaviors can become sensitive to the control of multiple schedules of reinforcement. A student might respond to basic arithmetic facts with her teacher, and also with her tutor. With the teacher, the student responds to arithmetic facts during small-group instruction. The tutor then provides individual instruction and practice on the facts. This situation follows a multiple schedule because there is one class of behavior (i.e., math facts), a discriminative stimulus for each contingency in effect (i.e., teacher/tutor, small group/individual), and different conditions for reinforcement (i.e., reinforcement is less frequent in group instruction). In another everyday example of the multiple schedule, Jim helps his mother and father clean house on Friday afternoons and Saturday mornings. Jim cleans his grandmother's bedroom and bathroom on Friday afternoons and the family room and downstairs bathroom on Saturday mornings. Jim receives $5 per week for cleaning his grandmother's rooms but does not receive money for cleaning the family room or downstairs bathroom. Again, there is one class of behaviors of interest (i.e., cleaning the house), a cue for each contingency in effect (i.e., grandmother's rooms on Fridays or other rooms on Saturdays), and different schedules of reinforcement associated with the different cues (i.e., $5 for grandmother's rooms and no money for the other rooms).

Chained Schedules

A **chained schedule (chain)** is similar to a multiple schedule. The multiple and chained schedules have two or more basic schedule requirements that occur successively, and have a discriminative stimulus correlated with each independent schedule. A chained schedule differs from a multiple schedule in three ways. First, the basic schedules in a chain schedule always occur in a specific order, never in the random or unpredictable order of multiple schedules. Second, the behavior may be the same for all elements of the chain, or different behaviors may be required for different elements in the chain. Third, conditioned reinforcement for responding in the first element in a chain is the presentation of the second element; conditioned reinforcement for responding in the second element is presentation of the third element, and so on until all elements in the chain have been completed in a specific sequence. The last element normally produces unconditioned reinforcement in a laboratory setting, or unconditioned or conditioned reinforcement in applied settings.

The following example shows an elaborate sequence of different behaviors that must occur in a specific order. To service a bicycle headset, the mechanic will complete a chain with 13 components: (1) Disconnect the front brake cable; (2) remove handlebar and stem; (3) remove front wheel; (4) remove locknut; (5) unscrew adjusting race; (6) take fork out of frame; (7) inspect races; (8) grease and replace bearing balls for lower stack; (9) grease and replace bearing balls for upper race; (10) grease threads of steering column; (11) put fork into frame and thread the screwed race; (12) return lock washer; (13) adjust and lock the headset. The final outcome (i.e., a clean, greased, and adjusted bicycle headset) is contingent on the completion of all 13 components.

Nondiscriminative Schedules of Reinforcement

Mixed Schedules

The **mixed schedule (mix)** uses a procedure identical to the multiple schedules, except the mixed schedule has no discriminative stimuli correlated with the independent schedules. For example, with a mix FR 10 FI 1 schedule, reinforcement sometimes occurs after the completion of 10 responses and sometimes occurs with the first correct response after a 1-minute interval from the preceding reinforcement.

Tandem Schedules

The **tandem schedule (tand)** uses a procedure identical to the chained schedule, except, like the mix schedule, the tandem schedule does not use discriminative stimuli with

the elements in the chain. After a participant makes 15 responses on a tand FR 15 FI 2, then the first correct response following an elapse of 2 minutes produces reinforcement.

Antecedent stimuli appear to relate functionally to most occurrences of behaviors in natural environments. Perhaps, therefore, the mixed and tandem schedules have little applied application at this time. However, basic research has produced considerable data concerning the effects of mixed and tandem schedules on behavior. It may become more apparent how applied behavior analysts can effectively apply mixed and tandem schedules in assessment, intervention, and analysis as the knowledge base of applied behavior analysis continues to develop.

Schedules Combining the Number of Responses and Time

Alternative Schedules

An **alternative schedule (alt)** provides reinforcement whenever the requirement of either a ratio schedule or an interval schedule—the basic schedules that comprise the alt—is met, regardless of which of the component schedule's requirements is met first. With an alt FR 50 FI 5-minute schedule, reinforcement is delivered whenever either of these two conditions has been met: (a) 50 correct responses, provided the 5-minute interval of time has not elapsed; or (b) the first response after the elapse of 5 minutes, provided that fewer than 50 responses have been emitted.

For instance, a teacher using an alt FR 25 FI 3-minute schedule of reinforcement assigns 25 math problems and assesses the student's correct and incorrect answers following the elapse of 3 minutes. If the student completes the 25 problems before the elapse of 3 minutes, the teacher checks the student's answers and provides a consequence consistent with the FR 25 schedule. However, if the ratio requirement of 25 math problems has not been completed after an elapse of 3 minutes, the first correct answer following the 3 minutes produces reinforcement. The alternative schedule offers the advantage of a second chance for reinforcement if the student has not met the FR requirement in a reasonable amount of time. The FI provides reinforcement for one response, and that one reinforced response might encourage continued responding with the new start of the FR requirement.

Conjunctive Schedules

A **conjunctive schedule (conj)** of reinforcement is in effect whenever reinforcement follows the completion of response requirements for both a ratio schedule and an interval schedule of reinforcement. For example, a student behavior produces reinforcement when at least 2 minutes have elapsed and 50 responses have been made. This arrangement is a conj FI 2 FR 50 schedule of reinforcement. With the conjunctive schedule of reinforcement, the first response following the conclusion of the time interval produces reinforcement if the criterion number of responses has been completed.

A 14-year-old boy with autism had higher rates of aggression with two of his four therapists during instruction. The higher rates of aggression were directed toward the two therapists who previously worked with the boy at a different treatment facility. Progar and colleagues (2001) intervened to reduce the levels of aggression with the therapists from the different facility to the levels that occurred with the other two therapists in the current setting. The boy's aggression occurred in demand situations (e.g., making his bed) and was escape maintained. The initial intervention used three consequences: (1) a 10-minute chair time-out for attempts to choke, (2) escape extinction, and (3) differential-reinforcement-other-behavior for the omission of aggression during the 10-minute sessions. This intervention was identical to the treatment used with the boy at the other facility. It was ineffective in reducing the boy's aggression in the current setting.

Because of the ineffectiveness of the initial intervention, Progar and colleagues added a conj FR VI-DRO schedule of reinforcement to their initial intervention. They delivered edible reinforcers contingent on completing a three-component task such as dusting or straightening objects (i.e., an FR 3 schedule) and the omission of aggression for an average of every 2.5 minutes (i.e., the VI-DRO 150-second). An occurrence of aggression reset the conj schedule. (*Note:* Resetting this conj schedule used a standard procedure because any occurrence of the problem behavior during a DRO interval immediately resets the time to the beginning of the interval.) Progar and colleagues demonstrated that the conj FR VI-DRO schedule produced a substantial reduction in aggression directed toward the two therapists previously from the other treatment facility.

Duvinsky and Poppen (1982) found that human performance on a conjunctive schedule is influenced by the ratio and interval requirements. When task requirements are high in relationship to the interval requirements, people are likely to work steadily on the task throughout the time available. However, people are likely to engage in behaviors other than the task requirements when there is a large time interval and a low ratio requirement.

Table 1 provides a summary of the characteristics of compound schedules of reinforcement.

Table 1 Summary and Comparison of Basic Dimensions Defining Compound Schedules of Reinforcement

	Compound Schedule Name						
Dimension	*Concurrent*	*Multiple*	*Chained*	*Mixed*	*Tandem*	*Alternative*	*Conjunctive*
Number of basic schedules of reinforcement in effect	2 or more	2 or more	2 or more	2 or more	2 or more	2 or more	2 or more
Number of response classes involved	2 or more	1	1 or more	1	1 or more	1	1
Discriminative stimuli or cues associated with each component schedule	Possible	Yes	Yes	No	No	Possible	Possible
Successive presentation of basic schedules	No	Yes	Yes	Yes	Yes	No	No
Simultaneous presentation of basic schedules	Yes	No	No	No	No	Yes	Yes
Reinforcement limited to final component of basic schedule	No	No	Yes	No	Yes	No	Yes
Reinforcement for independent components of basic schedule	Yes	Yes	No	Yes	No	Yes	No

Perspectives on Applying Schedules of Reinforcement in Applied Settings

Applied Research with Intermittent Schedules

Basic researchers have systematically analyzed the effects of intermittent schedules of reinforcement on the performance of organisms (e.g., Ferster & Skinner, 1957). Their results have produced well-established schedule effects. These schedule effects have strong generality across many species, response classes, and laboratories. However, a review of the applied literature on schedule effects (e.g., *Journal of Applied Behavior Analysis,* 1968 to 2006) will show that applied behavior analysts have not embraced the analysis of schedule effects with enthusiasm, as have basic researchers. Consequently, schedule effects have not been documented clearly in applied settings. Uncontrolled variables in applied settings, such as the following, influence a participant's sensitivity and insensitivity to the schedule of reinforcement:

1. Instructions given by the applied behavior analyst, self-instructions, and environmental aids (e.g., calendars, clocks) make human participants resistant to temporal schedule control.
2. Past histories of responding to intermittent schedules of reinforcement can affect current schedule sensitivity or insensitivity.
3. Immediate histories from schedules of reinforcement may affect current schedule performances more than remote past histories.
4. Sequential responses required in many applied applications of intermittent schedules of reinforcement (e.g., work leading to the paycheck, studying for a pop quiz) are uncommon applications of schedules of reinforcement, particularly with interval schedules.
5. Uncontrolled establishing operations in conjunction with schedules of reinforcement in applied settings will confound schedule effects.

Some well-established schedule effects found in basic research were presented earlier in this chapter. Applied behavior analysts, however, should use caution in extrapolating these effects to applied settings, for the following reasons:

1. Most applied applications of schedules of reinforcement only approximate true laboratory schedules of reinforcement, especially the interval schedules that may occur rarely in natural environments (Nevin, 1998).
2. Many uncontrolled variables in applied settings will influence a participant's sensitivity and insensitivity to the schedule of reinforcement (Madden, Chase, & Joyce, 1998).

Applied Research with Compound Schedules

Applied researchers have seldom analyzed the effects of compound reinforcement schedules, with the notable exceptions of concurrent schedules and, to a lesser degree, chained schedules. Applied researchers should include the analysis of compound schedules in their research agendas. A better understanding of the effects of compound schedules on behavior will advance the development of applied behavior analysis and its applications. This perspective is important because compound schedules of reinforcement act directly on human behavior, and they influence behavior also by interacting with other environmental variables (e.g., antecedent stimuli, motivating operations) (Lattal & Neef, 1996).

Applied Research with Adjunctive Behavior

This chapter has stressed the effects of schedules of reinforcement on the specific behaviors that produce reinforcement. Other behaviors can occur when an individual responds to a given contingency of reinforcement. These other behaviors occur independently of schedule control. Typical examples of such behaviors include normal time fillers, such as doodling, smoking, idle talking, drinking. Such behaviors are called **adjunctive behaviors,** or schedule-induced behaviors, when the frequency of these time-filling behaviors increases as a side effect of other behaviors maintained by a schedule of reinforcement (Falk, 1961, 1971).

A substantial body of experimental literature has developed on many types of adjunctive behaviors with nonhuman subjects (see reviews, Staddon, 1977; Wetherington, 1982) and some basic research with human subjects (e.g., Kachanoff, Leveille, McLelland, & Wayner 1973; Lasiter, 1979). Common diverse examples of adjunctive behaviors observed in laboratory experiments include aggression, defecation, pica, and wheel running. Some common excessive human problem behaviors might develop as adjunctive behaviors (e.g., the use of drugs, tobacco, caffeine, and alcohol; overeating; nail biting; self-stimulation; and self-abuse). These potentially excessive adjunctive behaviors are socially significant, but the possibility that such excesses are developed and maintained as adjunctive behaviors has been essentially ignored in applied behavior analysis.

Foster (1978), in an extended communication to the readership of the *Journal of Applied Behavior Analysis,* reported that applied behavior analysts have neglected the potentially important area of adjunctive behavior. He stated that applied behavior analysis does not have a data or knowledge base for adjunctive phenomena. Similarly, Epling and Pierce (1983) called for applied behavior analysts to extend the laboratory-based findings in adjunctive behavior to the understanding and control of socially significant human behavior. To our knowledge, Lerman, Iwata, Zarcone, and Ringdahl's (1994) article provides the only research on adjunctive behavior published in the *Journal of Applied Behavior Analysis* from 1968 through 2006. Lerman and colleagues provided an assessment of stereotypic and self-injurious behavior as adjunctive responses. Data from this preliminary study suggest that intermittent reinforcement did not induce self-injury, but with some individuals, stereotypic behavior showed characteristics of adjunctive behavior.

Foster (1978) and Epling and Pierce (1983) cautioned that many teachers and therapists may apply interventions directly to adjunctive behaviors rather than to the variables functionally related to their occurrence. These direct interventions may be futile and costly in terms of money, time, and effort because adjunctive behaviors appear resistant to interventions using operant contingencies.

The condition under which adjunctive behaviors are developed and maintained is a major area for future research in applied behavior analysis. Applied research directed to adjunctive behaviors will advance the science of applied behavior analysis and will provide an important foundation for improved practices in therapy and instruction.

Summary

Intermittent Reinforcement

1. A schedule of reinforcement is a rule that establishes the probability that a specific occurrence of a behavior will produce reinforcement.
2. Only selected occurrences of behavior produce reinforcement with an intermittent schedule of reinforcement.
3. Applied behavior analysts use continuous reinforcement during the initial stages of learning and for strengthening behavior.
4. Applied behavior analysts use intermittent reinforcement to maintain behavior.

Defining Basic Intermittent Schedules of Reinforcement

5. A fixed ratio schedule requires a specified number of responses before a response produces reinforcement.
6. A variable ratio requires a variable number of responses before reinforcement is delivered.
7. A fixed interval schedule provides reinforcement for the first response following the elapse of a specific, constant duration of time since the last reinforced response.
8. A variable interval schedule provides reinforcement for the first response following the elapse of variable duration of time since the last reinforced response.
9. When a limited hold is added to an interval schedule, reinforcement remains available for a finite time following the elapse of the FI or VI interval.
10. Each basic schedule of reinforcement has unique response characteristics that determine the consistency of responding, the rate of responding, and performance during extinction.

Thinning Intermittent Reinforcement

11. Applied behavior analysts often use one of two procedures to thin schedules of reinforcement. An existing schedule is thinned by gradually increasing the response ratio or by gradually increasing the duration of the time interval.
12. Applied behavior analysts should use small increments of schedule changes during thinning and ongoing evaluation of the learner's performance to adjust the thinning process and avoid the loss of previous improvements.
13. Ratio strain can result from abrupt increases in ratio requirements when moving from denser to thinner reinforcement schedules.

Variations on Basic Intermittent Schedules of Reinforcement

14. DRH and DRL are variations of ratio schedules and specify that reinforcement will be delivered contingent on responses occurring above or below criterion response rates.
15. The differential reinforcement of diminishing rates schedule provides reinforcement at the end of a predetermined time interval when the number of responses is below a criterion. The criterion for the number of responses is gradually decreased across time intervals based on the individual's performance.
16. Progressive schedules of reinforcement systematically thin each successive reinforcement opportunity independent of the participant's behavior.

Compound Schedules of Reinforcement

17. Continuous reinforcement, the four simple intermittent schedules of reinforcement, differential reinforcement of rates of responding, and extinction, when combined, produce compound schedules of reinforcement.
18. Compound schedules of reinforcement include concurrent, multiple, chained, mixed, tandem, alternative, and conjunctive schedules.

Perspectives on Applying Schedules of Reinforcement in Applied Settings

19. Some well-established schedule effects found in basic research were presented in this chapter. Applied behavior analysts, however, should use caution in extrapolating these effects to applied settings.
20. Applied researchers should include an analysis of the basic intermittent schedules and the compound schedules in their research agendas. A better understanding of the schedule effects in applied settings will advance the development of applied behavior analysis and its applications.
21. The conditions under which adjunctive behaviors are developed and maintained is an important area for future research in applied behavior analysis.