8

Schedules of Reinforcement

Did you know that

- schedules of reinforcement determine rates and patterns of responding?
- ratio schedules produce higher rates of responding than interval schedules?
- interval schedules do not provide the reinforcer automatically after the passage of a particular time interval?
- schedule effects are related to the feedback function that characterizes each schedule of reinforcement?
- some schedules of reinforcement focus on choice and provide reinforcement for two (or more) response alternatives?
- the generalized matching law describes choice behavior in a wide range of situations? According to the matching law, relative rates of responding equal relative rates of reinforcement.
- self-control is investigated using concurrent-chain schedules of reinforcement?
- the value of a reward declines as a function of how long you have to wait for it, but individuals differ in how rapidly reward value declines, and this psychological variable predicts measures of health and success in various aspects of life?

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In Chapter 7, we described examples of various forms of instrumental conditioning with the implication that the reinforcing outcome is delivered each time the required instrumental response occurs. Situations in common experience come close to this ideal if there is a direct causal link between an instrumental response and the reinforcer. Nearly every time you turn on the faucet, you get running water; most of the time you send a text message to a friend, it is delivered; and most of the time you buy an attractive piece of pastry, you enjoy eating it. However, even in these cases, the relation between making the response and getting the reinforcer is not perfect. The water main to your house may break, the phone may malfunction, and the pastry may be stale. In many instrumental conditioning situations, not every occurrence of the instrumental response is successful in producing the reinforcer.

Whether a particular occurrence of the instrumental response results in the reinforcer can depend on a variety of factors. Sometimes the response has to be repeated a number of times before the reinforcer is delivered. In other situations, a certain amount of time has to pass before the response is reinforced. In yet other cases, both response repetition and the passage of time are critical. The rule that specifies which occurrence of the instrumental response is reinforced is called a **schedule of reinforcement**.

Schedules of reinforcement have been of great interest because they determine many aspects of instrumental behavior (Ferster & Skinner, 1957; Jozefowiez & Staddon, 2008). Schedules of reinforcement determine the rate and pattern of responding as well as persistence of the response in extinction—features of behavior that are of critical importance in applied behavior analysis. As we noted in Chapter 7, schedules of reinforcement also determine whether responding will be sensitive to devaluation of the reinforcer (Garr et al., 2020; Perez & Dickinson, 2020). Seemingly trivial changes in a reinforcement schedule can produce profound changes in how frequently an individual responds and when they engage in one activity rather than another. One might assume that increasing the magnitude of the reinforcer (e.g., paying someone more for completing a job) will inevitably increase the vigor or rate of responding; however, the schedule of reinforcement is often more important than the magnitude of reinforcement.

Because schedules of reinforcement were first studied in laboratory experiments with rats and pigeons, they may seem abstract and of little relevance to our daily experience. Nothing could be further from the truth. In fact, contemporary society might be called the golden era of schedules of reinforcement. Setting up a schedule of reinforcement requires carefully monitoring someone's behavior. Because many of our activities these days involve interactions with the digital world, behavioral monitoring is now routine. This makes it easy for employers to link wages closely to employee performance and designers of video games to schedule reinforcers based on how a player interacts with the game. Ever wonder why children can spend hours captivated by something on a tablet or why you feel compelled to check your smartphone frequently for messages? It is all about schedules of reinforcement.

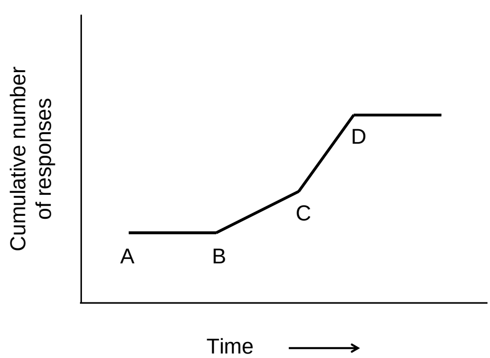
THE CUMULATIVE RECORD

The rate and pattern of responding produced by various schedules of reinforcement are typically investigated using free-operant procedures. Computers are programmed to record occurrences of the operant response (e.g., lever pressing in rats), as well as to determine which lever press is reinforced. Experimental sessions last about an hour each day, and in most experiments, numerous sessions are provided. After extensive experience with a particular schedule of reinforcement, the rate and pattern of responding stabilizes. The stable pattern of responding is conveniently represented in terms of a cumulative record.

A **cumulative record** is a special kind of graph in which the horizontal axis shows the passage of time, and the vertical axis represents the total or cumulative number of responses that have occurred up to a particular point in time (see Figure 8.1). If the participant does not respond for a while, its total or cumulative number of responses stays the same. This results in a flat line on the cumulative record, as between Points A and B in Figure 8.1. Each time the participant responds, the cumulative record goes up a notch. Because responses cannot be taken away, the cumulative record never goes down.

The slope of the cumulative record has special significance. Slope is calculated by dividing the vertical displacement between two points on a graph by the horizontal displacement between those two points. Vertical displacement on a cumulative record reflects number of responses, and horizontal displacement reflects time. Thus, the slope of a cumulative record represents responses per unit of time, or the *response rate*. Low rates of responding produce a shallow slope on the cumulative record (e.g., from Point B to Point C in Figure 8.1). Higher response rates result in a steeper slope (e.g., from Point C to Point D in Figure 8.1).

FIGURE 8.1. Cumulative Record Used to Represent Patterns of Responding Over Time



Note. There is no responding between Points A and B. A low rate of responding occurs between Points B and C. A higher response rate occurs from Points C and D, and responding ceases after Point D.

SIMPLE SCHEDULES OF REINFORCEMENT

In simple schedules of reinforcement, which occurrence of the response is reinforced depends either on the number of repetitions of the response since the last reinforcer or on how much time has passed since the last reinforcer. If the number of repetitions of the response is the critical factor determining reinforcement, the procedure is called a **ratio schedule**. If the timing of the response since the last reinforcer is the critical factor, the procedure is called an **interval schedule**. In either case, the participant does not receive the reinforcer unless it responds.

Ratio Schedules

In ratio schedules, the only thing that determines whether a response is reinforced is the number of repetitions of the response the participant has performed since the last reinforcer. How much time the participant takes to make those responses does not matter. There are two basic versions of ratio schedules, fixed and variable.

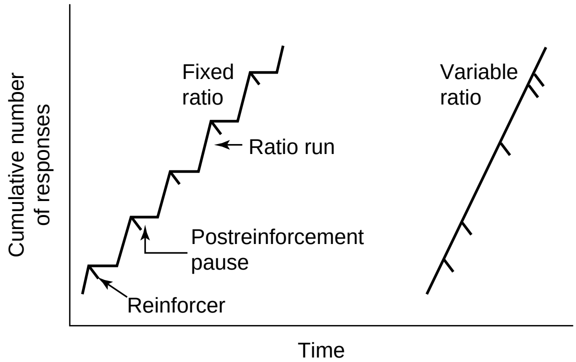
In a **fixed-ratio schedule**, the participant must repeat the response a fixed number of times for each delivery of the reinforcer. For example, each worksheet in a third-grade math class may have four problems on it, and students may receive a star for each worksheet they complete. This would be a fixed-ratio 4 schedule of reinforcement, abbreviated as FR 4.

Fixed-ratio schedules occur in situations where there is always a fixed amount of effort required to complete a job or obtain the reinforcer. Unlocking your laptop takes the same number of steps each time you do it. Calling someone on the phone requires putting the same number of digits into the phone each time. Walking up a flight of stairs requires going up the same number of stairs each time. Brushing your teeth each day requires cleaning the same number of teeth each time. All of these are examples of fixed-ratio schedules.

The left side of Figure 8.2 illustrates the stable pattern of responding that results from reinforcing behavior on a fixed-ratio schedule of reinforcement. These data were obtained in an experiment with a pigeon that had to peck 120 times for access to grain. Once the pigeon made 120 pecks and got the food, the counter started over again for the next reinforcer. The diagonal hatch marks in the records show the delivery of the reinforcer. Two features of the fixed-ratio response pattern are noteworthy. First, notice that after each hatch mark or reinforcer, the response rate is zero. The pigeon stops responding for a while. This pause in responding after the delivery of the reinforcer or at the start of a trial is called the **postreinforcement pause**. After the postreinforcement pause, a steady and high rate of responding occurs until the next delivery of the reinforcer. This rate is called the **ratio run**.

As illustrated in Figure 8.2, fixed-ratio schedules produce a break-run pattern. Either the participant does not respond at all (in the postreinforcement pause), or it responds at a steady and high rate (in the ratio run). The duration

FIGURE 8.2. Typical Results of Training on a Fixed-Ratio (FR) and Variable-Ratio (VR) Schedule of Reinforcement



Note. The data were obtained with pigeons pecking a response key on an FR 120 and VR 360 schedule of food reinforcement. The hatch marks indicate when the reinforcer was delivered. Based on Ferster and Skinner (1957).

of the postreinforcement pause is determined by the ratio requirement. Higher ratio requirements result in longer postreinforcement pauses (D. C. Williams et al., 2011).

A **variable-ratio schedule** is similar to a fixed-ratio schedule in that the only requirement for reinforcement is making a certain number of responses, irrespective of how long it takes to do that. The difference is that in a variable-ratio schedule, the number of responses required varies from one reinforcer delivery to the next.

When putting in golf, for example, reinforcement is provided by the ball going into the cup. On occasion, you may get the ball into the cup on the first try. More often, you will have to hit the ball several times before you succeed. Whether the ball goes into the cup depends only on your hitting the ball with the putter. How long you take between swings is irrelevant. The fact that time is irrelevant makes this a ratio schedule. But the number of putting responses required varies from one putting green to another, making it a variable-ratio schedule.

A variable-ratio schedule is abbreviated as VR. If on average you need to hit the ball three times to get it into the cup, you would be on a VR 3 schedule of reinforcement. The typical result of a variable-ratio schedule is illustrated in the right panel of Figure 8.2. Unlike fixed-ratio schedules, variable-ratio schedules produce a steady and high rate of responding, without predictable pauses (Crossman et al., 1987). Variable-ratio schedules are probably more common than fixed ratios. Doing laundry is a ratio task, but the number of responses required varies from one occasion to the next depending on the number of soiled clothes you have to wash. Completing a reading assignment requires reading a certain number of pages, but the number of pages may vary from one assignment to the next. Playing a song on a guitar requires playing a certain number of notes, but some songs have more notes than others. Placing bets or gambling is a classic example of a variable-ratio schedule. You have to place a bet to win, but the chance of winning is highly unpredictable.

Interval Schedules

Unlike ratio schedules, where the passage of time is irrelevant, in interval schedules, time is a critical factor. Specifically, whether a response is reinforced depends on when the response occurs after the start of the interval cycle. As with ratio schedules, there are two prominent types of interval schedules, fixed and variable.

In a **fixed-interval schedule**, a fixed amount of time must pass before a response can be reinforced. Fixed-interval schedules occur in situations in which it takes a certain amount of time for the reinforcer to be prepared or set up. Consider, for example, making a gelatin dessert (Jell-O, for example). After the ingredients are mixed, the Jell-O has to be cooled in the refrigerator for a certain amount of time before it is ready to eat. In this example, the instrumental response is taking the Jell-O out of the refrigerator to eat. If you take the Jell-O out too early, it will be watery, and you won't enjoy it. Attempts to eat the Jell-O before it solidifies will not be reinforced. Another important feature of this example (and of interval schedules generally) is that once the reinforcer is ready, it remains available until the individual responds to obtain it. When the Jell-O is done, you don't have to eat it right away. It will be there for you even if you wait to eat it the next day.

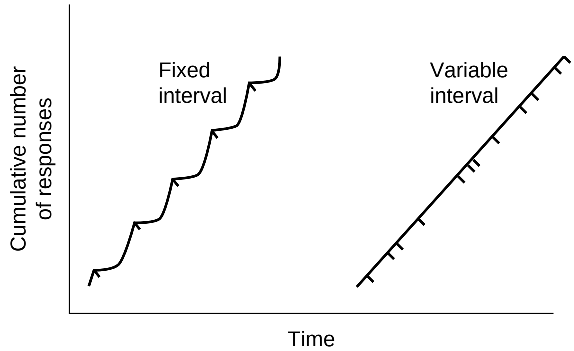
In a fixed-interval schedule of reinforcement, a fixed amount of time has to pass before the reinforcer becomes available. However, the reinforcer is not provided automatically at the end of the fixed interval. To obtain the reinforcer, the specified instrumental response must still be made. Early responses have no consequence. They do not get you the reinforcer sooner, nor do they result in a penalty. Finally, the reinforcer can be obtained at any time after it has been set up. In a simple interval schedule, the participant does not have to respond within a set period once the reinforcer has become available.

Digital newspapers arrive in one's email about the same time each day. Scanning your email to see if the newspaper has arrived is an operant response reinforced on a fixed-interval schedule of 24 hours. Checking your inbox frequently will not get you the paper sooner. On the other hand, you don't have to open your digital newspaper as soon as it arrives in your inbox. You can wait a few hours or even a day or two to read the paper.

Fixed-interval schedules are abbreviated FI, followed by a number indicating the duration of the fixed interval during which responding is not reinforced. Figure 8.3 shows data obtained from a pigeon pecking a response key on a free-operant FI 4-min schedule of food reinforcement. On this schedule, delivery of the reinforcer at the end of one fixed interval starts the next cycle. Four minutes after the start of the cycle, the reinforcer becomes available again and is delivered if the pigeon pecks the response key.

Fixed-interval schedules produce what has been called a scallop pattern of responding. There is no responding at the beginning of the interval because the chance of getting reinforced then is zero. Because the fixed interval begins just after delivery of the previous reinforcer, the lack of responding at the beginning of the interval is called a postreinforcement pause. Responding

FIGURE 8.3. Typical Results of Training on a Fixed-Interval (FI) and Variable-Interval (VI) Schedule of Reinforcement



Note. The data were obtained with pigeons pecking a response key on an FI 4-min and VI 2-min schedule of food reinforcement. The hatch marks indicate when the reinforcer was delivered. Based on Ferster and Skinner (1957).

then increases gradually as the end of the interval gets closer, with the participant responding at a high rate just as the fixed interval ends. Efficient responding on a fixed interval schedule requires accuracy in time perception. For that reason, fixed interval schedules are frequently used to study the cognitive mechanisms involved in timing (Balci et al., 2009; Galtress et al., 2012; Machado, 1997).

The studying behavior of college students is often similar to the scallop pattern of a fixed-interval schedule. Consider a course in which tests are scheduled every 3 weeks during the semester. Students are not likely to study after they have just taken a test. They may start looking at the class material a week before the next test, but the most vigorous studying occurs the night before the test.

Variable-interval schedules are similar to fixed-interval schedules except that the amount of time it takes to set up the reinforcer varies from trial to trial. The response of checking to see if a teacher has finished grading your paper is reinforced on a variable-interval schedule. It takes some time to grade a paper, but how long it takes varies from one occasion to the next. Checking to see if your paper has been graded is reinforced only after some time has passed since the start of the schedule cycle. Early responses (checking before the paper has been graded) are not reinforced. In contrast, you can get your grade any time after the paper has been graded.

Variable-interval schedules are abbreviated VI, followed by a number indicating the average duration of the intervals during which responding is not reinforced. Figure 8.3 shows data obtained from a pigeon pecking a response key on a free-operant VI 2-min schedule of food reinforcement. On this schedule, the reinforcer became available on average 2 minutes after the start of each schedule cycle.

Responding on variable-interval schedules is similar to responding on VR schedules of reinforcement. In both cases, a steady rate of behavior occurs, with no predictable pauses or changes in rate. This probably reflects the fact that on VI and VR schedules, the very next response is sometimes reinforced soon after the previous reinforcer was obtained. This does not occur on fixed-interval and fixed-ratio schedules. Interval schedules tend to produce lower rates of responding than ratio schedules.

In simple interval schedules, once the reinforcer has become available, it remains there until the individual responds and obtains it. The cycle then starts over again. Checking your text messages, for example, is on a variable-interval schedule. Messages arrive at unpredictable times. Checking to see if you have any new messages does not get you a message sooner or produce more messages. In addition, once a message has been delivered, you don't have to read it right away. It will remain available even if you wait several hours to read it.

Simple interval schedules can be modified so that once the reinforcer has been set up, it remains available only for a limited period of time. This limited interval is formally called a *limited hold.* For example, it takes a certain amount of time to bake a pan of cookies. Once the required time has passed, however, if you don't take the cookies out of the oven, they will burn. Thus, baking is on a fixed-interval schedule with a limited hold. The reinforcer is "held" for a limited period of time after it becomes available, and the response must occur during this hold period to be reinforced. Adding a limited hold to an interval schedule increases the rate of responding, provided the hold is not so short that the participant frequently misses the reinforcer altogether.

MECHANISMS OF SCHEDULE PERFORMANCE

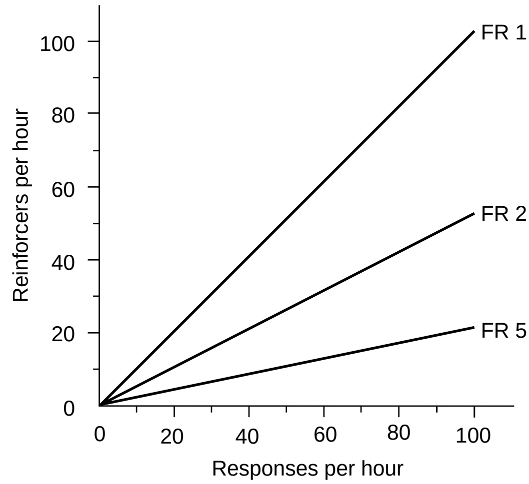
Delivery of a reinforcer in an instrumental procedure can be viewed as feedback for the instrumental response. Schedules of reinforcement determine how this feedback is arranged. One way to describe the arrangement is to consider how the rate of reinforcement obtained is related to the rate of responding. This relationship between rates of responding and rates of reinforcement allowed by a particular reinforcement is the **feedback function**.

Feedback Functions for Ratio Schedules

Feedback functions for ratio schedules are perhaps the easiest to understand. In a ratio schedule, how soon (and how often) the organism gets reinforced is determined only by how rapidly the required number of responses is performed. The more frequently individuals complete the ratio requirement, the more frequently they obtain the reinforcer.

Figure 8.4 shows examples of feedback functions for several ratio schedules. On an FR 1 or continuous-reinforcement schedule, the participant is reinforced for each occurrence of the instrumental response. Therefore, the rate of reinforcement is equal to the rate of responding. This results in a feedback function with a slope of 1.0.

FIGURE 8.4. Feedback Functions for Ratio Schedules of Reinforcement



Note. Notice that each feedback function is a straight line. Because of this, every increase in the response rate results in a corresponding increase in the rate of reinforcement.

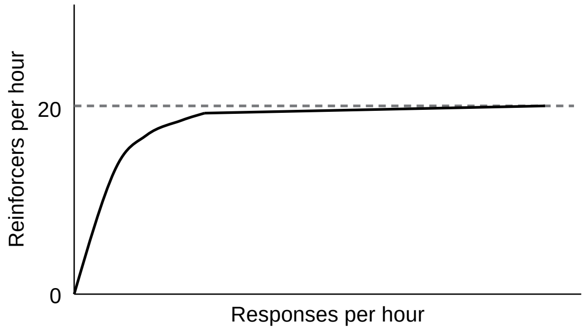
If more than one response is required for reinforcement, the rate of reinforcement will be less than the rate of responding, and the slope of the feedback function will be less than 1.0. For example, on an FR 5 schedule of reinforcement, the participant receives one reinforcer for every fifth response. Under these circumstances, the rate of reinforcement is one fifth the rate of responding, and the slope of the feedback function is 0.2. However, regardless of its slope, the feedback function for a ratio schedule is always a straight line. For this reason, on ratio schedules an increase in the rate of responding always yields an increase in the rate of reinforcement. This is true for both fixed- and variable-ratio schedules.

Feedback Functions for Interval Schedules

Interval schedules have feedback functions that differ markedly from those of ratio schedules. Figure 8.5 shows the feedback function for a VI 3-minute schedule of reinforcement. On such a schedule, the reinforcer becomes available, on average, 3 minutes after the last time it was delivered. Therefore, no matter how often or how rapidly participants respond, the maximum number of reinforcers they can obtain is limited to 20 per hour.

As with ratio schedules, if you do not make any responses on an interval schedule, you will not obtain any reinforcers. Increases in the rate of responding above zero will increase the chances of getting whatever reinforcers become available. Up to a point, therefore, increased responding is accompanied by higher rates of reinforcement. However, once the participant responds often enough to get all 20 reinforcers that can be obtained each hour, any further increase in response rate will have no further benefit. Thus, the feedback

FIGURE 8.5. Feedback Function for a Variable-Interval 3-Minute Schedule of Reinforcement



Note. No matter how rapidly the individual responds, they cannot obtain more than 20 reinforcers per hour. (Responding is assumed to be randomly distributed in time.)

function for an interval schedule becomes flat once the maximum possible reinforcement rate has been achieved.

Feedback Functions and Schedule Performance

One of the striking facts about instrumental behavior is that ratio schedules produce considerably higher rates of responding than interval schedules, even if the rate of reinforcement is comparable in the two situations (e.g., Perez, 2021; Raia et al., 2000). Why is this? The answer has to do with differences in the feedback functions for ratio and interval schedules. Because the feedback function for a ratio schedule is a straight line, increases in the rate of responding always result in higher rates of reinforcement. Another way to think about this is that reducing the time between responses (the interresponse time, or IRT) results in higher rates of reinforcement. Thus, ratio schedules differentially reinforce shorter IRTs. This makes ratio schedules highly stressful. You feel like you are never going fast enough because responding faster will always yield a greater payoff.

Interval schedules work differently. Because the feedback function for an interval schedule quickly reaches a limit, increases in the response rate beyond that point provide no additional benefit. Thus, increases in response rate are not differentially reinforced on interval schedules. In fact, just the opposite is the case. By slowing down, you burn up more of the setup time for the next reinforcer and increase the chances that your next response will occur once the interval has timed out. Thus, interval schedules differentially reinforce long IRTs and encourage low rates of responding.

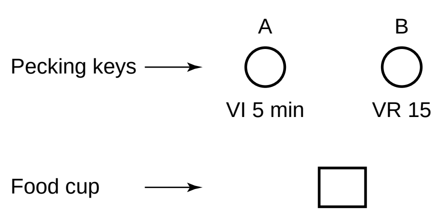
Although feedback functions have played an important role in efforts to explain schedule performance, they have some conceptual limitations. One problem is that feedback functions are sometimes difficult to characterize. This is particularly true for interval-based schedules. In interval schedules, reinforcement depends not only on the rate of responding but also on how the responses are distributed in time. The feedback function for a VI 3-minute schedule presented in Figure 8.5 assumes that responses are distributed randomly in time. Other assumptions may alter the initial increasing portion of the feedback function. Despite such complications, investigators continue to find it useful to think about schedule performance as ultimately determined by how schedules of reinforcement provide feedback for instrumental behavior.

CONCURRENT SCHEDULES

In each of the schedules of reinforcement considered so far, the participant could either perform the specified instrumental response or not. Only one response manipulandum was provided (a lever or a pecking key), and only responses on that manipulandum were measured and recorded. Since the procedures did not provide different response alternatives, they do not seem to involve a choice. Interestingly, however, all instrumental conditioning situations involve a choice. With simple schedules, the choice is to perform the response specified by the reinforcement schedule or to do something else that is not a part of the experiment.

A complete understanding of instrumental behavior requires understanding why organisms choose to engage in one response rather than another. Unfortunately, simple schedules of reinforcement are not good for analyzing the mechanisms of choice. In simple schedules, the alternative to the instrumental response—the "something else" the individual might do—is poorly specified and not measured. These shortcomings are remedied in concurrent schedules. In a **concurrent schedule**, at least two response alternatives, A and B, are available at the same time (see Figure 8.6). Responding on alternative A is reinforced on one schedule of reinforcement (e.g., VI 5-minute), whereas responding on B is reinforced on a different schedule (e.g., VR 15). The participant can switch from one activity to the other at any time. Because concurrent schedules of reinforcement provide clearly defined and measured alternative responses, they are more appropriate for studying how organisms elect to engage in one activity rather than another.

FIGURE 8.6. Diagram of a Concurrent Schedule of Reinforcement



Note. Pecking the response key on the left is reinforced on a VI 5-minute schedule of reinforcement. Pecking the response key on the right is reinforced on a VR 15 schedule of reinforcement. VI = variable interval; VR = variable ratio.

As you might suspect, whether you do one thing or another depends on the benefits you derive from each activity. In the terminology of conditioning, how often you engage in activity A compared to activity B will depend on the schedule of reinforcement that is in effect for response A compared with response B. On a playground, Joe could play with Peter, who likes vigorous physical games, or Joe could play with Matt, who prefers to play quietly in the sandbox. If Joe is not getting much enjoyment from playing with Peter, he can go play with Matt. Concurrent schedules are used to model this type of choice situation in the laboratory.

Numerous factors determine how organisms distribute their behavior between two response alternatives. These include the effort required to make each response, the effort and time involved in switching from one response to the other, the attractiveness of the reinforcer provided for each response, and the schedule of reinforcement in effect for each response. Experiments have to be designed carefully so that the effects of these various factors can be studied without being confounded with other features of the choice situation.

Laboratory studies of concurrent schedules are often carried out with laboratory rats and pigeons. For pigeons, one wall of the experimental chamber has two response keys positioned at about the height of the bird's head. A feeder from which the bird can obtain grain is centered below the two keys. This arrangement has the advantage that the two responses require the same effort. Although pecks on the right and left keys are reinforced on different schedules, the reinforcer in each case is usually the same type of food. Another advantage is that the pigeon can easily switch from one response to the other because the two response keys are located near each other.

If similar effort is required for the response alternatives, if the same reinforcer is used for both responses, and if switching from one side to the other is fairly easy, the distribution of responses between the two alternatives will depend only on the schedule of reinforcement in effect for each response. Research has shown that choices made under these circumstances are well characterized by the **matching law**, which was originally described by Richard Herrnstein (1970). According to the matching law, *the relative rate of responding on a response alternative is equal* to *the relative rate of reinforcement obtained with that response alternative.* For example, 70% of the responses will be made on the left side of a two-key chamber if 70% of all reinforcers are earned on the left side. (For reviews of the matching law, see Dallery & Soto, 2013; Davison & McCarthy, 2016.)

In a concurrent choice situation, organisms tend to match relative rates of responding to relative rates of reinforcement. Departures from perfect matching occur if the response alternatives require different degrees of effort, if different reinforcers are used for each response alternative, or if switching from one response to the other is made more difficult. The effects of these factors have been incorporated into what has come to be known as the *generalized matching law* (W. M. Baum, 1974).

The generalized matching law has made a major contribution to our understanding of how behavior is controlled by schedules of reinforcement. It has shown us that how individuals react when a schedule of reinforcement is set up for one response depends on the alternate activities that are available and the schedules of reinforcement that are in effect with those alternative activities. This basic conclusion has profound implications for applications of instrumental conditioning (E. A. Jacobs et al., 2013). Teachers usually focus on a particular response that they are trying to teach (completing math problems, for example). However, they quickly discover that effort spent on this response depends on the availability of alternative responses and alternative sources of reinforcement. If students are allowed to play games on their cell phones, they are much less likely to work on math problems.

The generalized matching law accurately characterizes how we make choices in a remarkably wide range of situations. It can also be used to describe decisions made in playing baseball and basketball (Alferink et al., 2009; Cox et al., 2021). The matching law is also helping us understand a variety of clinical problems, including antisocial and delinquent behavior, attention-deficit/hyperactivity disorder, chronic pain syndrome, and self-injurious behavior (McDowell, 2021).

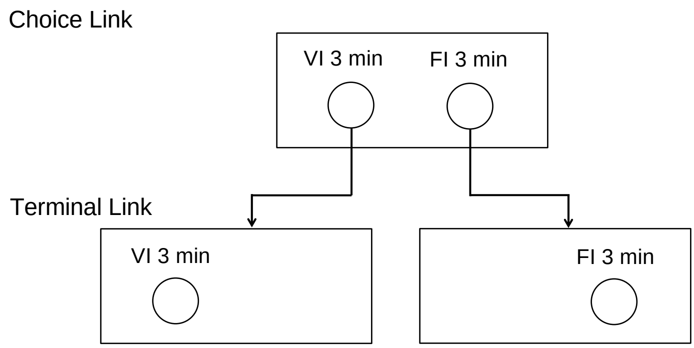
CONCURRENT-CHAIN SCHEDULES AND SELF-CONTROL

In a concurrent schedule, the various response alternatives are available at the same time. This allows the participant to switch back and forth between alternatives at any time and with relative ease. Many situations are like that. You can easily go back and forth among entertainment programs that you watch on television. You may also have a variety of options about what to do for entertainment on the weekend. You can go to a concert, watch a ballgame, or go to dinner with friends. However, in these situations, once you have made your choice, the other alternatives are no longer available. If you purchased your tickets and entered the concert venue, going to a ballgame is no longer an option. The basic features of such choice situations are captured in the laboratory by the design of a concurrent-chain schedule of reinforcement. In a **concurrent-chain schedule**, once you choose a particular course of action, other possible choices become unavailable.

A concurrent-chain schedule has two stages or links. Each trial begins with the choice link, during which two or more alternatives are available. Once a selection is made during the choice link, the procedure moves to the terminal link, which only has the option you selected. You remain in the terminal link for the remainder of the trial. Thus, the current-chain schedule involves choice with commitment.

Concurrent-chain schedules can be used to investigate whether variability in outcomes is preferred over predictability—whether variety is truly the spice of life. Figure 8.7 outlines a procedure to study this question in pigeons. The birds have access to two pecking keys. Pecking on one is reinforced on a VI 3-minute schedule of reinforcement, whereas pecking on the other key is reinforced on an FI 3-minute schedule. The fixed-interval schedule is highly predictable, whereas the VI schedule is not, but the overall rate of reinforcement is the same

FIGURE 8.7. Diagram of a Concurrent Chain Schedule of Reinforcement



Note. During the Choice Link, the participant can select either the VI 3-minute or the FI 3-minute schedule. Choosing an alternative moves the participant into the Terminal Link in which only the chosen alternative is available. FI = fixed interval; VI = variable interval.

for the two alternatives. The choice link provides access to each alternative, but once the pigeon has made its selection, it is "stuck" with that alternative for the rest of the trial. Investigation of concurrent-chain procedures of this sort have indicated a preference for the variable-schedule alternative (Andrzejewski et al., 2005).

Concurrent-chain schedules are also frequently used to study self-control. **Self-control** is involved when you have a choice between one alternative that provides a small reward quickly versus a second option that provides a larger reward but with a considerable delay. Do you choose to have a piece of cake that provides immediate gratification or forgo the dessert in favor of a healthier lifestyle, which provides much more delayed benefits? Do you give in to the temptation of going out with friends in the evening or stay at home to study for an upcoming test, which will enable you to succeed in school and get a better job? Do you spend your hard-earned dollars on video games that you can enjoy right away or put that money away to build your savings to buy a car? All these are examples of a choice between a smaller-sooner reward (SS) versus a larger-later reward (LL).

Self-control is modeled in behavioral experiments using a concurrent-chain schedule. During the choice link, participants have the option of choosing a small reward provided right away (one food pellet) versus a large reward provided after a delay (three food pellets). Once they select one or the other of these alternatives, they move to the terminal link in which they can obtain the type of reward (SS or LL) that they selected. Experimental studies have confirmed what we all know—namely, that it is more tempting to go for the smaller, immediate reward than to wait for the larger, delayed reward. Why is that?

Central to explanations of self-control in the context of schedules of reinforcement is the concept that the longer you have to wait for a reinforcer, the less valuable it is. The discounting of reward value by waiting time is called the

delay discounting function (Vanderveldt et al., 2016). In laboratory studies of the delay discounting function with human participants, individuals are asked to choose between hypothetical amounts of money. Would you prefer \$5 now or \$5 tomorrow? For most people this is an easy decision. Obviously, we would prefer to get the \$5 now rather than tomorrow. This indicates that the value of \$5 is reduced by having to wait a day to get the money. Because delaying a reward reduces its value, people tend to select small immediate rewards over larger delayed rewards.

Not everyone discounts the value of future rewards to the same degree (Odum & Baumann, 2010). Steeper delay discounting functions indicate greater perceived loss of reward value as a function of waiting time. Individuals with steep delay discounting functions tend to show less self-control. This relationship has been of particular interest in dysfunctional health behaviors including drug abuse and addiction (Bickel et al., 2014, 2017). The choice to consume a recreational drug is a self-control problem. Do you take the drug and enjoy its immediate effects or select another activity whose benefits are more delayed (studying, investing in a personal relationship, improving your skills in sports or music)? Drug addicts choose the drug, and serious addicts make this choice even if it costs them their job, their marriage, and their physical health.

Studies have shown that drug addicts have steeper delay discounting functions than nonaddicts, even after they have recovered from their addiction (MacKillop et al., 2011; Yi et al., 2010). Addicts are driven by what is reinforcing right now (SS) rather than what they can do that will improve their lives in the future (LL). One may suggest that the inability to see the value of future rewards is a consequence of drug addiction. However, research has shown that the steepness of an individual's delay discounting function is predictive of future drug use (Brody et al., 2014; Carroll et al., 2010).

Self-control and reward discounting have been related to a remarkably large range of health and life outcomes. For example, in one longitudinal study, the degree of self-control evident before age 10 was predictive of better health, higher income levels, lower rates of drug use, and lower rates of criminal behavior in early adulthood (e.g., Moffitt et al., 2011). These types of findings have encouraged investigators to explore ways to increase self-control. A variety of cognitive, behavioral, and environmental interventions have been tested (e.g., Duckworth et al., 2018). Training procedures that introduce delays to the large reward slowly significantly increase choice of the LL reward. Self-control is also increased by training that improves response inhibition, time estimation, and episodic future thinking (Renda et al., 2021; Rung & Madden, 2018; T. Smith et al., 2019).

SUMMARY

Schedules of reinforcement are of interest because, in many cases, responding does not produce a reinforcer every time. A response may be reinforced after a fixed or variable number of responses have occurred (fixed-ratio and variable-ratio schedules) or after a fixed or variable amount of time has passed since the last reinforcer (fixed-interval and variable-interval schedules). Fixed-interval and fixed-ratio schedules produce rapid responding just before delivery of the reinforcer and a pause just after reinforcement. Variable-interval and variable-ratio schedules produce steady response rates. In general, ratio schedules produce higher rates of responding than interval schedules. This difference is related to the contrasting feedback functions for the two types of schedules. Ratio schedules differentially reinforce short IRTs whereas interval schedules encourage long IRTs.

Reinforcement schedules can also involve a choice between two or more activities, each associated with its own schedule of reinforcement. In a concurrent schedule, two (or more) response alternatives are available at the same time, and the participant can switch between response alternatives at any time. Responding on concurrent schedules is characterized by the generalized matching law. A concurrent-chain schedule also provides two response alternatives, but in this case, once one of responses is selected, the other alternative is no longer available. Concurrent-chain schedules are used to study self-control. Self-control is determined by how rapidly the value of a reinforcer is discounted by how long you have to wait for it, which is called the delay discounting function. Research shows that there are considerable individual differences in how rapidly people discount delayed rewards, and this is related to subsequent health outcomes and life success.

SUGGESTED READINGS

Cox, D. J., Klapes, B., & Falligant, J. M. (2021). Scaling *N* from 1 to 1,000,000: Application of the generalized matching law to big data contexts. *Perspectives on Behavior Science*, *44*(4), 641–665. https://doi.org/10.1007/s40614-021-00298-8

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TECHNICAL TERMS

schedule of reinforcement, page 122
cumulative record, page 123
ratio schedule, page 124
interval schedule, page 124

fixed-ratio schedule, page 124
postreinforcement pause, page 124
ratio run, page 124
variable-ratio schedule, page 125
fixed-interval schedule, page 126
variable-interval schedule, page 127
feedback function, page 128
concurrent schedule, page 131
matching law, page 132
concurrent-chain schedule, page 133
self-control, page 134
delay discounting function, page 135

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