Handbook of Applied Behavior Analysis

Edited by

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CHAPTER 4

Schedules of Reinforcement

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Rules that describe the relationship between responses and reinforcer deliveries are known as *schedules of reinforcement*. These rules can be deliberately arranged in the context of an experiment or behavioral treatment, or they can be surmised from the pattern of responses to reinforcer deliveries that occur naturally. In either case, schedules of reinforcement are important for applied behavior analysts to consider because each schedule can be expected to have predictable effects on one or more dimensions of behavior. With this knowledge, applied behavior analysts are better positioned to describe the conditions of reinforcement that maintain undesirable behavior and to design interventions that have a higher likelihood of increasing desirable behavior.

This chapter discusses the dimensions of behavior that schedules of reinforcement can affect, and presents descriptions and examples of basic schedules and combined schedules of reinforcement.

Schedules of Reinforcement in Context

It is important to understand the effects schedules of reinforcement have on behavior in the broader context in which they operate. The basic unit of analysis in applied behavior analysis (ABA) is the *discriminated operant*, which is a class of responses defined by both the effect the responses have on the environment and the stimuli present when responses occur (Catania, 1998). Occurrences of discriminated operants are affected by events that motivate their occurrence, known as *motivating operations* (Laraway, Snycerski, Michael, & Poling, 2003). Motivating Operations are events preceding occurrences of discriminated operants that can have evocative or abative effects on behavior (i.e., increase or decrease their occurrence). They can also alter the effectiveness of consequences of behavior by establishing or abolishing their reinforcing or punishing effects. Discriminated operants are also affected by antecedent occurrences of stimuli or events that are correlated with the increased or decreased availability of reinforcement (or punishment), known as *discriminative stimuli*. Discriminative stimuli are said to set the occasion for operants to occur because they predict the likely consequences responses will have. However, the effects of discriminative stimuli on behavior are dependent on the presence or absence of related motivating operations (Laraway et al., 2003).

In all natural human environments, individuals are free to engage in any of several concurrently available discriminated operants. Each one is associated with one or more consequences and the individual is said to have a *choice* to engage in any of the alternatives (Fisher & Mazur, 1997; Mace & Roberts, 1993). The variables that influence choice have been studied extensively and are formally developed in the *generalized matching law* (Baum, 1974), which we briefly discuss in a later section of this chapter; however, one of the variables that affects choice is the relative schedule of reinforcement operating for each of the concurrently available alternatives. We also provide a conceptual framework for understanding how concurrent discriminated operants are influenced in a dynamic manner by changes in relative motivation and relative history of reinforcement or punishment (i.e., behavioral mass; Mace, Gritter, Johnson, Malley, & Steege, 2007) (Figure 4.1). A final contextual factor to consider is each discriminated operant's history of reinforcement or punishment. These learning histories affect the relative resistance to change or momentum each discriminated operant has and, in turn, can affect the relative value of concurrently available alternatives and the choices individuals make. Nevin and Grace (2000) refer to these histories as *behavioral mass* in the context of their formulation of *behavioral momentum theory* (see later sections on resistance to change and behavioral momentum).

The purpose of this preface to our discussion of schedules of reinforcement is to emphasize that the effects of reinforcement schedules on behavior are *relative, not absolute* (Herrnstein, 1961, 1970); that is, the influence of any given schedule of reinforcement on a discriminated operant will depend on the relative factors that affect choice including reinforcer rate, quality, and delay, response effort, motivation, and behavioral mass. The practical significance of this conceptual model is that applied behavior analysts may need to consider a broad range of factors that influence both desirable and undesirable behavior to maximize the effectiveness of their interventions.

Behavior Dimensions Affected by Schedules of Reinforcement

In ABA practice, reinforcers are delivered contingently. There are three general types of contingencies. First, the contingency can be between the number of responses that occur and the delivery of a reinforcer, known as a *ratio contingency*. Second, the contingency can be between the occurrence of responses and the passage of intervals of time, known as an *interval contingency*. Finally, the contingency can be between the passage of an interval of time with no relation to the occurrence of responses, known as a *time contingency*. The particular arrangement of ratio, interval, and time contingencies can affect the rate of a response, the periodicity of a response, and the resistance to change of a response.

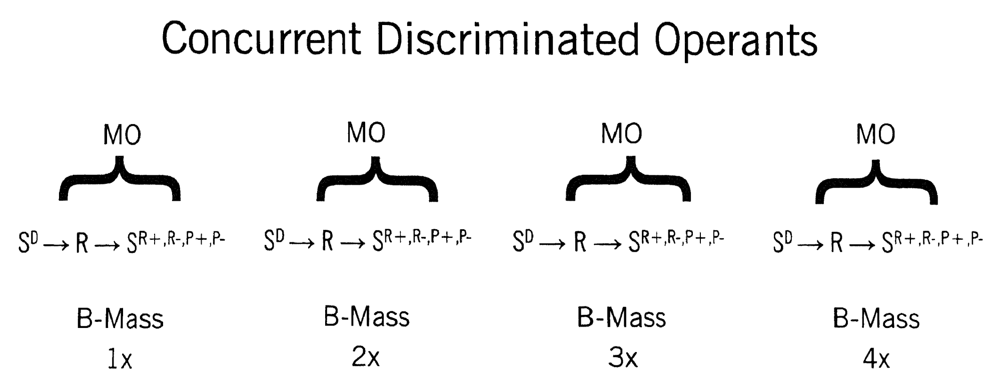

FIGURE 4.1. Framework for conceptualizing discriminated operants in context: The dynamic interplay between motivating operations, behavioral mass, and the classic three-term contingency.

Response Rate

Response rate is defined as the ratio of the number of responses to an interval of time, or response count divided by time. Its synonym is *frequency*. An alternative expression of response rate is the average time between responses, or *interresponse time* (IRT), which is defined as the average time that elapses between the offset of one response and the onset of the next response in the response class. Response rate and IRT have a perfect inverse correlation such that a unit increase in response rate will have a corresponding unit decrease in IRT. In ABA practice, response rate is often an important dimension of behavior that the behavior analyst aims to alter, generally attempting to increase the frequency of desirable behaviors and/or decrease the frequency of undesirable ones. Thus, knowing the effects of different schedules of reinforcement on response rate is important in the design of interventions.

Response Periodicity

Response periodicity refers to the pattern of responses in relation to the passage of time. Whereas IRT expresses the *average* time between responses, response periodicity reflects the pattern of times between individual responses, or individual IRTs, during a specified time period. In general, schedules of reinforcement promote four patterns of response periodicity. The first possible pattern is a fairly *constant* time between responses showing little variability in individual IRTs. This pattern is characteristic of variable-ratio (VR) and variable-interval (VI) schedules (which we discuss subsequently). A second pattern is a *pause* in responding that follows a comparatively higher response rate. Both fixed-ratio (FR) and fixed-interval (FI) schedules can promote temporary pauses in responding after reinforcer deliveries before responding resumes. A third pattern is the *suspension* of responding following a given response pattern. Time, extinction, and differential reinforcement of other behavior (DRO) schedules can result in a reduction in response rates to zero or near zero. Finally, response periodicity can show a pattern of *celeration* (Johnston & Pennypacker, 1980, 1993), which refers to a progressive change in individual IRTs. Progressively shorter IRTs reflect *acceleration* in response rate, whereas progressively longer IRTs reflect *deceleration*. A variety of schedules of reinforcement can promote these response patterns, as we discuss in the following sections of the chapter.

Resistance to Change

An important dimension of behavior that applied behavior analysts increasingly take into consideration is its resistance to change, which refers to the rate of deceleration in responding that follows the introduction of some *response disruptor* (i.e., events that disrupt the response–reinforcer relation; Nevin, 1974; Nevin, Mandell, & Atak, 1983). Common response disruptors include extinction, satiation, alternative reinforcement, punishment, dark-key (or between-session) reinforcement, and distraction. Each of these operations can decelerate responding. This dimension of behavior is particularly relevant to ABA work aimed at strengthening the resistance to change of desirable behavior and weakening the resistance to change of undesirable behaviors.

Basic Schedules of Reinforcement

Ferster and Skinner (1957) provided the foundational work for schedules of reinforcement in their compilation of over 100 experimental demonstrations of the patterns of responding promoted by various schedules. Numerous applications of various schedules of reinforcement in ABA work have demonstrated the relevance of these schedules to the assessment and treatment of human behavior.

Basic schedules are single schedules of reinforcement applied to one class of responses, which form the building blocks for the more complex, combined schedules of reinforcement (described later). Table 4.1 summarizes the basic schedules discussed in this chapter, along with schedule definitions, the response patterns each schedule promotes, and applications of the schedule in ABA work.

TABLE 4.1. Basic Schedules of Reinforcement, ABA Example, and the Response Patterns Promoted

Schedule	Definition	ABA example	Response pattern promoted
FR—fixed ratio	Reinforcers are contingent on every *i*th response (e.g., FR4—every fourth response)	Cohen et al. (2001) demonstrated FR patterns by measuring muscle contractions emitted by undergraduate students.	High response rate with comparatively short and uniform IRTs. Pause in responding follows reinforcer deliveries.
VR—variable ratio	Reinforcers are contingent on a variable number of responses; the average number of responses defines the schedule.	DeLuca and Holburn (1992) showed VR patterns by measuring obese children's rate of stationary bike revolutions.	High response rate with comparatively short and uniform IRTs.
FI—fixed interval	Reinforcers are contingent on the first response following a fixed time interval.	Critchfield et al. (2003) analyzed the bill-passing behavior of the U.S. Congress.	Possible cumulative record scalloping when measurement of the passage of time is unavailable.
VI—variable interval	Reinforcers are contingent on the first response following a variable interval of time; the average of these intervals defines the schedule.	Martens, Lockner, and Kelly (1992) demonstrated VI response patterns in the academic engagement of typically developing 8-year-olds.	Moderate response rates with uniform but longer IRTs than ratio schedules.
EXT—extinction	Discontinuation of a reinforcement contingency either by withholding contingent reinforcement or delivering reinforcers independently of behavior according to FT or VT schedules.	Magee and Ellis (2001) demonstrated the extinction process for several challenging behaviors (e.g., out-of-seat behavior, hand mouthing, yelling, and property destruction) exhibited by children with developmental disabilities.	When contingent reinforcement is withheld—a sudden increase in response rate (burst) followed by a reduction to zero. When the reinforcement contingency is discontinued but reinforcers are delivered on FT or VT schedules—a sharp drop in response rate to near-zero or zero levels.
FT-VT—fixed or variable time schedules	Reinforcers are delivered independently of any behavior at FT or VT intervals.	Vollmer et al. (1998) used FT schedules to reduce problem behaviors (i.e., aggression, self-injurious behavior, disruption, and tantrums) displayed by both children and adults with mental retardation. Mace and Lalli (1991) used VT schedules to reduce bizarre vocalizations emitted by an adult with moderate mental retardation.	When combined with EXT, sharp drop in response rate to near-zero or zero levels. When combined with ratio or interval schedules, a reduction in the reinforced class of behaviors.

(cont.)

TABLE 4.1. *(cont.)*

Schedule	Definition	ABA example	Response pattern promoted
DRA—differential reinforcement of alternative behavior	Reinforcers are contingent on specific topographies of behavior and *not* others. Combines ratio or intervals schedules with extinction.	Harding et al. (2004) used DRA schedules to increase adults' correct execution of various martial arts techniques.	Comparatively higher response rates for behaviors that produce reinforcers than for those that do not.
DRH-DRL—differential reinforcement of high or low rate behavior	Reinforcers are delivered after a specified time interval if response rates are at or above (DRH) or at or below (DRL) a specified rate.	Lane et al. (2007) used DRH schedules to increase a child's class participation (i.e., rates of hand raising and question answering). Wright and Vollmer (2002) used a DRL schedule to reduce rapid eating in an adolescent with mental retardation.	DRH schedules promote response rates higher than the specified criterion. DRL schedules promote response rates below the criterion.
DRO—differential reinforcement of other behavior	Reinforcers are contingent on the absence of specified behavior(s) during a specified time interval. Also called omission training.	Heard and Watson (1999) used an interval DRO schedule to reduce wandering behavior exhibited by geriatric patients. Kahng, Abt, and Schonbachler (2001) used a momentary DRO schedule to reduce the rate of aggression displayed by a woman with developmental disabilities.	Low or zero rates of the target behavior omitted from reinforcement. Behaviors other than the target behavior increase in rate.

Ratio Schedules

Ratio schedules of reinforcement specify the number of responses that are required to effect delivery of a reinforcer, independent of the amount of time taken to complete the schedule requirement. However, because slow response rates delay the time to reinforcement, ratio schedules generally promote relatively high response rates with relatively constant individual IRTs, with some exceptions noted below. The response patterns promoted by ratio schedules are influenced by two schedule features: (1) the ratio of responses to reinforcers (RRR) and (2) the predictability of this ratio.

FR Schedules

In an FR schedule, the number of responses required to produce a reinforcer is constant (e.g., inputting three-digit area code and seven-digit phone number to make a call is an example of an FR 10 schedule).

When the RRR is very low, as in the case of the FR 1 schedule (also known as a *continuous reinforcement schedule* [CRF]), responses rates are also typically low. However, as reinforcer deliveries become less frequent (e.g., FR 5), the response rates promoted by the schedule increase rapidly and eventually support comparatively high rates of responding. As the RRR increases, pauses in responding after the reinforcer delivery also increase, known as the *postreinforcement pause* (Felton & Lyon, 1966). Finally, as the RRR becomes comparatively high, pauses in responding can appear before the reinforcer is delivered. This is known as *ratio strain*, and it can result in either the temporary interruption of responding or its cessation. The predictability of the RRR in FR schedules generally promotes the highest response rates with uniform individual IRTs. However, humans may show FR response patterns even when the RRR is not held constant. For example, a parent may tell a child that he or she may engage in a leisure activity as soon as a math homework assignment is completed. Because the child knows how many math problems must be completed, the RRR is predictable and the characteristic FR response pattern may be promoted.

Cohen, Richardson, Klebez, Febbo, and Tucker (2001) provided undergraduate psychology majors with auditory and visual biofeedback for electromyography (EMG) readings from their forearms. Participants were instructed alternately to tense and relax their forearms. Different groups of students received feedback on whether their EMG values moved from below a predetermined threshold to above the threshold (responses). Feedback was provided for these responses according to five different schedules of reinforcement. Two of the schedules were FR schedules: FR 1 (CRF) and FR 4 schedules. The FR 4 schedule generated the highest rates of responding, whereas the FR 1 schedule produced response rates that were approximately half of the higher RRR.

VR Schedules

Like FR schedules, VR schedules (also known as *random-ratio* [RR] schedules) deliver reinforcers contingent on the number of responses that are emitted. However, in VR schedules, the interreinforcement response criteria vary for each reinforcer delivery. The *schedule value* is defined as the average RRR over the course of the VR condition (e.g., reinforcers delivered after the second response, then after the sixth response, and then after four more responses would be a VR 4). Many human behaviors maintained by VR schedules include sampling restaurants in search of ones that suit one's taste, purchasing lottery tickets, looking for misplaced items, and answering questions on weekly homework assignments.

VR schedules generally promote high rates of responding, with short and fairly uniform individual IRTs. However, when the RRR exceeds a threshold (in pigeons, this value can exceed 200 key pecks per minute [Brandauer, 1958]), response rates decline as the RRR increases. In addition, ratio strain can occur at lower RRR values when single interreinforcer intervals become quite large. Finally, the unpredictability of the individual RRRs tends to promote short postreinforcement pauses.

DeLuca and Holburn (1992) reinforced revolutions on an exercise bicycle with preferred objects on a VR schedule for three obese children. Following calculation of baseline revolutions per minute, an initial VR schedule value was set at 15% above baseline. Two additional increases in VR values were implemented after participants demonstrated stability in each VR condition. The progressive arrangement of the VR schedule value, also known as a *progressive VR schedule*, resulted in an approximate doubling of pedal revolution rates.

Interval Schedules

Interval schedules of reinforcement define the point in time that responses become eligible for reinforcement. The *interval value* indicates the minimum time that must elapse before a response produces a reinforcer. Unlike ratio schedules, the rate of responding does not affect the rate of reinforcement—response rate and reinforcement rate are independent to the extent that higher response rates do not produce higher rates of reinforcement in interval schedules. The contingency is between the response periodicity and the delivery of reinforcers. Thus, interval schedules generally support lower response rates than ratio schedules do (Cohen et al., 2001).

An *adjunctive* procedure known as a *limited hold* is sometimes needed for interval schedules to support a consistent response pattern. A limited hold specifies the amount of time that reinforcers are available once they have been "set up" by the schedule. Thus, a 5-second limited hold means that if a response does not occur within 5 seconds of becoming eligible for reinforcement, the opportunity for reinforcement is forfeited.

FI Schedules

In an FI schedule of reinforcement, the first response that occurs following the expiration of a constant time interval results in the delivery of a reinforcer. Thus, a FI 5-minute schedule arranges the availability of reinforcement to occur every 5 minutes. The predictability of reinforcer availability can promote a pattern of behavior that is sensitive to this periodicity. In the laboratory, especially with nonhuman participants, FI schedules tend to promote an escalation in response rates toward the end of the interval. When expressed in a cumulative record of responses, the pattern takes the appearance of a "scallop." Following delivery of each reinforcer, there is a postreinforcement pause that can last more than half of the interreinforcement interval.

There has been some speculation whether FI scalloping occurs in humans in natural environments. For example, Critchfield, Haley, Sabo, Colbert, and Macropoulis (2003) analyzed the bill-passing behavior of the United States Congress over a 52-year period. Each 2-year Congress comprises two sessions of approximately equal duration. Critchfield and colleagues found that, graphed in cumulative records, bill passing escalated toward the end of each session in accord with the FI scalloping seen in nonhuman species experiments in the laboratory. However, FI scalloping is a productive response pattern only when there is no external means to discriminate time. When the end of an FI schedule is clearly signaled, the most parsimonious response pattern would be to emit a single response at the completion of the interval. In the case of Congressional behavior, the contingency would appear to be between the number of bills passed and the production of the reinforcing consequence of reelection or campaign donations rather than the particular timing of the completion of any one legislative act. The escalation in bill passing toward the end of Congressional sessions bears resemblance to procrastination in completing work that can be referred to during a campaign as the basis for financial or electoral support. The consensus of other authors examining FI scalloping in humans is that it is a rare occurrence (Hyten & Madden, 1993; Ninness, Ozenne, & McCuller, 2000).

VI Schedules

VI schedules (also known as *random interval* [RI]) make responses eligible for reinforcement on the basis of an average interval of time that elapses (e.g., reinforcers delivered after the 10th second, then after 20 more seconds, and then after 15 more seconds would be a VI 15-second schedule). Hantula and Crowell (1994) provided a BASIC program for deriving interval values based on the formula by Fleshler and Hoffman (1962) such that the time between reinforcer deliveries is truly random. Because the interreinforcement interval is unpredictable, VI schedules promote consistent response rates with fairly uniform individual IRTs.

Teacher attention is often delivered on a VI schedule because its availability is dependent not on the number of responses a student makes but on the availability of the teacher to observe and reinforce student behavior. Martens, Lochner, and Kelly (1992) provided praise contingent on academic engagement for two 8-year-old students with low baseline rates of academic engagement. Praise was delivered alternately on VI 5-minute and VI 2-minute schedules of reinforcement. Both schedules improved academic engagement; however, the VI 2-minute schedules consistently resulted in higher levels of engagement for both students, a finding consistent with basic research with nonhuman specifies (Catania & Reynolds, 1968).

Extinction Schedules

Extinction (EXT) schedules withhold reinforcement for specified response topographies during certain time periods. EXT schedules come in two general forms. First, they can constitute a change from a condition in which responses were reinforced to one in which reinforcement is discontinued. When extinction follows positive reinforcement, it is denoted as EXT+, and when it follows negative reinforcement, the denotation is EXT–. Second, an EXT schedule can be arranged for responses that have not been explicitly reinforced in the past but should not be reinforced during the process of teaching a new skill. For example, when teaching a child with autism to say the word *apple*, vocalized sounds unrelated to *a*, *p*, and *l* would be designated as ineligible for reinforcement.

Magee and Ellis (2001) used EXT alone to reduce multiple undesirable behaviors for two children. A functional analysis showed that one child's out-of-seat behavior occurred at high levels when a therapist discontinued instructions contingent on the behavior. Escape extinction (EXT–) consisted of the continuous presentation of instructions every 10 seconds regardless of occurrences of undesirable behavior. The second child's functional analysis showed that his object mouthing was maintained by adult attention. Positive reinforcement extinction (EXT+) for this child involved withholding attention following any undesirable responses. Both EXT schedules were effective in reducing out-of-seat behavior and hand mouthing. However, Magee and Ellis found that when these two behaviors were placed on extinction, other topographies of undesirable behaviors emerged—first yelling in one child and property destruction in the other. When these behaviors were placed on extinction, additional topographies of undesirable behaviors began occurring. The sequential emergence of multiple undesirable behaviors demonstrated that the behaviors were members of a response class hierarchy (Lalli, Mace, Wohn, & Livezey, 1995).

Magee and Ellis (2001) illustrated that EXT schedules can have collateral effects in addition to the reduction of responses subject to extinction. These include the extinction burst (initial increases in responding), extinction-induced aggression (violent acts related and unrelated to the source of reinforcement), agitated or emotional behavior, resumption of previously reinforced behaviors, behavioral contrast (increased occurrences of undesirable behavior in settings not employing extinction), and spontaneous recovery (recurrence of the extinguished target behavior). Lerman, Iwata, and Wallace (1999) examined the prevalence of extinction bursts and extinction-induced aggression for 41 cases of individuals with self-injurious behavior who received treatment using EXT alone or EXT plus additional treatment components. They found response bursting was evident in 39% of all cases; 22% showed increased aggression and 58% showed neither side effect. However, of the cases treated with EXT alone, 69% showed response bursting and 29% showed increased aggression compared to only 15% for either side effect when treated with EXT plus another treatment component. These findings suggest the importance of combining EXT with other schedules to avoid unwanted side effects.

Time Schedules

Time schedules arrange occurrence of reinforcer deliveries contingent on the passage of an interval of time and independent of an individual's behavior. Reinforcers are said to be *response-independent* and delivered *noncontingently*.[1] In ABA work, time schedules are employed to (1) *enrich* an environment and alter the motivation of individuals to engage in undesirable behavior to obtain reinforcement (Horner, 1980); (2) serve as an experimental control procedure to demonstrate the effects of a contingency between a response and a reinforcer (Thompson & Iwata, 2005); and (3) reduce undesirable behavior. Our discussion here focuses on this last application of time schedules.

Fixed or Variable Time Schedules

Reinforcers can be delivered in time schedules at regular or fixed intervals (FT schedules) or at random or variable intervals (VT schedules). Mace and Lalli (1991) combined descriptive and experimental analysis to show that a man's bizarre vocalizations were maintained by staff attention. The functional relationship between bizarre speech and staff attention was then disrupted by delivering neutral comments to the participant on a VT 90-second schedule and discontinuing attention for bizarre comments. Numerous studies have demonstrated that time schedules are an effective and efficient method for reducing a wide range of undesirable behavior maintained by both positive and negative reinforcement (Vollmer, Marcus, & Rihgdahl, 1995; for reviews, see Tucker, Sigafoos, & Bushell, 1998; Vollmer & Hackenberg, 2001).

Time schedules are an attractive treatment alternative for a number of reasons. First, they often result in rapid suppression of undesirable behavior when the reinforcer maintaining undesirable behavior is time contingent (Lalli, Casey, & Kates, 1997; Mace & Lalli, 1991). Second, as indicated earlier, adding time-contingent reinforcers to a context can reduce the motivation to engage in extreme acts (undesirable behavior) to obtain reinforcement. This may also increase the attractiveness of prosocial alternative behaviors that require less effort to effect reinforcement (Ecott & Critchfield, 2004). Third, relative to EXT schedules, time schedules often obviate an extinction burst. For example, Vollmer and colleagues (1998) compared FT deliveries of maintaining reinforcers with the withholding of those reinforcers (i.e., EXT). For all three of the participants in their study, an extinction burst was evident during EXT. However, the FT schedule resulted in rapid or immediate suppression of undesirable behavior without response bursting. We note that response bursting has been reported when the rate of time schedule reinforcer deliveries is faded and apparently becomes too lean. Vollmer, Rihgdahl, Roane, and Marcus (1997) found that undesirable behavior escalated to approximately five times the baseline rate during FT schedule thinning; Mace and colleagues (2008) reported similar findings.

There are several procedural variations of time schedules to consider when designing interventions. First, a time schedule value must be selected that is sufficiently dense to suppress undesirable behavior. For example, Rihgdahl, Vollmer, Borrero, and Connell (2001) evaluated whether initial time schedule values are best set at those similar or dissimilar to the rates of baseline reinforcement. They found that FT schedule values that were similar to baseline rates of reinforcement for undesirable behavior were less effective than those that were dissimilar. This finding held even when the FT schedule values were four to nine times leaner than the baseline reinforcement rates. This counterintuitive finding may be attributed to dissimilar rates being easier to discriminate from baseline. A second procedural question is whether time schedules must be used in conjunction with EXT to be effective (see discussion on conjunctive schedules below). Lalli and colleagues (1997) compared FT schedules with and without EXT and found that they were comparably effective at reducing undesirable behavior; however, this finding was based on only one participant receiving FT intervention without EXT. Third, the majority of clinical studies employing time schedules have evaluated FT rather than VT schedules, but studies comparing the efficacy of FT versus VT schedules have found them to be similarly effective (Carr, Kellum, & Chong, 2001; Van Camp, Lerman, Kelley, Contrucci, & Vorndran, 2000). We suggest the initial use of FT schedules and a shift to VT schedules after initial treatment effects are established. The predictability of reinforcer deliveries in FI and VI schedules, and the characteristic response patterns they promote, may logically extend to time schedules.

There is some theoretical interest in which behavioral process(es) are invoked in time schedules to make them effective. The shift from contingent baseline reinforcement to time-contingent reinforcer deliveries involves two simultaneous operations. First, the response–reinforcer contingency in baseline is discontinued, constituting a procedural variation of extinction. Second, the motivating operations (MOs) change by supplying reinforcers on a time schedule. This presumably abolishes the consequence as an effective reinforcer for undesirable behavior and abates those same responses. Kahng, Iwata, Thompson, and Hanley (2000) examined response patterns in the time period immediately following FT intervention. They reasoned that if FT effects were due to extinction, responding would not resume following FT treatment because the response–reinforcer contingency was not reinstated. Alternatively, if FT effects were the result of altered MOs, response rates could be expected to resume when reinforcers shift from being available to unavailable. The findings of Kahng and colleagues were mixed in their analysis, with one participant each supporting the EXT and MO accounts, and a third showing a change in response patterns over time from supporting the MO account to the EXT account. Finally, Ecott and Critchfield (2004) suggested that time schedules may be effective because reinforcer deliveries may temporally coincide with other behaviors and result in adventitious reinforcement of those responses. In a laboratory demonstration with undergraduate students, two behaviors were concurrently reinforced with

[1] The term *noncontingent reinforcement* (NCR) was introduced to describe fixed-time (FT) and variable-time (VT) schedules (Vollmer, Iwata, Zarcone, Smith, & Mazaleski, 1993). However, Poling and Normand (1999) questioned the technical accuracy of the term to describe the noncontingent delivery of reinforcers. Because noncontingent delivery of reinforcers does not constitute a reinforcement operation or process (i.e., nothing is reinforced), the term NCR does appear to be a misnomer and is not used in our discussion of the topic.

points. The "target behavior" was reinforced on a VI 10-second schedule, and the "alternative behavior" was placed on a VI 30-second schedule (see discussion of concurrent schedules of reinforcement below). Following stability in this baseline phase, the proportion of reinforcer deliveries for the target behavior that was response contingent was systematically varied from 100, 66, and 33 to 0%. Results showed that as the proportion of time-contingent reinforcer deliveries increased, the response rates for the alternative behavior increased. Ecott and Critchfield suggested that adventitious reinforcement of alternative behavior is one possible account of the behavioral process involved in time schedule treatment effects.

Differential Reinforcement Schedules

Differential schedules of reinforcement specify the dimensions of behavior that are and are not eligible for reinforcement. They may also define the stimuli that must be present for responses to be reinforced (i.e., an S^D), as well as the stimuli in the presence of which responses will not be reinforced (i.e., an S^Δ), thus defining the discriminated operant. As such, differential reinforcement schedules implicitly involve two types of operations: (1) positive or negative reinforcement and (2) extinction. The behavior dimensions subject to reinforcement and extinction include specific forms or topographies of responses, response rates and the periodicity of responding, and the amount of time spent engaging in specific behaviors.

In ABA practice, the criteria for reinforcement are often changed systematically to promote gradual and progressive changes in responding toward a target criterion. When this involves the discriminative stimuli correlated with reinforcement, the operation is known as *fading*. For example, Flood and Wilder (2004) used differential reinforcement and fading to increase the amount of time an 11-year-old boy with separation anxiety disorder could spend away from his mother without crying, whining, or exhibiting other emotional behavior. Access to preferred items was made contingent on the boy meeting his goals for time spent away from his mother without distress. The time goals were faded from 3 minutes to 90 minutes over 27 treatment sessions. A similar fading and differential reinforcement procedure was used to increase the distance the boy's mother was from the therapy room. By contrast, when changes in specific response topographies or in response rates are subject to changing criteria for reinforcement, the operation is known as *shaping*. Ricciardi, Luiselli, and Camare (2006) used shaping and differential reinforcement to increase approach responses to feared animated toys in an 8-year-old boy with autism. Distance from the feared objects was gradually decreased from 6 meters to being able to touch the feared toys. Access to preferred items was contingent on the boy remaining in a target proximity of the feared objects that gradually increased in five steps. Differential reinforcement procedures and their application are discussed more fully by Hanley and Tiger (Chapter 14, this volume).

Combined Schedules of Reinforcement

Combined schedules of reinforcement comprise two or more basic schedules. Each basic schedule is referred to as a *schedule component*. These components are arranged to alternate, be available at the same time, occur in a sequence, or in some combination of these arrangements. Combined schedules are particularly relevant to ABA because they better represent the circumstances humans encounter in everyday life. Our coverage of combined schedules includes definitions, examples, and a discussion of the relationship between certain combined schedules and contemporary developments in ABA, such as behavioral contrast, matching theory, and behavioral momentum. Table 4.2 summarizes the combined schedules discussed here, along with schedule definitions, response patterns promoted by each schedule, and applications in ABA work.

Multiple and Mixed Schedules

In a multiple and mixed schedule, two or more schedule components alternate in a random, counterbalanced, or natural temporal sequence. The difference between multiple and mixed schedules is that schedule components are correlated with distinct stimuli in multiple schedules and are not in mixed schedules. As an individual experiences the

TABLE 4.2. Combined Schedules of Reinforcement, ABA Example, and the Response Patterns Promoted

Schedule	Definition	ABA example	Response pattern promoted
Multiple/ mixed schedules	Alternation of two or more schedules of reinforcement. In a multiple schedule, each schedule is correlated with a distinct stimulus (e.g., a VR schedule in context *A* alternates with a DRL schedule in context *B*). In a mixed schedule, no distinct stimuli are correlated with each schedule (e.g., a VR schedule and DRL schedule alternate in the same context).	Tiger and Hanley (2005) used MULT and MIX FR 1 EXT_1 EXT_2 schedules to produce differential rates of social approach responses emitted by preschoolers.	Schedule-specific patterns of behavior are observed in each component. Schedule-specific response patterns are more pronounced in multiple than in mixed schedules.
Concurrent/ conjoint schedules	Two or more schedules of reinforcement are available at the same time. In a concurrent schedule, each schedule is correlated with a distinct stimulus (e.g., a choice between VR reinforcement from source *A* and VI reinforcement from source *B* in the same context). In a conjoint schedule, no distinct stimuli are correlated with each schedule (e.g., behavior *A* produces VR reinforcement and behavior *B* produces DRH reinforcement in the same context).	Conger and Killeen (1974) employed CONC VI VI schedules to demonstrate college students' allocation of attending responses.	Concurrent interval schedules promote allocation of responding to each schedule in proportion to relative rates of reinforcement obtained on each schedule. Concurrent ratio schedules promote exclusive responding on the relatively denser schedule of reinforcement.
Chained/ tandem schedules	Two or more schedules of reinforcement are available. Completion of schedule *A* produces schedule *B*, and completion of schedule *B* produces reinforcement. In a chained schedule, each schedule component is correlated with a distinct stimulus. In a tandem schedule, no distinct stimuli are correlated with each schedule component.	Hoerger and Mace (2006) used concurrent-chain schedules to measure impulsive versus self-controlled choices made by male children with and without symptoms of ADHD.	Schedule-specific patterns of behavior are observed in each component. Schedule-specific response patterns are more pronounced in chained than in tandem schedules.
Conjunctive schedule	Two or more schedules of reinforcement are arranged. All schedule requirements must be completed to receive reinforcement.	Vollmer et al. (1997) used a conjunctive FT DRO schedule to reduce aggression in an adolescent with mental retardation.	Schedule-specific patterns of behavior are observed in each component.
Alternative schedule	Two or more schedules of reinforcement are available concurrently. The first schedule completed produces reinforcement.	Bowman et al. (1997) utilized an ALT FR 1 FR 1 EXT schedule to evaluate the reinforcer preferences of children with mental retardation.	Responding reflects a preference for one schedule component.

multiple schedules, the correlated stimuli acquire stimulus control over responding and become discriminative stimuli. To the extent that the schedule components differ, differential responding in the schedule components usually occurs more rapidly and is more pronounced in multiple schedules compared to mixed schedules.

Humans encounter multiple schedules with regularity. Students in school who attend a sequence of classes throughout the day experience a multiple schedule. Each class is a schedule component and is correlated with distinct stimuli, such as different teachers, textbooks, classrooms, and seating arrangements. The teachers in each class undoubtedly reinforce students' participation in classroom activities on different schedules, with some on ratio schedules, others on interval schedules, and still others on DRH schedules. Mixed (MIX) schedules are also frequently encountered. The first time we read a novel, watch a film, or drive through unfamiliar countryside, our points of interest (i.e., the availability of reinforcement) for attention to the activity vary from one point in time to another. However, there is no indication that the reinforcing properties of the novel, film, or drive are about to shift. Because these activities are usually not repeated, any stimuli correlated with changes in reinforcement do not develop stimulus control (i.e., the MIX schedule does not become a multiple [MULT] schedule).

Tiger and Hanley (2005) used MULT and MIX schedules to study variables that promote discriminative control of social approach responses in preschool children. Two children sat facing the experimenter at tables containing a variety of academic materials. The experimenter looked down except when delivering 5 seconds of attention contingent on social approach responses. The children were alternately presented with three schedule components in a randomized order. In the FR 1 component, each social approach response was reinforced with attention. In the EXT_1 component, one child's social initiatives were reinforced while the other child's were not, and in the EXT_2 component, neither child's approaches were reinforced. In the MULT schedule, denoted MULT FR 1 EXT_1 EXT_2, the experimenter wore a different colored floral lei during each component. The leis were not worn during the MIX schedule: MIX FR1 EXT_1 EXT_2. The students first experienced the MIX schedule and their social approach responses were undifferentiated across the three components, indicating that the children were unaware of when approach responses would and would not be reinforced. In the subsequent MULT schedule, approach responses became somewhat differentiated for one child, showing more approaches during the FR 1 component than the EXT components. However, approaches remained undifferentiated for the second child. To enhance stimulus control, the experimenter then described the rules of reinforcement and extinction for each schedule component and how each was correlated with a different colored lei, resulting in a MULT schedule with rules. This condition resulted in the greatest differential responding, which continued following a return to the MIX schedule.

Behavioral Contrast

Behavioral contrast is a phenomenon that results from an interaction among schedule components in a MULT schedule; that is, events in one schedule component affect responding in the other components. Reynolds (1961) first described this interaction in an experiment with pigeons exposed to two different MULT schedules. In the first schedule, key pecking was reinforced on a VI 3-minute schedule when the response keys were alternately illuminated red and green, resulting in a MULT VI 3-minute VI 3-minute schedule. Following stable responding in this schedule, the second multiple schedule was introduced. In this schedule, the green component was changed from VI 3-minute to extinction resulting in a MULT VI 3-minute EXT schedule. Figure 4.2 shows the results of Reynolds's experiment. Behavioral contrast is evident in the second MULT schedule. Whereas responding declined as expected during the EXT component, responding in the unchanged VI 3-minute component increased substantially. It is noteworthy that the increased response rate evident in the unchanged component did not result in an increased rate of reinforcement because response rate and reinforcement rate are largely independent in interval schedules. Behavioral contrast in interval schedules represents an "irrational" expenditure of responses (and caloric expenditure). This would not be the case in multiple ratio schedules in which increased responding in the unchanged component would compensate for the loss of reinforcement in the EXT component. There are numerous accounts for behavioral contrast (see Catania, 1998, p. 183, for this discussion).

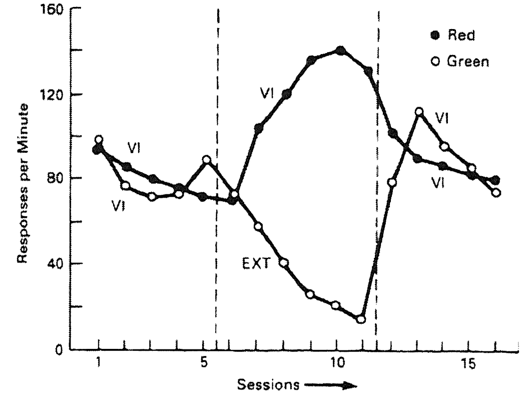

FIGURE 4.2. Reynolds's (1961) illustration of behavioral contrast in the multiple schedule arrangement: MULT VI 3-minute VI 3-minute schedules followed by MULT VI 3-minute EXT schedules resulted in relative increases in response rates in the unchanged VI 3-minute component.

There is growing evidence that humans show behavioral contrast. For example, Hantula and Crowell (1994) exposed undergraduate psychology students to equal MULT VI VI schedules in the context of a computerized stock investment task. Participants could make "investments" in stocks in two different markets that were alternately available and signaled by a written notice. Investments were reinforced with a 30% gain according to VI schedules. Following the MULT VI VI baseline, one market was placed on EXT and the other remained on the unchanged VI schedule. Five of the six study participants showed substantially increased investments in the unchanged VI component under the MULT VI EXT schedule.

Behavioral contrast can be particularly relevant in clinical ABA work. Interventions typically involve the discontinuation of reinforcement for undesirable behavior. When the undesirable behavior has been reinforced at a high rate and is then placed on EXT in one context, such as school, contrast effects may emerge in other contexts in which the intervention has not been implemented (e.g., home). This may be more likely if the reinforcement of prosocial alternative behavior does not fully compensate for the reduction in reinforcement from the EXT schedule. This possibility should guide the selection of reinforcement schedules for the prosocial behavior and the advisement of parents, for example, of the possible side effects of intervention.

Concurrent and Conjoint Schedules

Concurrent and conjoint schedules arrange for two or more schedule components to be available at the same time, such that the individual is free to alternate among the components at any point. This arrangement permits the assessment of the relative preference for the schedule components and the study of choice. As with MULT and MIX schedules, the difference between concurrent and conjoint schedules is that schedule components in concurrent schedules are correlated with distinct stimuli and are not in conjoint schedules. Concurrent schedules are characteristic of all human environments where numerous alternatives are available at any point in time and are generally correlated with distinct stimuli. For example, a woman commuting to work with a friend on a subway will have many different, concurrently available alternatives. She can converse with her friend on a variety of topics, read a newspaper, do a crossword puzzle, listen to music, people watch, plan her work day, and so on. Each of these activities is correlated with distinct stimuli, and each provides reinforcers according to some schedule. Because human environments are characterized by concurrent schedules of reinforcement, this is our emphasis in this chapter.

Concurrent (CONC) schedules can be arranged for any combination of interval, ratio, or differential schedules of reinforcement (Davison & McCarthy, 1988). However, the majority of studies employing concurrent schedules have used CONC VI VI schedules. This is because CONC ratio schedules ordinarily result in exclusive responding on the richer of the two schedules (Herrnstein & Loveland, 1975). The arrangement of asymmetrical schedules such as CONC VI

FR can produce a preference for the qualitative features of one of the schedules that is independent of the amount of reinforcement derived from the schedule (Baum, 1974). Experiments arranging CONC VI VI schedules generally include an adjunctive procedure known as a *changeover delay* (COD), which imposes a brief time interval during which responses cannot be reinforced immediately after switching from one schedule to another. The COD reduces the likelihood that schedule switching will be accidentally reinforced should the first response after the schedule switch be eligible for reinforcement.

Matching Theory

CONC schedules promote a pattern of response allocation that is very orderly. Herrnstein (1961, 1970) formulated the *matching law* that quantitatively described the functional relationship between relative response rates on CONC alternatives and relative obtained rates of reinforcement. The matching law states that relative response rate will match or be equal to relative reinforcement rate. In its simplest form, the matching law is expressed as $B1/B1 + B2 = r1/r1 + r2$, where $B1$ and $B2$ are response rates for two behaviors, and $r1$ and $r2$ are the obtained reinforcement rates for the two behaviors. This equation can be reduced to $B1/B2 = r1/r2$, and a line can be fitted to logarithmic transformations of the obtained data in the form of $\log (B1/B2) = a \log (r1/r2) + \log k$, where a is the slope of the line and $\log k$ is its intercept at the y-axis (see Baum, 1974, and McDowell, 1989, for full descriptions of mathematical transformations of the simplified form of the matching law). When there is perfect matching, $a = 1.0$ and $\log k = 0$. Values of $a > 1.0$ are known as *overmatching,* and values < 1.0 are referred to as *undermatching*, reflecting the individual's sensitivity to relative reinforcement rate. Values of $\log k > 0$ reflect a bias for $B1$, and values < 0 show a bias for $B2$ due to variables other than relative reinforcement rate (see below).

Conger and Killeen (1974) provided one of the first demonstrations of the matching law involving human social behavior. Their study participants engaged in conversation with two experimenters who provided comments of approval contingent on statements of the participant. The experimenters' comments were provided on different sets of CONC VI VI schedules. The dependent measure in the study, relative time participants directed verbal statements to the two experimenters, was found to match closely the relative rates of experimenter attention. Numerous studies have established the generality of the matching law relative to human behavior in the laboratory (Pierce & Epling, 1984) and to a wide range of socially relevant human behavior, from academic engagement (Martens et al., 1992) to the performance of basketball players (Vollmer & Bourret, 2000). Although generally robust, there have also been several reports of human performance departing from matching (Pierce & Epling, 1984). For example, Mace, Neef, Shade, and Mauro (1994) needed to employ a variety of adjunctive procedures in addition to a 15-seconds LH and COD (4 seconds, 8 seconds, or 10 seconds), such as a timer counting down to the end of each reinforcement interval and demonstrating how to allocate responding to maximize obtained reinforcement in order for adolescents to allocate their time to arithmetic problems in accordance with matching.

When choices differ only by the variable of relative rate of reinforcement, the choices are said to be *symmetrical.* However, human choices in natural environments are most often *asymmetrical.* Response alternatives can differ along several different parameters of reinforcement, including reinforcer quality, reinforcer delay, reinforcer amount, reinforcement schedule features, and control of reinforcers. Alternatives can also differ with respect to the response requirements or effort involved in obtaining reinforcement. Baum (1974) provided a matching equation that accommodated independent variables other than relative reinforcement rate. The *generalized matching law* expresses that $B1/B2 = V1/V2$, where V refers to the *value* of the given alternative as defined by the sum of the relative reinforcement parameters and response effort.

Mace and Roberts (1993) illustrated the applied relevance of the generalized matching law. They provided a conceptual framework to guide the functional assessment of undesirable behaviors and the selection of behavioral treatments. In a descriptive analysis of undesirable behavior under natural conditions, the behavior analyst can identify

the quality of the reinforcing consequence, the magnitude of delay to reinforcement, the amount of reinforcement provided, and the response requirement to produce reinforcement, and estimate the operative schedule of reinforcement. With this information, the behavior analyst can design an intervention that should effectively compete with the parameters of reinforcement and response effort that maintain undesirable behavior. This tool affords a more refined approach to the development of interventions based on the variables that affect choice.

Chained and Tandem Schedules

Chained and tandem schedules organize sequences of behavior that lead to reinforcement. Both schedules comprise two or more components arranged in a sequence. In a two-component example, completion of the schedule requirements for the *initial link* produces the onset of the second component, or *terminal link.* Completion of the terminal link schedule requirements results in delivery of a reinforcer. Schedule components in chained schedules are correlated with distinct stimuli, whereas components in tandem schedules are not. Human behavior is regularly exposed to chained and tandem schedules. For example, numerous sequences of behavior required to experience a vacation constitute a chained schedule, such as planning the vacation (initial link), booking transportation (*interim link*), and transportation to the desired location (terminal link). Completion of all of these schedule components produces access to the reinforcing events available at the vacation site.

As is true of the basic schedules of reinforcement discussed earlier, chained and tandem schedules rarely operate in isolation. The more common characteristic of natural human environments is for initial links to consist of a concurrent schedule; that is, humans are typically presented with a choice of sequential activities and terminal reinforcers. This arrangement is known as a *concurrent chain schedule.* In laboratory experiments, the initial link schedule requirements are usually identical (e.g., CONC VI 20 seconds VI 20 seconds). However, terminal link reinforcers, and sometimes schedule requirements, differ. Completion of the initial link alternative produces the S^D for the terminal link associated with that alternative. For example, completion of initial link A results in presentation of the S^D for terminal link A, and completion of this schedule requirement results in delivery of reinforcer A. A parallel sequence is followed for meeting the schedule requirements for initial link B (see Figure 4.3 for a diagram of the concurrent chain schedule employed by Rachlin & Green, 1972).

Self-Control

One contemporary development in ABA that employs concurrent-chain schedules is the behavioral model of self-control. Rachlin and Green (1972) formally developed the model in an experiment with pigeons. Figure 4.3 diagrams the concurrent-chain procedure they employed. The initial link was a CONC FR 25 FR 25 schedule with both response keys illuminated white. Completion of the right FR 25 schedule (top sequence) resulted in darkening of the response keys and houselight for T-seconds. After the blackout, the response keys were reilluminated green (right key) and red (left key).

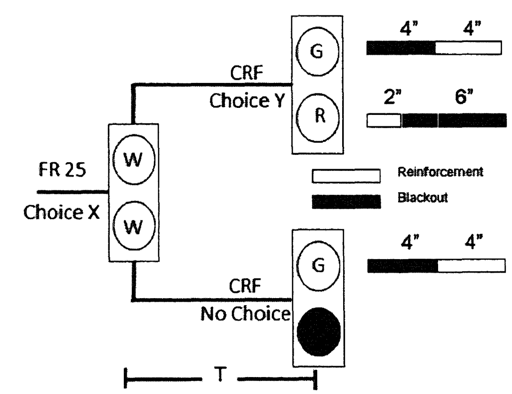

FIGURE 4.3. Rachlin and Green's (1972) concurrent-chain schedule illustrates a behavioral model of self-control. The initial link (CONC FR 25 FR 25) presented a choice between access to the terminal link schedules. Completion of the top (right) link produced a T-second delay followed by CONC CRF CRF schedules that presented a choice between small immediate reinforcement and large delayed reinforcement. Completion of the bottom (left) link produced a T-second delay followed by CONC CRF EXT schedules and the option only for large delayed reinforcement.

The terminal link was a CONC CRF CRF schedule in which a single key peck on green resulted in a 4-second blackout followed by a 4-second access to food, and a single key peck on red resulted in immediate access to 2 seconds of food followed by a 6-second blackout. Thus, completion of the right FR 25 initial link resulted in later exposure to a choice between small immediate reinforcement (SIR) and large delayed reinforcement (LDR). By contrast, completion of the left initial link FR 25 schedule resulted in a similar blackout for *T*-seconds followed by the illumination of the green key alternative only with the LDR contingency. When the time interval between completion of the initial link and onset of the terminal link was short (e.g., 0.5 seconds), the pigeons reliably chose the red key alternative. Rachlin and Green describe this choice as an *impulsive* one because it forfeits an additional 2-second access to food available for the green key. Thus, the delay to reinforcement discounts the value of the LDR. When the experimenters varied the value of *T*, pigeons showed a shift in their preference on the initial link. In general, as the value of *T* increased, so did the probability of choosing the left initial link FR 25 schedule that later resulted in no choice and the LDR contingency only. Rachlin and Green referred to choosing the left initial link key as making a *commitment response*, one that avoids the "temptation" of SIR and exposes the individual to the LDR contingency only. *Self-control* is said to occur when the individual (1) chooses the LDR over the SIR contingency when exposed to both or (2) makes the commitment response in the initial link.

Numerous applied studies have utilized concurrent-chain schedules to study impulsivity and self-control. The behavior of children with attention-deficit/hyperactivity disorder (ADHD) is particularly relevant to this procedure because a defining characteristic of this disorder is impulsivity and a primary clinical goal is the development of self-control. For example, numerous studies have found that children with ADHD are more likely than their typically developing peers to choose SIR over LDR impulsively (e.g., Hoerger & Mace, 2006; Neef, Marckel, et al., 2005; Schweitzer & Sulzer-Azaroff, 1988). Other studies have shown that impulsive behavior is sensitive to variables other than delayed reinforcement, such as response effort (Hoerger & Mace, 2006). Finally, this paradigm has been used guide the development of specific interventions to promote self-control, such as delay fading and commitment training (Binder, Dixon, & Ghezzi, 2000; DuPaul & Ervin, 1996), and to evaluate response to stimulant medication (Neef, Bicard, Endo, Coury, & Aman, 2005). Thus, the concurrent-chain schedule has provided a conceptual model for understanding impulsivity and self-control, a procedure for objectively assessing an individual's sensitivity to delayed reinforcement and other variables, and a model for identifying specific interventions to promote self-control and evaluating pharmacological interventions.

Behavioral Momentum Theory

Behavioral momentum is a metaphor proposed by Nevin and colleagues (1983) to describe the tendency for baseline response rates to persist following some response disruptor (see earlier discussion of resistance to change). As in Newton's second law of motion, behavioral momentum is the product of behavioral mass and behavioral velocity, where *behavioral velocity* is baseline response rate and *behavioral mass* is the resistance of baseline response rate to change following application of varying amounts of some response disruptor. When response rates are graphed across varying amounts of the response disruptor (e.g., sessions of extinction, amounts of presession food), the height of the curve or function on the *y*-axis reflects behavioral velocity, and the slope of the function across the *x*-axis reflects resistance to change; the total area under the curve represents a response's behavioral momentum.

Behavioral momentum has been studied using a variety of schedules of reinforcement, including multiple schedules (Nevin et al., 1983), multiple concurrent schedules (Nevin, Tota, Torquato, & Shull, 1990), and concurrent-chain schedules (Grace & Nevin, 1997). Numerous studies have shown that resistance to change is a function of the reinforcement conditions related to these schedules. For example, Nevin (1974) and Nevin and colleagues (1983) used a two-component multiple schedule to demonstrate that resistance to change is a positive function of baseline rate of reinforcement. Different pairs of MULT VI VI schedules arranged a higher rate of reinforcement in one component relative to the other. During conditions of EXT, satiation, and dark-key food, key pecking in pigeons was more persistent in the component with the higher baseline reinforcement rate. In a subsequent series of experiments, Nevin and colleagues (1990) tested the competing hypotheses that resistance to change is a function of baseline response–reinforcer relations versus baseline stimulus–reinforcer relations. In their Experiment 2, baseline consisted of a three-component multiple concurrent schedule. In each component of the MULT, two CONC schedules operated, where the left key is the first CONC schedule and the right key the second: CONC VI 45/hour VI 15/hour (green), CONC EXT VI 15/hour (red), and CONC EXT VI 60/hour (white). In this arrangement, the response–reinforcer contingencies were equal in the green- and red-key components (15/hour each) and less than the white-key component (60/hour). By contrast the stimulus–reinforcer contingences (i.e., the total reinforcers delivered in the presence of each color) were equal in green and white (60/hour each) and less than red (15/hour). Tests of the resistance of right-key pecking to extinction and satiation showed that resistance to change was a positive function of the total number of reinforcers delivered in each component (color-reinforcer contingency) rather the number of reinforcers delivered on the right key (peck-reinforcer contingency). Nevin and colleagues' general findings have been replicated in several human studies (e.g., Cohen et al., 2001; Dube & McIlvane, 2001; Mace et al., 1990).

Ahern, Clark, Gardenier, Chung, and Dube (2003) illustrated the relevance of the Nevin and colleagues (1990) findings to clinically important human behavior. A functional analysis of the stereotypical behavior of three children with autism supported the conclusion that stereotypy was maintained by automatic reinforcement. Next, preferred objects were identified via a preference assessment. Levels of stereotypical behavior were then compared in a test sequence of conditions and a control sequence. The test sequence consisted of baseline (no play materials available) → VT delivery of a preferred item → test (continuous access to a second preferred item) → baseline. The control sequence consisted of baseline → baseline → test → baseline. Ahern and colleagues found that while both the VT and test conditions reduced stereotypical behavior relative to baseline (due to the effects of alternative reinforcement), stereotypy was higher in the test condition that followed VT reinforcer deliveries than in the test condition that followed baseline with no toys available. Mace (2000) and Ahern and colleagues pointed out that while interventions based on differential reinforcement of alternative behaviors (DRA) and FT or VT schedules reliably reduce occurrences of undesirable behavior, these same interventions can have persistence-strengthening effects on undesirable behavior.

Grace and Nevin (2000) proposed a unifying theory of choice and behavioral momentum in which the variables functionally related to preference or choice are the same as those related to resistance to change. One study forming the basis of this theory was conducted by Grace and Nevin (1997), who randomly alternated a concurrent-chain procedure and a multiple schedule procedure within a single experimental session. Three response keys were mounted on a wall above a food magazine. In the concurrent-chain procedure, the side keys were illuminated white in the initial link consisting of equal CONC VI 20-second VI 20-second schedules. Initial link reinforcement consisted of terminal link entry and darkening of the side keys, and illumination of the center key either green or red depending on whether terminal link entry was contingent on a left or a right initial link key peck. The terminal key colors were correlated with a higher- or lower-rate VI schedule. Thirty-six cycles of the concurrent-chain arrangement were presented each session. Thus, the concurrent-chain procedure permitted the assessment of preference for the terminal link as a function of choice in the initial link. The multiple schedule procedure in the experimental session involved the usual alternation of green and red keys correlated with the same VI schedules used in the concurrent-chain procedure. Following this baseline arrangement, resistance to change was tested by dark-key food deliveries between components in the multiple schedule. Grace and Nevin found that preference in the concurrent chains and resistance to change in the multiple schedule were comparably predicted by relative rate of reinforcement. Mace, Mauro, Boyajian, and Eckert (1997) demonstrated the applied significance of Grace and Nevin's work. They modified the high-*p* procedure that was inspired by the behavioral momentum metaphor to increase its effectiveness. Knowing that reinforcer quality affects choice, Mace et al. reasoned that supplying a higher-quality reinforcer (food) contingent on compliance to high-*p* instructions would increase the resistance of compliance to change when a low-*p* instruction was presented. The high-*p* procedure with food proved effective at increasing compliance to low-*p* instructions that were unresponsive to the high-*p* procedure without food.

Conjunctive and Alternative Schedules

Both conjunctive and alternative schedules comprise two or more schedule components. In conjunctive schedules, the schedule requirements for *all* components must be satisfied to produce a reinforcer delivery. Unlike chained schedules, the order of schedule completion is irrelevant in conjunctive schedules. By contrast, alternative schedules arrange schedule components to be available concurrently. The reinforcer is contingent on completion of *either* component, whichever occurs first.

Vollmer and colleagues (1997) evaluated the effectiveness of FT schedules to reduce the severe aggressive behavior of a 13-year-old girl with severe mental retardation, whose aggression was maintained by tangible reinforcement. Following a functional analysis baseline, access to a preferred magazine was initially delivered continuously, resulting in zero occurrences of aggression. During attempts to thin the schedule to an FT schedule, aggression reemerged sharply at an FT 30-second schedule. A within-session analysis of the temporal relationship between FT reinforcer deliveries and occurrences of aggression showed that scheduled reinforcer deliveries often coincided within 10 seconds of aggressive acts. This suggested that the FT schedule could have adventitiously reinforced aggressive behavior. To avoid this possibility, Vollmer and colleagues introduced a conjunctive FT DRO 10-second schedule. Access to the preferred magazine was set up by the FT schedule; however, the magazine was delivered only if there had been no aggression during the last 10 seconds of the FT interval; that is, both the FT and DRO schedule requirements had to be satisfied to give the girl access to the magazine. After an initial response burst, the conjunctive schedule reduced aggression to low levels, and the FT schedule was then successfully thinned to a conjunctive FT 5-minute DRO 10-second schedule.

Bowman, Piazza, Fisher, Hagopian, and Kogan (1997) used an alternative (ALT) schedule of reinforcement to evaluate preference for varied presentation of less preferred reinforcers versus constant delivery of highly preferred reinforcers. Participants were taught a simple response such as sitting in a chair, standing in a square, operating a microswitch, or stuffing an envelope to obtain a reinforcer. The study compared three conditions of reinforcement that were made available concurrently: varied reinforcers, constant reinforcers, and EXT. For example, three chairs were positioned in a room, and the reinforcers available for each response were placed on the chair. Each time the criteria for reinforcement were met (e.g., sitting in a chair or operating a microswitch), the reinforcer (varied, constant, or no reinforcer) was delivered. Thus, the schedule denotation was ALT FR 1 FR 1 EXT. Unlike concurrent schedules of reinforcement in which the individual can switch among schedules to obtain reinforcement from all schedule components, the alternative schedule reflects a preference for one reinforcer over another. Bowman and colleagues found that four out of six participants showed a preference for the varied lower-preference reinforcer, suggesting that lower-preference reinforcers can be made more effective when varied.

Summary and Conclusion

We have reviewed basic and combined schedules of reinforcement, and have provided definitions for each schedule and illustrations of the applications of the schedules in the ABA research literature. Schedules of reinforcement promote specific patterns of responding but do so only in a broader context of available concurrent discriminated

operants. That broader context includes the temporary motivational conditions for each discriminated operant and its particular history of reinforcement or behavioral mass. We have provided an overview of some contemporary developments in ABA, such as behavioral contrast, the matching theory, self-control, and behavioral momentum theory, and have illustrated that these topics are directly related to specific schedules of reinforcement. Deliberate use of schedules of reinforcement offers applied behavior analysts a powerful tool to understand the conditions that maintain behavior and to design highly effective interventions.

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