CHAPTER 2

THE FIVE PILLARS OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR

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"What is the experimental analysis of behavior?" Skinner (1966) famously asked in an address to Division 25 of the American Psychological Association, now the Division for Behavior Analysis (then the Division for the Experimental Analysis of Behavior). His answer included a set of methods and a subject matter, both of which originated with his research and conceptual analyses that began in the 1930s. Since those early days, what began as operant conditioning has evolved from its humble laboratory and nonhuman animal origins to encompass the breadth of contemporary psychology. This handbook, which is itself testimony to the preceding observation, is the impetus for revisiting Skinner's question. The developments described in each of the handbook's chapters are predicated on a few fundamental principles, considered here as the pillars that constitute the foundation of the experimental analysis of behavior (TEAB). These five pillars—research methods, reinforcement, punishment, control by stimuli correlated with reinforcers and punishers, and contextual and stimulus control—are the subject of this chapter. Together, they provide the conceptual and empirical framework for understanding the ways in which environmental events interact with behavior. The pillars, although discussed separately from one another here for didactic purposes, are inextricably linked: The methods of TEAB are pervasive in investigating the other pillars; punishment and stimulus control are not possible in the absence of the reinforcement that maintains the behavior being punished or under control of other stimuli; stimuli correlated with reinforcers and punishers also have their effects only in the context of reinforcement and are also closely related to other, more direct stimulus control processes; and punishment affects both reinforcement and stimulus control.

PILLAR 1: RESEARCH METHODS

Research methods in TEAB are more than a set of techniques for collecting and analyzing data. They certainly enable those activities, but, more important, they reflect the basic epistemological stance of behavior analysis: The determinants of behavior are to be found in the interactions between individuals and their environment. This stance led to the adoption and evolution of methods and concepts that emphasize the analysis of functional relations between features of that environment and the behavior of individual organisms. Skinner (1956) put it as follows:

> We are within reach of a science of the individual. This will be achieved not by resorting to some special theory of knowledge in which intuition or understanding takes the place of observation

This chapter is dedicated to Stephen B. Kendall, who, as my first instructor and, later, mentor in the experimental analysis of behavior, provided an environment that allowed me to learn about the experimental analysis of behavior by experimenting.

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> and analysis, but through an increasing grasp of relevant conditions to produce order in the individual case. (p. 95)

Single-Case Procedures and Designs

Two distinguishing features of research methods in TEAB are emphases on what Bachrach (1960) called the *informal theoretical approach* and on examining the effects of independent variables on well-defined responses of individual subjects. Skinner's (1956) review of his early research defined Bachrach's label. The inductive tradition allows free rein in isolating the variables of which behavior is a function, unencumbered by many of the shoulds, oughts, and inflexibilities of research designs derived from inferential statistical research methods (Michael, 1974; see Chapters 5 and 7, this volume).

The essence of the second feature, single-case experimental designs, is that by investigating the effects of the independent variable on individual subjects, each subject serves as its own control. Thus, effects of independent variables are compared, within individual subjects, with a baseline on which the independent variable is absent (or present at some other value). This methodological approach to analyzing the subject matter of psychology can be contrasted with an approach based on the inferential statistical analysis of the data generated across different groups of subjects exposed to the presence or absence or different values of the independent variable (Michael, 1974; see Chapters 7 and 8, this volume). A single-case analysis precludes a major source of variation inherent in all group designs: that variation resulting from between-subjects comparisons. It also minimizes other so-called threats to internal validity such as those associated with statistical regression toward the mean and subject selection biases (cf. Kazdin, 1982).

Three central features of single-case research are selecting an appropriate design, establishing baseline performance, and selecting the number of subjects to study. The most basic design involves first establishing a baseline, A; then introducing the independent variable, B; and finally returning to the baseline. From this basic A-B-A design, many variations spring (Kazdin, 1982; see Chapter 5, this volume). Within-subject designs in the tradition of TEAB involve the repeated observation of the targeted response over multiple sessions until an appropriate level of stability is achieved. Without an appropriate design and an appropriate degree of stability in the baseline, attributing the changes in the dependent variable to the independent variable is not possible.

Decisions about the criteria for the baseline begin with a definition of the response. Skinner (1966) noted that "an emphasis on rate of occurrence of repeated instances of an operant distinguishes the experimental analysis of behavior" (p. 213). Unless the response is systematically measured and repeatable, stability will be difficult, if not impossible, to achieve. The dimensions of baseline stability are the amount of variability or bounce in the data and the extent of trends. Baseline stability criteria are typically established relative to the anticipated effects of the independent variable. Thus, if a large effect of the independent variable is anticipated, more variation in the baseline is acceptable because, presumably, the effect will be outside the baseline range. Similarly, if a strong downward trend is expected when the independent variable is introduced, then an upward trend in the baseline data is more acceptable than if the independent variable were expected to increase the rate of responding.

Some circumstances may not seem to lend themselves readily to single-case designs. An example is that in which behavioral effects cannot be reversed, and thus baselines cannot be recovered. Sidman (1960), however, observed that even in such cases, "the use of separate groups destroys the continuity of cause and effect that characterizes an irreversible behavioral process" (p. 53). In the case of irreversible effects, creative designs in the single-case tradition have been used to circumvent the problem. Boren and Devine (1968), for example, investigated the repeated acquisition of behavioral chains by arranging a task in which monkeys learned a sequence of 10 responses. Once that pattern was stable, the pattern was changed, and the monkeys had to learn a new sequence. This procedure allowed the study of repeated acquisition of behavioral chains in individual subjects across a relatively long period of time. In other cases either in which baselines are unlikely to be reversed or in which it is ethically

questionable to do so, a multiple-baseline design often can be used (Baer, Wolf, & Risley, 1968; see Chapter 5, this volume).

Selecting the number of subjects is based on both practical concerns and experimenter judgment. A few studies in the *Journal of the Experimental Analysis of Behavior* were truly single subject in that they involved only one subject (e.g., de Lorge, 1971), but most have involved more. Decisions about numbers of subjects interact with decisions about the design, types of independent variables being studied, and range of values of these variables. Between-subjects direct replications and both between- and within-subject systematic replications involving different values of the independent variable increase the generality of the findings (see Chapter 7, this volume).

Individual-subject research has emphasized experimental control over variability, as contrasted with group designs in which important sources of variability are isolated statistically at the conclusion of the experiment. Sidman (1960) noted that "acceptance of variability as unavoidable or, in some sense as representative of 'the real world' is a philosophy that leads to the ignoring of relevant factors" (p. 152). He methodically laid out the tactics of minimizing variability in experimental situations and identified several sources of such variability. Between-subjects variability already has been discussed. Another major source of variability discussed by Sidman is that resulting from weak experimental control. Inferential statistical analysis is sometimes used to supplement experimental analysis. Such analysis is not needed if baseline and manipulation of response distributions do not overlap, but sometimes they do, and in these cases some behavior analysts have argued for their inclusion (see, e.g., Baron [1999] and particularly Davison [1999] on the potential utility of nonparametric statistics in within-subject designs in which baseline and intervention distributions overlap). Others (e.g., Michael, 1974), however, have noted that statistical analysis of group data draws the focus away from an experimental analysis of effects demonstrable in individual subjects, removes the experimenter from the data, and substitutes statistical control for experimental control.

A final point with respect to single-case designs relates to the previous discussion of the inductive method. When individual subjects' behavior is studied, it is not surprising that the same value of a variable may have different effects across subjects. For example, a relatively brief delay of reinforcement may markedly reduce the responding of one subject and not change the responding of another. Rather than averaging the two, the tactic in TEAB is to conduct a parametric analysis of delay duration with both subjects, to search for orderly and qualitatively similar functional relations across subjects even though, on the basis of intersubject comparisons, individuals may respond differently at any particular value. The achievement of these qualitatively similar functional relations contributes to the generality of the effect. The establishment of experimental control through the methods described in this section is a major theme of TEAB, exemplified in each of the other, empirical pillars of TEAB. Before reviewing those empirical pillars, however, examining how critical features of the environment are defined and used in TEAB is important.

Defining Environmental Events

In the laboratory, responses often are defined operationally, as a matter of convenience, in terms of, for example, a switch closure. In principle, however, they are defined functionally, in terms of their effects. Baer (1981) observed that although every response or class of responses has form or structure, operant behavior has no necessary structure. Rather, its structure is determined by environmental circumstance:

> The structure of operant behavior is limited primarily by our ability to arrange the environment into contingencies with that behavior; to the extent that we can wield the environment more and more completely, to that extent behavior has less and less necessary structure. This is tantamount to saying that it is mainly our current relatively low level of technological control over the environment that seems to leave behavior with apparent necessary structure and that such a limitation is trivial. (Baer, 1981, p. 220).

Functional definitions in TEAB originated with Skinner's (1935) concept of the operant. With that analysis, he organized fluid, unique individual responses into integrated units or classes—operants—whereby all the unique members have the same effect on the environment. Stimuli were similarly organized into functional classes on the basis of similarity of environmental (behavioral) effect. He also conceptualized reinforcement not in terms of its forms or features, but functionally, in terms of its effects on responses. Thus, any environmental event can function, in principle, as a reinforcer or as a punisher, or as neither, depending on how it affects behavior. On the question of circularity, Skinner (1938) simply noted that

> a reinforcing stimulus is defined as such by its power to produce the resulting change. There is no circularity about this; some stimuli are found to produce the change, others not, and they are classified as reinforcing and non-reinforcing accordingly. (p. 62)

Another aspect of the contextual basis of reinforcers and punishers is what Keller and Schoenfeld (1950; cf. Michael, 1982) called the *establishing operation*. The establishing operation delineates the conditions necessary for some event or activity to function as a reinforcer or punisher. In most laboratory research, establishing a reinforcer involves restricted access, be it, for example, to food or to periods free of electric shock delivery. That is, reinforcers and punishers have to be established by constructing a specific context or history. Morse and Kelleher (1977) summarized several experiments in which they suggested that electric shock delivery sufficient to maintain avoidance behavior was established as a positive reinforcer. This establishment was accomplished by creating particular kinds of behavioral histories. McKearney (1972), for example, first maintained responding by a free-operant shock-avoidance schedule and then concurrently superimposed a schedule of similar shocks delivered independently of responding. This schedule was in turn replaced by response-dependent shocks scheduled at the same rate as the previously response-independent ones, and the avoidance schedule was eliminated. Responding then was maintained when its only consequence was to deliver an electric shock that had previously been avoided.

As the research cited by Morse and Kelleher (1977) suggests, the type of event is less important than its behavioral effect (which in turn depends on the organism's history of interaction with the event). Events that increase or maintain responding when made dependent on the response are categorized as reinforcers, and events that suppress or eliminate responding are categorized as punishers. Associating a valence, positive or negative, with these functionally defined reinforcers and punishers is conventional. The valence describes the operation whereby the behavioral effect of the consequence occurs, that is, whether the event is added to or subtracted from the environment, which yields a 2×2 contingency table in which valence is shown as a function of behavioral change (maintain or increase in the case of reinforcement, and decrease or eliminate in the case of punishment).

Despite widespread adoption of this categorization system, the use of valences has been criticized on the grounds that they are arbitrary and ambiguous (Baron & Galizio, 2005; Michael, 1975). Baron and Galizio (2005) cited an experiment in which "rats kept in a cold chamber would press a lever that turned on a heat lamp" (p. 87) to make the point that in such cases it indeed is difficult to separate cold removal and heat presentation. Presenting food, it has been argued, may be tantamount to removing (or at least reducing) deprivation and removing electric shock may be tantamount to presenting a shock-free period (cf. Verhave, 1962). Although the Michael (1975) and Baron and Galizio position falls on sympathetic ears (e.g., Marr, 2006), the distinction continues. The continued use of the positive–negative distinction is a commentary on its utility in the general verbal community of behavior analysts as well as in application and teaching. Despite potential ambiguities in some circumstances, the operations are clear—events that experimenters present and remove are sufficiently straightforward to allow description. The question of valences, as with any question in a science, should have an empirical answer. Because the jury is still out on this question, the long-enduring practice

of identifying valences on the basis of experimental operations is retained in this chapter.

PILLAR 2: REINFORCEMENT

An organism behaves in the context of an environment in which other events are constantly occurring, some as a result of its responses, and others independent of its responses. One outcome of some of these interactions is that the response becomes more likely than it would be in their absence. Such an outcome is particularly effective when a dependency exists between such environmental events and behavior, a two-term contingency involving responding and what will come to function as a reinforcer. This process of reinforcement is fundamental in understanding behavior and is thus a pillar of TEAB. Of the four empirical pillars, reinforcement may be considered the most basic because the other three cannot exist in the absence of reinforcement. Each of the other pillars adds another element to reinforced responding.

Establishing a Response

As noted, to establish an operant response, a reinforcer must be established and the target response specified precisely so that it is distinguished from other response forms. Several techniques may then be used to bring about the target response. One is to simply wait until it occurs (e.g., Neuringer, 1970); however, the target response may never occur without more direct intervention. Some responses can be elicited or evoked through a technique known colloquially as "baiting the operandum." Spreading a little peanut butter on a lever, for example, evokes considerable exploration by the rat of the lever, typically resulting in its depression, which then can be reinforced conventionally. The difficulty is that such baiting sometimes results in atypical response topographies that later can be problematic. A particularly effective technique related to baiting is to elicit the response through a Pavlovian conditioning procedure known as autoshaping (Brown & Jenkins, 1968). Once elicited, the response then can be reinforced. With humans, instructions are often an efficient means of establishing an operant response (see Rules and Instructions section). As with all techniques for establishing operant responses, the success of the instructions depends on their precision. An alternative form of instructional control is to physically guide the response (e.g., Gibson, 1966). Such guided practice may be considered a form of imitation, although imitation as a more general technique of establishing operant behavior does not involve direct physical contact with the learner.

The gold-standard technique for establishing an operant response is the differential reinforcement of successive approximations, or shaping. Discovered by Skinner in the 1940s, *shaping* involves immediately reinforcing successively closer approximations to the target response (e.g., Eckerman, Hienz, Stern, & Kowlowitz, 1980; Pear & Legris, 1987). A sophisticated analysis of shaping is that of Platt (1973), who extensively studied the shaping of interresponse times (IRTs; the time between successive responses). Baron (1991) also described a procedure for shaping responding under a shock-avoidance contingency. Shaping is part of any organism's day-to-day interactions with its environment. Whether one is hammering a nail or learning a new computer program, the natural and immediate consequences of an action play a critical role in determining whether a given response will be eliminated, repeated, or modified.

Some researchers have suggested that shaping occurs when established reinforcers occur independently of responding. Skinner (1948; see also Neuringer, 1970), for example, provided food-deprived pigeons with brief access to food at 15-s intervals. Each pigeon developed repetitive stereotyped responses. Skinner attributed the outcome to accidental temporal contiguity between the response and food delivery. His interpretation, however, was challenged by Staddon and Simmelhag (1971) and Timberlake and Lucas (1985), who attributed the resulting behavior to biological and ecological processes rather than reinforcement. Nonetheless, the notion of superstitious behavior resulting from accidental pairings of response and reinforcer remains an important methodological and interpretational concept in TEAB (e.g., the changeover delay used ubiquitously in concurrent schedules is predicated on its value in eliminating the adventitious reinforcement of changing between concurrently available operanda).

Positive Reinforcement

Positive reinforcement is the development or maintenance of a response resulting from the response-dependent, time-limited presentation of a stimulus or event (i.e., a positive reinforcer).

Schedules of positive reinforcement. A *schedule* is a prescription for arranging reinforcers in relation to time and responses (Zeiler, 1984). The simplest such arrangement is to deliver reinforcers independently of responding. Zeiler (1968), for example, first stabilized key pecking of pigeons on fixed-interval (FI) or variable-interval (VI) schedules. Then, the response–reinforcer dependency was eliminated so that reinforcers were delivered independently of key pecking at the end of fixed or variable time periods. This elimination generally reduced response rates, but the patterns of responding continued to be determined by the temporal distribution of reinforcers: Fixed-time schedules yielded positively accelerated responding across the interfood intervals, and variable-time (VT) schedules yielded more evenly distributed responding across those intervals.

Zeiler's (1968) experiment underlines the importance of response–reinforcer dependency in schedule-maintained responding. This dependency has been implemented in two ways in reinforcement schedules. In ratio schedules, either a fixed or a variable number of responses is the sole requirement for reinforcement. In interval schedules (as distinguished from time schedules, in which the response–reinforcer dependency is absent), a single response after a fixed or variable time period is the requirement for reinforcement. Each of these four schedules—fixed ratio (FR), variable ratio (VR), FI, and VI—control well-known characteristic response patterns. In addition, the distribution of reinforcers in VI and VR schedules, respectively, affect the latency to the first response after a reinforcer and, with the VI schedule, the distribution of responses across the interreinforcer interval (Blakely & Schlinger, 1988; Catania & Reynolds, 1968; Lund, 1976).

Other arrangements derive from these basic schedules. For example, reinforcing a sequence of two responses separated from one another by a relatively long or a relatively short time period results in, respectively, low and high rates of responding. The former arrangement is described as differential-reinforcement-of-low-rate (DRL), or an IRT > *t*, schedule, and the latter as a differential-reinforcement-of-high-rate, or an IRT < *t*, schedule. The latter in particular often is arranged such that the first IRT < *t* after the passage of a variable period of time is reinforced.

The various individual schedules can be combined to yield more complex arrangements, suited for the analysis of particular behavioral processes. The taxonomic details of such schedules are beyond the scope of this chapter (see Ferster & Skinner, 1957; Lattal, 1991). Several of them, however, are described in other sections of this chapter in the context of particular behavioral processes.

Schedules of reinforcement are important in TEAB because they provide useful baselines for the analysis of other behavioral phenomena. Their importance, however, goes much further than this. The ways in which consequences are scheduled are fundamental in determining behavior. This point resonates with the earlier Baer (1981) quotation in the Defining Environmental Events section about behavioral structure. The very form of behavior is a function of the organism's history, of the ways in which reinforcement has been arranged—scheduled—in the past as well as in the present.

Parameters of positive reinforcement. The schedules described in the previous section have their effects on behavior as a function of the parameters of the reinforcers that they arrange. Four widely studied parameters of reinforcement are dependency, rate, delay, and amount.

The importance of the response–reinforcer dependency in response maintenance has been described in the preceding section. Its significance is underscored by subsequent experiments showing that variations in the frequency with which this dependency is imposed or omitted modulate response rates (e.g., Lattal, 1974; Lattal & Bryan, 1976). In addition, adding response-independent reinforcers when responding is maintained under different schedules changes both rates and patterns of responding (e.g., Lattal & Bryan, 1976; Lattal, Freeman, & Critchfield, 1989).

Reinforcement rate is varied on interval schedules by changing the interreinforcer interval and on ratio schedules by varying the response requirement.

The effects of reinforcement rate depend on what is measured (e.g., response rate, latency to the first response after a reinforcer). Generally speaking, positively decelerated hyperbolic functions describe the relation between response rate and reinforcement rate (Blakely & Schlinger, 1988; Catania & Reynolds, 1968; Felton & Lyon, 1966; but see the Behavioral Economics section later in this chapter—if the economy is closed, a different relation may hold).

Delaying a reinforcer from the response that produces it generally decreases response rates as a function of the delay duration (whether the delay is accompanied by a stimulus change) and the schedule on which it is imposed (Lattal, 2010). The effects of the delay also may be separated from the inevitable changes in reinforcement rate and distribution that accompany the introduction of a delay of reinforcement (Lattal, 1987).

Amount of reinforcement includes both its form and its quantity. In terms of form, some reinforcers are substitutable for one another to differing degrees (e.g., root beer and lemon-lime soda), whereas other qualitatively different reinforcers do not substitute for one another, but may be complementary. Two complementary reinforcers covary with one another (e.g., food and water). Reinforcers that vary in concentration (e.g., a 10% sucrose solution vs. a 50% sucrose solution), magnitude (one vs. six food pellets), or duration (1 s versus 6 s of food access) often have variable effects on behavior (see review by Bonem & Crossman, 1988), with some investigators (e.g., Blakely & Schlinger, 1988) reporting systematic differences as a function of duration, but others not (Bonem & Crossman, 1988). One variable that affects these different outcomes is whether the quantitatively different reinforcers are arranged across successive conditions or within individual sessions (Catania, 1963). DeGrandpre, Bickel, Hughes, Layng, and Badger (1993) suggested that reinforcer amount effects are better predicted by taking into account both other reinforcement parameters and the schedule requirements (see Volume 2, Chapter 8, this handbook).

Negative Reinforcement

Negative reinforcement is the development or maintenance of a response resulting from the response-dependent, time-limited removal of some stimulus or event (i.e., a negative reinforcer).

Schedules of negative reinforcement. Schedules of negative reinforcement involve contingencies in which situations are either terminated or postponed as a consequence of the response. The prototypical stimulus used as the negative reinforcer in laboratory investigations of negative reinforcement is electrical stimulation, because of both its reliability and its specifiability in physical terms, although examples of negative reinforcement involving other types of events abound.

Escape. Responding according to some schedule intermittently terminates the delivery of electric shocks for short periods. Azrin, Holz, Hake, and Allyon (1963) delivered to squirrel monkeys response-independent shocks according to a VT schedule. A fixed number of lever presses suspended shock delivery and changed the stimulus conditions (turning on a tone and dimming the chamber lights) for a fixed time period. Lever pressing was a function of both the duration of the time out and shock intensity, but the data were in the form of cumulative records, precluding a quantitative analysis of the functional relations between responding and these variables. This and an earlier experiment on VI escape schedules with rats (Dinsmoor, 1962) are among the few studies reporting the effects of schedules of negative reinforcement based on shock termination, thereby limiting the generality of the findings.

One problem with using escape from electric shock is that shock can elicit responses, such as freezing or emotional reactions, that are incompatible with the operant escape response. An alternative method of studying escape that circumvents this problem is a timeout from the avoidance procedure first described by Verhave (1962). Perone and Galizio (1987, Experiment 1) trained rats to lever press when this response postponed the delivery of scheduled shocks. At the same time, a multiple schedule was in effect for a second lever in the chamber. During one of the multiple-schedule components, pressing the second lever produced timeouts from avoidance (i.e., escape from the avoidance contingency and the stimuli associated with it) according

to a VI schedule. Presses on the second lever had no effect during the other multiple-schedule component (escape extinction). During the VI escape component, responding on the second lever was of moderate rate and constant over time, but it was infrequent in the escape-extinction component. Other parameters of timeout from avoidance largely have been unexplored.

Avoidance. The difference between escape and avoidance is one of degree rather than kind. When the escape procedure is conceptualized conventionally as allowing response-produced termination of a currently present stimulus, avoidance procedures allow responses to preclude, cancel, or postpone stimuli that, in the absence of the response, will occur. The presentation of an electric shock, for example, is preceded by a warning stimulus, during which a response terminates the stimulus and cancels the impending shock. Thus, there is escape from a stimulus associated with a negative reinforcer as well as avoidance of the negative reinforcer itself. Although a good bit of research has been conducted on discriminated avoidance (in which a stimulus change precedes an impending negative reinforcer, e.g., Hoffman, 1966), avoidance unaccompanied by stimulus change is more commonly investigated in TEAB.

Free-operant avoidance, sometimes labeled *nondiscriminated* or *unsignaled avoidance,* is characterized procedurally by the absence of an exteroceptive stimulus change after the response that postpones or deletes a forthcoming stimulus, such as electric shock. The original free-operant avoidance procedure was described by Sidman (1953) and often bears his name. Each response postponed for a fixed period an otherwise-scheduled electric shock. If a shock was delivered, subsequent shocks were delivered at fixed intervals until the response occurred. These two temporal parameters, labeled, respectively, the *response–shock* (R-S) and *shock–shock* (S-S) intervals together determine response rates. Deletion and fixed- and variable-cycle avoidance schedules arrange the cancellation of otherwise unsignaled, scheduled shocks as a function of responding, with effects on responding similar to those of Sidman avoidance (see Baron, 1991).

Parameters of negative reinforcement. Two variables that affect the rate of responding under schedules of negative reinforcement are the parameters (e.g., type, frequency [S-S interval in the case of free-operant avoidance], intensity, duration) of the stimulus that is to be escaped or avoided and the duration of the period of stimulus avoidance or elimination yielded by each response (e.g., the R-S interval in Sidman avoidance). Leander (1973) found that response rates on free-operant avoidance schedules were an increasing function of the interaction between electric shock intensity and duration (cf. Das Graças de Souza, de Moraes, & Todorov, 1984). Shock frequency can be manipulated by changing either the S-S or the R-S interval. With other parameters of the avoidance contingency held constant, Sidman (1953) showed that response rates increased with shorter S-S intervals. Response rates also vary inversely with the duration of the R-S interval during free-operant avoidance, such that shorter R-S intervals control higher response rates than longer R-S intervals (Sidman, 1953). Furthermore, Logue and de Villiers (1978) used concurrent variable-cycle avoidance schedules to show that response rates on operanda associated with these schedules were proportional to the frequency of scheduled shocks (rate of negative reinforcement) arranged on the two alternatives. That is, more frequently scheduled shocks controlled higher response rates than did less frequently scheduled shocks.

Extinction

Extinction is functionally a reduction or elimination of responding brought about in either of two general operations: by removing the positive or negative reinforcer or by rendering the reinforcer ineffective by eliminating the establishing operation. The former is described hereafter as *conventional extinction,* because these operations are the ones more commonly used in TEAB when analyzing extinction. With positive reinforcement, the latter is accomplished by either providing continuous access to the reinforcer (satiation) or by removing the response–reinforcer dependency (Rescorla & Skucy, 1969; see Schedules of Positive Reinforcement section earlier in this chapter for the effects of this operation on responding). With

negative reinforcement, extinction is accomplished by making the negative reinforcer inescapable.

The rapidity of extinction depends both on the organism's history of reinforcement and probably (although experimental analyses are lacking) on which of the aforementioned procedures are used to arrange extinction (Shnidman, 1968). Herrnstein (1969) suggested that the speed of extinction of avoidance is related to the discriminability of the extinction contingency, an observation that holds as well in the case of positive reinforcement. Extinction effects are rarely permanent once reinforcement is reinstated. Permanent effects of extinction are likely the result of the alternative reinforcement of other responses while extinction of the targeted response is in effect.

Extinction also can generate other responses, some of which may be generalized or induced from the extinguished response itself and others of which depend on other stimuli in the environment in which extinction occurs (see Volume 2, Chapter 4, this handbook). Some instances of such behavior are described as schedule induced and are perhaps more accurately labeled *extinction induced* because they typically occur during those parts of a schedule associated with nonreinforcement (local extinction). For example, such responding is observed during the period after reinforcement under FR or FI schedules, in which the probability of a reinforcer is zero. Azrin, Hutchinson, and Hake (1966; see also Kupfer, Allen, & Malagodi, 2008) found that pigeons attack conspecifics when a previously reinforced key peck response is extinguished. Another example of the generative effects of extinction is resurgence. If a response is reinforced and then extinguished while a second response is concurrently reinforced, extinguishing that second response leads to a resurgence of the first response. The effect occurs whether the second response is or is not extinguished before concurrently reinforcing the second, and the effect depends on parameters of both the first and the second reinforced response (e.g., Bruzek, Thompson, & Peters, 2009; Lieving & Lattal, 2003).

Frameworks

Different frameworks have evolved that summarize and integrate the empirical findings deriving from analyses of the reinforcement of operant behavior. All begin with description. Many involve quantitative analysis and extrapolation through modeling. Others, although also quantitative in the sense of reducing measurement down to numerical representation, are less abstract, remaining closer to observed functional relations. Each has been successful in accounting for numerous aspects of behavioral phenomena. Each also has limitations. None has achieved universal acceptance. The result is that instead of representing a progression with one framework leading to another, these frameworks together make up a web of interrelated observations, each contributing something to the general understanding of how reinforcement has its effects on behavior. The following sections provide an overview of some of these contributions to this web.

Levels of influence. Thorndike (1911) observed that

> of several responses made to the same situation, those which are accompanied or closely followed by satisfaction to the animal will, other things being equal, be more firmly connected with the situation, so that, when it recurs, they will be more likely to recur. (p. 244)

The temporal relation between a response and the reinforcer that follows has been a hallmark of the reinforcement process. Skinner's (1948) "superstition" demonstration underscored the importance of this relation by suggesting that even in the absence of a programmed consequence of responding, the environment will strengthen whatever response occurs contiguously with the reinforcer. Ferster and Skinner (1957) frequently assigned response–reinforcer temporal contiguity a primary role in accounting for the effects of reinforcement schedules.

To say that all were not content with response–reinforcer temporal contiguity as the central mechanism for reinforcement is an understatement. In a seminal experiment, Herrnstein and Hineline (1966) exposed rats to a schedule consisting of two response-independent shock distributions, one frequent, the other less so. Each session started in the

frequent-shock distribution, and a lever press shifted the distribution of shocks to the leaner one, at which the rat remained until a shock was delivered. At this point, the frequent shock distribution was reinstated and remained in effect until the next response, at which point the above-described cycle repeated. Responses did not eliminate shocks; they only reduced shock frequency. Furthermore, because shocks were distributed randomly in time, temporal discriminations were precluded. Herrnstein and Hineline reasoned that if responding were maintained under this schedule, it would be because of an aggregated effect of reductions in shock frequency over noninstantaneous time periods (cf. Sidman, 1966). Consistent with Herrnstein and Hineline's findings, Baum's (1973) description of the correlation-base law of effect remains a cogent summary of a molar framework for reinforcement (see also Baum, 1989; Williams [1983] critiqued the correlational framework).

TEAB makes frequent reference to *level of analysis*. This phrase refers to both the description of data and the framework for accounting for those data. *Molecular descriptions* are of individual or groups of responses, often in relation to reinforcement. *Molar descriptions* are of aggregated responses across time and the allocation of time to differing activities. Molecular accounts of reinforcement effects emphasize the role of events occurring at the time of reinforcement (e.g., Peele, Casey, & Silberberg, 1984), and molar accounts emphasize the role of aggregated effects of reinforcers integrated over noninstantaneous time periods (e.g., Baum, 1989). Proponents of each framework have at various times claimed primacy in accounting for the effects of reinforcement, but the isolation of an irrefutable single mechanism at one level or another seems remote. The issue is not unlike others concerning levels of analysis in other disciplines, for example, punctuated equilibrium versus continuous evolution and wave and particle theories of light. The "resolution" of the molar versus molecular issue may ultimately be pragmatic: The appropriate level is that at which behavior is predicted and controlled for the purposes at hand.

Relational reinforcement theory. Reinforcers necessarily involve activities related to their access, consumption, or use. Premack (1959) proposed reinforcement to be access to a (relatively) preferred activity, such as eating. For Premack, the first step in assessing reinforcement was to create a preference hierarchy. Next, highly preferred activities were restricted and made accessible contingent on engagement in a nonpreferred activity, with the outcome that the low-probability response increased in frequency. Timberlake and Allison (1974) suggested that the Premack principle was a corollary of a more general response deprivation principle whereby any response constrained below its baseline level can function as a reinforcer for another response that allows the constrained response to rise to its baseline level. Premack's analysis foreshadowed other conceptualizations of reinforcement contingencies in terms of constraints on behavioral output (e.g., Staddon, 1979).

Choice and matching. Perhaps the contribution to modern behavior analysis with the greatest impact is the matching law (Herrnstein, 1970; see Chapter 10, this volume). The matching law is both a summary of a number of empirical reinforcement effects and a framework for integrating those effects. Herrnstein's (1961) original proposal was a simple quantitative statement that relative responding is distributed proportionally among concurrently available alternatives as a function of the relative reinforcement proportions associated with each alternative. He and others thereafter developed it into its more generalized form, expressed by Baum (1974; see also Staddon, 1968; McDowell, 1989) as

$$\frac{R_1}{R_2} = b\left(\frac{r_1}{r_2}\right)^a,$$

where R_1 and R_2 are response rates to the two alternatives and r_1 and r_2 are reinforcement rates associated with those alternatives. The parameters a and b are indices of, respectively, sensitivity (also sometimes labeled the *discriminability of the alternatives*) and bias (e.g., a preexisting preference for one operandum over the other). When restated in logarithmic form, a and b describe the slope and intercept of a straight line fitted to the plot of the two ratios on either axis of a graph. A rather typical, but not universal, finding in many experiments is undermatching, that is, preferences for the richer alternative are less

than is predicted by a strict proportionality between response and reinforcement ratios. This undermatching and overmatching (a greater-than-predicted preference for the richer alternative, and bias) were the impetus for developing the generalized matching law.

One of Herrnstein's (1970) insights was that all behavior should be considered in the framework of choice. Even when only one response alternative is being measured, there is a choice between that response and engaging in other behavior. This observation led to two further conclusions: The total amount of behavior in a situation is constant or fixed (but see McDowell, 1986); it is simply distributed differently depending on the circumstances, and there are unmeasured sources of reinforcement (originally labeled r_o, but later r_e). Thus, deviations from the strict proportionality rule, such as undermatching, are taken by some to reflect changes in r_e as well as perhaps bias or sensitivity changes.

Davison and Tustin (1978) considered the matching law in the broader context of decision theory, in particular, signal detection theory (D. M. Green & Swets, 1966). Originally developed to distinguish sensitivity and bias effects in psychophysical data, Davison and Tustin used signal detection theory to describe the discriminative function of reinforcement in maintaining operant behavior. Their analysis thus describes the mathematical separation of the biasing and discriminative stimulus effects of the reinforcer. More generally, the analysis of choice has been extended across TEAB, from simple reinforcement schedules to foraging, social behavior, and applied behavior analysis (see Volume 2, Chapter 7, this handbook).

Response strength and behavioral momentum. Reinforcement makes a response more likely, and this increase in response probability or rate has conventionally been taken by many as evidence of the strength of that response. One difficulty with such a view of response strength is that response rate is not determined simply by whether the response has been reinforced but by how the contingencies by which the response is reinforced are arranged. Thus, the absence of the target response may index its strength in the case of a differential-reinforcement-of-other-behavior (DRO) schedule, in which reinforcement occurs only if the target response does not occur for the specified period.

Nevin (1974; see Volume 2, Chapter 5, this handbook) conceptualized response strength as resistance to change of a response when competing reinforcement contingencies impinge on that response. The relation between response strength and resistance to change originated early in the psychology of learning (e.g., Hull, 1943), but Nevin expanded it to schedule-maintained responding. He arranged multiple schedules of reinforcement in which the parameters of the reinforcer—rate, magnitude, and delay, in different experiments—differed in the two components. The reinforcer maintaining the response was made less effective by, in different conditions, removing it (extinction), prefeeding the food-restricted animals (satiation), or providing response-independent reinforcers at different rates during the chamber blackout that separated the two components. Each of these disrupting operations had similar disruptive (response rate–lowering) effects such that the responding maintained by more frequent, larger, or less delayed reinforcers was less reduced than was responding in the other component in which the reinforcers were less frequent, shorter, or more delayed.

In considering the resistance of behavior to change, Nevin, Mandell, and Atak (1983) proposed a behavioral analogy to physical momentum, that is, the product of mass and velocity:

> When responding occurs at the same rate in two different schedule components, but one is less affected by an external variable than is the other, we suggest that the performance exhibiting greater resistance to change be construed as having greater mass. (p. 50)

Nevin et al. have shown that reinforcement rate, regardless of the contingency between responses and reinforcers, is a primary determinant of momentum: More frequently reinforced responses are more resistant to change. For example, Nevin, Tota, Torquato, and Shull (1990, Experiment 1) found that responding maintained by a combination of response-dependent and response-independent food deliveries (a VI schedule + a VT schedule) was

more resistant to disruption than was responding maintained by response-dependent food delivery only. This was the case because the reinforcement rate in the VI + VT component was higher, even though response rate was lower in this component. Nevin et al. (1990) observed that "as a result of Pavlovian contingencies, nonspecific effects underlying Pavlovian contingencies resulting from the association of discriminative stimuli with different rates of reinforcement may have nonspecific effects that 'arouse or motivate operant behavior'" (p. 374).

Another consideration in behavioral momentum may be response rate. Different reinforcement rates result in different response rates. When reinforcement rates are held constant and response rates are varied, the lower response rates are often more resistant to change (Blackman, 1968; Lattal, 1989).

Behavioral economics. Skinner (1953) observed that "statements about goods, money, prices, wages, and so on, are often made without mentioning human behavior directly, and many important generalizations in economics appear to be relatively independent of the behavior of the individual" (p. 398). The chasm described by Skinner has long since been bridged, both in TEAB (Madden, 2000; see Volume 2, Chapter 8, this handbook) and in the discipline of economics. This bridging has come about through the mutual concern of the two disciplines with the behavior of consumption of goods and services as a function of environmental circumstances. The behavioral–economic framework has been a useful heuristic for generating experimental analyses that have expanded the understanding of reinforcement in several ways.

In a token economy on a psychiatric ward (Allyon & Azrin, 1968), for example, consumption of a nominal reinforcer was reduced if the same item was available at a lower cost, or no cost, elsewhere. Thus, for example, if visitors brought desirable food items onto the ward from outside, demand for those food items within the token economy diminished. Hursh (1980) captured the essential features of this scenario by distinguishing *open economies,* in which items are available from multiple sources, from *closed economies,* in which those items are only available in a defined context. Hall and Lattal (1990) directly compared the effects of reinforcement rate on VI schedule performance in open and closed economies. In the open economy, sessions were terminated before the pigeon earned its daily food allotment; postsession feeding was provided so the animal was maintained at a target weight. In the closed economy, the pigeons earned all of their food by key pecking. The functions relating response rate to reinforcement rate differed for the two economic contexts. In the open economy, response rates decreased with decreasing reinforcement rate, whereas in the closed economy, response rates increased with decreasing reinforcement rate. Such findings suggest that the functional relations that obtain between reinforcement parameters and behavior are not universal, but depend on the context in which they occur.

Consumption also differs as a function of the reinforcer context. The interaction between reinforcers lies on a continuum. At one extreme, one reinforcer is just as effective as another in maintaining behavior (perfect substitutes). At the other extreme, reinforcers do not substitute for one another at all. Instead, as consumption of one increases (decreases) with price changes, so does the other despite its price being unchanged. Such a relation reveals that the reinforcers function as perfect complements. Between the extremes, reinforcers substitute for one another to varying degrees (for a review, see L. Green & Freed, 1998).

Behavioral–economic analyses have shown that qualitatively different reinforcers may vary differentially in the extent to which they sustain behavior in the context of different environmental challenges, often expressed as cost in economic analyses. Some reinforcers continue to sustain behavior even as cost, measured, for example, by the number of responses required for reinforcement, increases, and the behavior sustained by others diminishes with such increased cost. This difference in response sustainability across increasing cost distinguishes inelastic (fixed sustainability regardless of cost) from elastic (sustainability varies with cost) reinforcers.

Other ways of increasing the cost of a reinforcer are by increasing the delay between the reinforcer and the response that produced it or by reinforcing a

response with decreasing probability. These two techniques of changing reinforcer cost have been combined with different magnitudes of reinforcement to yield what first was called a self-control paradigm (Rachlin & Green, 1972) but now generally is described as delay (or probability, as appropriate) discounting. A choice is arranged between a small or a large (or a less or more probable) reinforcer, delivered immediately after the choice response. Not surprisingly, the larger (or more probable) reinforcer almost always is selected. Next, a delay is imposed between the response and delivery of the larger reinforcer (or the probability of the larger reinforcer is decreased), and the magnitude of the small, immediate (or small but sure thing) reinforcer is varied systematically until an indifference point is reached at which either choice is equally as likely (e.g., Mazur, 1986; Richards, Mitchell, de Wit, & Seiden, 1997). Using the delay or probability discounting procedure, a function can be created relating indifference points to the changing cost. Steep discounting of delayed reinforcers correlates with addictions such as substance use disorder and pathological gambling (see Madden & Bickel, 2010, for a review).

A final, cautionary note that applies to economic concepts and terms as well as more generally to verbal labels commonly used in TEAB, such as *contrast* or even *reinforcement*: Terms such as *elastic* or *inelastic* or *complementary* or *substitutable* are descriptive labels, not explanations. Reinforcers do not have their effects because they are inelastic, substitutable, or discounted.

Behavior dynamics. The emphasis in TEAB on steady-state performance sometimes obscures the centrality of the environment–behavior dynamic that characterizes virtually every contingency of reinforcement. Dynamics implies change, and change is most immediately apparent when behavior is in transition, as in the acquisition of a response previously in the repertoire in only primitive form, transitions from one set of reinforcement conditions to another, or behavioral change from reinforcement to extinction. Steady-state performance, however, also reveals a dynamic system. As Marr (personal communication, November 2010) observed, "[All] contingencies engender and manifest systems dynamics." The imposed contingency is not necessarily the effective one because that imposed contingency constantly interacts with responding, and the resulting dynamic is what is ultimately responsible for behavioral modulation and control. This distinction was captured by Zeiler (1977b), who distinguished between direct and indirect variables operating in reinforcement schedules. In a ratio schedule, for example, the response requirement, *n*, is a direct, specified variable (e.g., as in FR *n*), but responding takes time, so as one varies the ratio requirement, one is also indirectly varying the time between reinforcer deliveries. Another way of expressing this relation is by the feedback function of a ratio schedule: Reinforcement rate is determined directly by response rate. The feedback function is a quantitative description of the contingency specifying the dynamic interplay between responding and reinforcement.

Using the methods developed by quantitative analysis of dynamical systems, a few behavior analysts have explored some properties of reinforcement contingencies (see Marr, 1992). For example, in an elegant analysis Palya (1992) examined the dynamic structure among successive IRTs in interval schedules, and Hoyert (1992) applied nonlinear dynamical systems (chaos) theory in an attempt to describe the cyclical interval-to-interval changes in response output that characterize steady-state FI schedule performance. Indeed, much of the response variability that is often regarded as a nuisance to be controlled (e.g., Sidman, 1960) may, from a dynamic systems perspective, be the inevitable outcome of the dynamic nature of any reinforcement contingency.

Reinforcement in biological context. Skinner, (1981; see also Donahoe, 2003; Staddon & Simmelhag, 1971) noted the parallels between the selection of traits in evolutionary time and the selection of behavior over the organism's lifetime (i.e., ontogeny). Phylogeny underlies the selection of behavior by reinforcement in at least two ways. First, certain kinds of events may come to function as reinforcers or punishers in part because of phylogeny. Food, water, and drugs of various sorts, for example, may function as reinforcers at

least in part because of their relation to the organism's evolved physiology. It is both retrograde and false, however, to suggest that reinforcers reduce to physiological needs. Reinforcers have been more productively viewed functionally; however, the organism's phylogeny certainly cannot be ignored in discussions of reinforcement (see also Breland & Breland, 1961). Second, the mere fact that organism's behavior is determined to a considerable extent by consequences is *prima facie* evidence of evolutionary processes at work. Thus, Skinner (1981) proposed that some responses are selected (reinforced) and therefore tend to recur, and those that are not selected or are selected against tend to disappear from the repertoire. The research of Neuringer (2002; see Chapter 22, this volume) on variability as an operant sheds additional light on the interplay between behavioral variation and behavioral selection.

The analysis of foraging also has been a focal point of research attempting to place reinforcement in biological perspective. Foraging, whether it is for food, mates, or other commodities such as new spring dresses, involves choice. Lea (1979; see also Fantino, 1991) described an operant model for foraging based on concurrent chained schedules (see Response-Dependent Stimuli Correlated With Previously Established Reinforcers section later in this chapter) in which foraging is viewed as consisting of several elements, beginning with search and ending in consumption (including buying the new spring dress). Such an approach holds out the possibility of integrating ecology and TEAB (Fantino, 1991).

A related integrative approach is found in parallels between foraging in natural environments and choice as described by the matching law and its variants (see Choice and Matching section earlier in this chapter). Optimal foraging theory, for example, posits that organisms select those alternatives in such a way that costs and benefits of the alternatives are weighed in determining choices (as contrasted, e.g., with maximizing theory, which posits that choices are made such that reinforcement opportunities are maximum). Optimal foraging theory is not, however, without its critics. Zeiler (1992), for example, has suggested that "optimality theory ignores the fact that natural selection works on what it has to work with, not on ideals" (p. 420) and

> optimizing means to do the best conceivable. However, natural selection need not maximize returns. . . . What selection must do is follow a satisficing principle. . . . To satisfice means to do well enough to get by, not necessarily to do the best possible. (p. 420)

Zeiler thus concluded that optimization in fact may be rare in natural settings. He distinguished evolutionary and immediate function of behavior, noting that the former relates to the fitness enhancement of behavior and the latter to its more immediate effects. In his view, optimal foraging theory errs in using the methods of immediate function to address questions of evolutionary function.

PILLAR 3: PUNISHMENT

An outcome of some interactions between an organism's responses and environmental events is that the responses become less likely than they would be in the absence of those events. As with reinforcement, this outcome is particularly effective when there is a dependency between such environmental events and behavior, a two-term contingency involving responding and what comes to function as a punisher. Such a process of punishment constitutes the third pillar of TEAB.

Positive Punishment

Positive punishment is the suppression or elimination of a response resulting from the response-dependent, time-limited presentation of a stimulus or event (i.e., a negative reinforcer). In the laboratory, electric shock is a prototypical positive punisher because, at the parameters used, it produces no injury to the organism, it is precisely initiated and terminated, and it is easily specified in physical terms (e.g., its intensity, frequency, and duration). Furthermore, parameters of shock can be selected that minimize sensitization (overreactivity to a stimulus) and habituation (adaptation or underreactivity to a stimulus).

Punishment always is investigated in the context of reinforcement because responding must be

maintained before it can be punished. As a result, the effects of punishers always are relative to the prevailing reinforcement conditions. Perhaps the most important of these is the schedule of reinforcement. Punishment exaggerates postreinforcement pausing on FR and FI schedules, and it decreases response rates on VI schedules (Azrin & Holz, 1966). Because responding on DRL schedules is relatively inefficient (i.e., responses are frequently made before the IRT > *t* criterion has elapsed), by suppressing responding punishment actually increases the rate of reinforcement. Even so, pigeons will escape from punishment of DRL responding to a situation in which the DRL schedule is in effect without punishment (Azrin, Hake, Holz, & Hutchinson, 1965). Although most investigations of punishment have been conducted using baselines involving positive reinforcement, negative reinforcement schedules also are effective baselines for the study of punishment (e.g., Lattal & Griffin, 1972).

Punishment effects vary as a function of parameters of both the reinforcer and the punisher. With respect to reinforcement, punishment is less effective when the organism is more deprived of the reinforcer (Azrin, Holz, & Hake, 1963). The effects of reinforcement rate on the efficacy of punishment are less clear. Church and Raymond (1967) reported that punishment efficacy increased as the rate of reinforcement decreased. When, however, Holz (1968) punished responding on each of two concurrently available VI schedules arranging different rates of reinforcement, the functions relating punishment intensity and the percentage of response reduction from a no-punishment baseline were virtually identical. Holz's results suggest a similar relative effect of punishment independent of the rate of reinforcement. Perhaps other tests, such as those suggested by behavioral momentum theory (see Response Strength and Behavioral Momentum section earlier in this chapter) could prove useful in resolving these seemingly different results.

Parameters of punishment include its immediacy with respect to the target response, intensity, duration, and frequency. Azrin (1956) showed that punishers dependent on a response were more suppressive of responding than were otherwise equivalent punishers delivered independently of responding at the same rate. Punishers that are more intense (e.g., higher amperage in the case of electric shock) and more frequent have greater suppressive effects, assuming the conditions of reinforcement are held constant (see Azrin & Holz, 1966, for a review). The effects of punisher duration are complicated by the fact that longer duration punishers may adventitiously reinforce responses contiguous with their offset, thereby potentially confounding the effect of the response-dependent presentation of the punisher.

Negative Punishment

Negative punishment is the suppression or elimination of a response resulting from the response-dependent, time-limited removal of a stimulus or event. Both negative punishment and conventional extinction involve removing the opportunity for reinforcement. Negative punishment differs from extinction in three critical ways. In conventional extinction, the removal of the opportunity for reinforcement occurs independently of responding, is relatively permanent (or at least indefinite), and is not correlated with a stimulus change. In negative punishment, the removal of the opportunity for reinforcement is response dependent, time limited, and sometimes (but not necessarily) correlated with a distinct stimulus. These latter three characteristics are shared by three procedures: DRO schedules (sometimes also called *differential reinforcement of pausing* or *omission training*), timeout from positive reinforcement, and response cost.

Under a DRO schedule, reinforcers depend on the nonoccurrence of the target response for a predetermined interval. Responses during the interreinforcer interval produce no stimulus change, but each response resets the interreinforcer interval. Despite the label of reinforcement, the response-dependent, time-limited removal of the opportunity for reinforcement typically results in substantial, if not total, response suppression, that is, punishment. With DROs, both the amount of time that each response delays the reinforcer and the time between successive reinforcers in the absence of intervening responding can be varied. Neither parameter seems to make much difference once responding is reduced. They may, however, affect the speed with which responding

is reduced and the recovery after termination of the contingency (Uhl & Garcia, 1969).

As with other punishment procedures, a DRO contingency may be superimposed on a reinforcement schedule maintaining responding (Zeiler, 1976, 1977a), allowing examination of the effects of punishers, positive or negative, on steady-state responding. Lattal and Boyer (1980), for example, reinforced key pecking according to an FI 5-min schedule. At the same time, reinforcers were available according to a VI schedule for pauses in pecking of $x-s$ or more. Pecking thus postponed any reinforcers that were made available under the VI schedule. No systematic relation was obtained between required pause duration and response rate. With a constant 5-s pause required for reinforcement of not pecking, however, the rate of key pecking was a negative function of the frequency of DRO reinforcement. That is, the more often a key peck postponed food delivery, the lower the response rates were and thus the greater the punishment effect was.

Timeouts are similar to DROs in that, when used as punishers, they occur as response-dependent, relatively short-term periods of nonreinforcement. They differ from DROs because the periods of nonreinforcement are not necessarily resetting with successive responses, and they are accompanied by a stimulus change. Timeout effects are relative to the prevailing conditions of reinforcement. As was described earlier, periods of timeout from negative reinforcement function as reinforcers, as do periods of timeout from extinction (e.g., Azrin, 1961). Timeouts from situations correlated with reinforcement, however, suppress responding when they are response dependent (Kaufman & Baron, 1968).

With response cost, each response or some portion of responses, depending on the punishment schedule, results in the immediate loss of reinforcers, or some portion of reinforcers. Response cost is most commonly used in laboratory and applied settings in which humans earn points or tokens according to some schedule of reinforcement. Weiner (1962), for example, subtracted one previously earned point for each response made by adult human participants earning points by responding under VI schedules. The effect was considerable suppression of responding. Response cost, similar to timeout, can entail a concurrent loss of reinforcement as responding is suppressed. Pietras and Hackenberg (2005), however, showed that response cost has a direct suppressive effect on responding, independent of changes in reinforcement rate.

Frameworks

Punishment has been conceptualized by different investigators as either a primary or a secondary process.

Punishment as a primary or direct process. Thorndike (1911) proposed that punishment effects are equivalent and parallel to those of reinforcement but opposite in direction. Thus, the response-strengthening effects defining reinforcement were mirror-image effects of the response-suppressing effects defining punishment. Schuster and Rachlin (1968) suggested three examples: (a) the suppressive and facilitative effects of following a conditioned stimulus (CS) with, respectively, shock or food; (b) mirror-image stimulus generalization gradients around stimuli associated with reinforcement and punishment; and (c) similar indifference when given a choice of response-dependent and response-independent food or between response-dependent shock and response-independent shock (Shuster & Rachlin, 1968). Although (c) has held up to experimental analysis (Brinker & Treadway, 1975; Moore & Fantino, 1975; Schuster & Rachlin, 1968), (a) and (b) have proven more difficult to confirm. For example, precise comparisons of generalization gradients based on punishment and reinforcement are challenging to interpret because of the complexities of equating the food and shock stimuli on which the gradients are based. The research described in the Response-Independent Stimuli Correlated With Reinforcers and Punishers section later in this chapter illustrates the complexities of interpreting (a).

Punishment as a secondary or indirect process. Considered a secondary process, the response suppression obtained when responding is punished comes about indirectly as the result of negative reinforcement of other responses. Thus, punishment is interpreted as a two-stage (factor) process whereby, first, the stimulus becomes aversive and, second, responses that result in its avoidance are then

negatively reinforced. Hence, as unpunished responses are reinforced because they escape or avoid punishers, punished ones decrease, resulting in what appears as target-response suppression (cf. Arbuckle & Lattal, 1987).

A variation of punishment as a secondary process is the competitive suppressive view that responding decreases because punishment degrades or devalues the reinforcer (e.g., Deluty, 1976). Thus, the suppressive effect of punishment is seen as an indirect effect of a less potent reinforcer for punished responses, thereby increasing the potency of reinforcers for nonpunished responses. Contrary to Deluty (1976), Farley's (1980) results, however, supported a direct suppressive interpretation of punishment. Critchfield, Paletz, MacAleese, and Newland (2003) compared the direct and competitive suppression interpretations of punishment. Using human subjects in a task in which responding was reinforced with points and punished by the loss of a portion of those same points, a quantitative model based on the direct suppression interpretation yielded better fits to the data. Furthermore, Rasmussen and Newland (2008) suggested that the negative law of effect may not be symmetrical. Using a procedure similar to Critchfield et al.'s, they showed that single punishers subtract more value than single reinforcers add.

PILLAR 4: CONTROL BY STIMULI CORRELATED WITH REINFORCERS AND PUNISHERS

Reinforcers and punishers often are presented in the context of other stimuli that are initially without discernable effect on behavior. Over time and with continued correlation with established reinforcers or punishers, these other events come to have behavioral effects similar to the events with which they have been correlated. Such behavioral control by these other events is what places them as the fourth pillar of TEAB.

Response-Independent Stimuli Correlated With Previously Established Reinforcers and Punishers

In the typical operant arrangement for studying the effects of conditioned stimuli, responding is maintained according to some schedule of reinforcement, onto which the stimuli and their correlated events are superimposed. In the first such study, Estes and Skinner (1941) trained rats' lever pressing on an FI food reinforcement schedule and periodically imposed a 3-min tone (a warning stimulus or conditional stimulus [CS] followed by a brief electric shock). Both the CS and the shock occurred independently of responding, and the FI continued to operate during the CS (otherwise, the response would simply extinguish during the CS). Lever pressing was suppressed during the tone relative to no-tone periods. This conditioned suppression effect occurs under a variety of parameters of the reinforcement schedule, the stimulus at the end of the warning stimulus, and the warning stimulus itself (see Blackman, 1977, for a review).

When warning stimuli that precede an unavoidable shock are superimposed during avoidance-maintained responding (see the earlier Avoidance section), responses during the CS may either increase or decrease relative to those during the no-CS periods. The effect appears to depend on whether the shock at the end of the CS period is discriminable from those used to maintain avoidance. If the same shocks are used, responding is facilitated during the CS; if the shocks are distinct, the outcome is often suppression during the warning stimulus (Blackman, 1977).

A similar arrangement has been studied with positive reinforcement–maintained responding, in which a reinforcer is delivered instead of a shock at the end of the CS. The effects of reinforcers at the end of the CS that are the same as or different from that arranged by the baseline schedule have been investigated. Azrin and Hake (1969) labeled this procedure *positive conditioned suppression* when they found that VI-maintained lever pressing of rats during the CS was generally suppressed relative to the no-CS periods. Similar suppression occurred whether the event at the end of the CS was the same as or different from the reinforcer used to maintain responding. LoLordo (1971), however, found that pigeons' responding increased when the CS ended with the same reinforcer arranged by the background schedule, a result he related to autoshaping (Brown & Jenkins, 1968). Facilitation or suppression during a CS followed by a positive reinforcer

seems to depend on both CS duration and the schedule of reinforcement. For example, Kelly (1973) observed both suppression and facilitation during a CS as a function of whether the baseline schedule was DRL or VR.

Response-Dependent Stimuli Correlated With Previously Established Punishers

Despite being commonplace in everyday life, conditioned punishment has only rarely been studied in the laboratory. In an investigation of positive conditioned punishment, Hake and Azrin (1965) first established responding on a VI 120-s schedule of positive reinforcement in the presence of a white key light. The key-light color irregularly changed from white to red for 30 s. Reinforcement continued to be arranged according to the VI 120-s schedule during the red key light; however, at the end of the red-key-light period, a 500-ms electric shock was delivered independently of responding. This shock suppressed but did not eliminate responding when the key light was red. To this conditioned suppression procedure, Hake and Azrin then added the following contingency. When the white key light was on, each response produced a 500-ms flash of the red key light. Responding in the presence of the white key light was suppressed. When white-key-light responses produced a 500-ms flash of a green key light, when green previously had not been paired with shock, responding during the white key light was not suppressed. In addition, the degree of response suppression was a function of the intensity of the shock after the red key light.

A parallel demonstration of negative conditioned punishment based on stimuli correlated with the onset of a timeout was conducted by Gibson (1968). Gibson used Hake and Azrin's (1965) procedure, except that instead of terminating the red key light with an electric shock, it terminated with a timeout during which the chamber was dark and reinforcement was precluded. The effect was to facilitate key pecking by pigeons during the red key light relative to rates during the white key light. When, however, responses during the white key light produced 500-ms flashes of the red key light, as in Hake and Azrin, responding during the white key light was suppressed. This demonstration of conditioned negative punishment is of particular interest because it occurred despite the fact that stimuli preceding timeouts typically facilitate rather than suppress responding. Thus, the results cannot be interpreted in terms of the red key light serving as a discriminative stimulus for a lower rate of reinforcement (as they could be in Hake and Azrin's experiment).

Response-Dependent Stimuli Correlated With Previously Established Reinforcers

Stimuli correlated with an already-established reinforcer maintain responses that produce them (Williams, 1994). This is the case for stimuli correlated with either the termination or postponement of a negative reinforcer (Siegel & Milby, 1969) or with the onset of a positive reinforcer. In the latter case, early research on conditioned reinforcement used chained schedules (e.g., Kelleher & Gollub, 1962), higher order schedules (Kelleher, 1966), and a two–response-key procedure (Zimmerman, 1969). Interpretational limitations of each of these methods (Williams, 1994) led to the use of two other procedures in the analysis of conditioned reinforcement.

The observing–response procedure (Wyckoff, 1952) involves first establishing a discrimination between two stimuli by using a multiple schedule in which one stimulus is correlated with a schedule of reinforcement and the other with extinction (or a schedule arranging a different reinforcement rate). Once discriminative control is established, a third stimulus is correlated with both components to yield a mixed schedule. An observing response on a second operandum converts the mixed schedule to a multiple schedule for a short interval (typically 10–30 s with pigeons). Observing responses are maintained on the second operandum. These responses, of nonhumans at least, are maintained primarily, if not exclusively, by the positive stimulus (S+) and not by the stimulus correlated with extinction (see Fantino & Silberberg, 2010; Perone & Baron, 1980; for an alternative interpretation of the role of the negative stimulus [or S−], see Escobar & Bruner, 2009). The general interpretation has been that the stimulus correlated with reinforcement functions as a conditioned reinforcer maintaining the observing response.

Fantino (1969, 1977) proposed that stimuli function as conditioned reinforcers to the extent that they represent a reduction in the delay (time) to reinforcement relative to the delay operative in their absence. Consider the observing procedure described earlier, assuming that the two components alternate randomly every 2 min. Observing responses convert, for 15-s periods, a mixed VI 2-min extinction schedule to a multiple VI 2-min extinction schedule. Because components are 2 min each, the mixed-schedule stimulus is correlated with a 4-min period (delay) between successive reinforcers. In the presence of the stimulus correlated with the VI schedule, the delay between reinforcers is 2 min, a 50% reduction in delay time relative to that in the mixed-schedule stimulus. Fantino's delay reduction hypothesis asserts that this signaled reduction in delay to reinforcement maintains observing responses.

In other tests of the delay reduction hypothesis, concurrent chained schedules have been used (in a chained schedule, distinct stimuli accompany the different links). In such tests, two concurrently available identical VI schedules serve as the initial links of the chained schedules. The equivalent VI initial links ensure that either terminal link is accessed approximately equally as often. The terminal links are mutually exclusive: The first initial link requirement met leads to its terminal link and simultaneously cancels the alternative chained schedule for that cycle. When the terminal link requirement is met, the response is reinforced, and the concurrent initial links recur. Thus, for example, if the two terminal links are VI 1 min and VI 5 min and the initial links are both VI 1 min, the average time to reinforcement achieved by responding on both alternatives is 3.5 min (0.5 min in the initial link + 3 min in the terminal link). Responding exclusively on the operandum leading to the VI 1-min terminal link produces a reinforcer on average every 2 min, a reinforcement delay reduction of 1.5 min from the average for responding on both. Responding exclusively on the operandum leading to the VI 5-min terminal link produces a reinforcer once every 6 min, yielding a reinforcement delay increase of 2.5 min relative to the average for responding on both. The greater delay reduction for responding on the operandum leading to the VI 1-min terminal link predicts an exclusive preference for this alternative, a prediction confirmed by experimental analysis.

Before leaving the topic of conditioned reinforcement, it should be noted that there is not uniform agreement as to the significance of conditioned reinforcement (and, by extrapolation, conditioned punishment) as a concept. Although it has strong proponents (Dinsmoor, 1983; Fantino, 1977; Williams, 1994), among its critics are Davison and Baum (2006), who suggested that the concept had outlived its usefulness and that conditioned reinforcement is more usefully considered in terms of discriminative stimulus control. This suggestion harkens back to an earlier one that conditioned reinforcers must first be established as discriminative stimuli (e.g., Keller & Schoenfeld, 1950), but Davison and Baum called for the abandonment of the concept (see also Chapter 17, this volume).

PILLAR 5: CONTEXTUAL AND STIMULUS CONTROL

Interactions between responding and reinforcers and punishers occur in broader environmental contexts, both distal or historical and proximal or contemporary. These contexts define what is sometimes called *antecedent control of behavior*. The term is something of a misnomer because under such circumstances, the behavior is controlled by the two-term contingency in the context of the third, antecedent event. Such joint control by reinforcement contingencies in context is what constitutes the final pillar of TEAB.

Behavioral History

Perhaps the broadest context for the two-term contingency is historical. Although the research is not extensive, several experiments have examined with some precision functional relations between past experiences and present behavior. These analyses began with the work of Weiner (e.g., 1969), who showed that different individuals responded differently on contemporary reinforcement schedules as a function of their previous experience responding on other schedules. Freeman and Lattal (1992)

investigated the effects of different histories under stimulus control within individual pigeons. The pigeons were first trained on FR and DRL schedules, equated for reinforcement rate and designed to generate disparate response rate, in the presence of distinct stimuli. When subsequently exposed to FI schedules in the presence of both stimuli, they responded for many sessions at higher rates in the presence of the stimuli previously associated with the FR (high response rate) schedule. This effect not only replicated Weiner's human research, but it showed within individual subjects that an organism's behavioral history could be controlled by the stimuli with which that history was correlated. Other experiments have elaborated such behavioral history effects. Ono (2004), for example, showed how preferences for forced versus free choices were determined by the organism's past experiences with the two alternatives.

Discriminative Stimulus Control

By correlating distinct stimuli with different conditions of reinforcement or punishment, responding typically comes to be controlled by those stimuli. Such discriminative stimulus control occurs when experimental variations in the stimuli lead to correlated variations in behavior. Discriminative stimulus control can be established with both reinforcement and punishment.

The prototypical example of discriminative stimulus control is one in which responding is reinforced in the presence of one stimulus, the S+ or S^D, and not in the presence of another, the S− or S^Δ. Stimulus control, however, can involve different stimuli correlated with different conditions of reinforcement, in which case there would be two positive stimuli, or it can involve conditions in which punishment is present or absent in the presence of different stimuli.

The lack of overriding importance of the form of the stimulus in establishing positive discriminative stimulus control was illustrated by Holz and Azrin (1961). They first punished each of a pigeon's key responses otherwise maintained by a VI schedule of reinforcement. Then, both punishment and reinforcement were discontinued, allowing responding to drop to low, but nonzero, levels. At that point, each response again was punished, but reinforcement was not reinstated. Because of its prior correlation with reinforcement, punishment functioned as an S+, thereby resulting in considerable responding, at least in the short term. This result underlines the functional definition of discriminative stimuli: They are defined in terms of their effect, not by their form.

Two prerequisites for stimulus control are (a) that the stimuli be different from both the absence of stimulation (i.e., above the absolute threshold) and that they be discriminable from one another (i.e., above the difference threshold) and (b) that the stimuli be correlated with different reinforcement or punishment contingencies. Thresholds are in part physiological and phylogenic. Human responding, for example, cannot be brought under control of visual stimuli outside the range of physical detection of the human eye. Signal detection theory (D. M. Green & Swets, 1966) posits that the discriminable dimension of a stimulus can be separated from the reinforcement contingencies that bias choices in assessments of threshold measurements. Researchers in TEAB have used signal detection methods to not only complement other methods of assessing control by conventional sensory modality stimuli (i.e., visual and auditory stimuli; cf. Nevin, 1969) but also to isolate the discriminative and reinforcing properties of a host of other environmental events, including reinforcement contingencies themselves (e.g., Davison & Tustin, 1978; Lattal, 1979).

Another issue that receives considerable attention in the analysis of stimulus control is attention (see Chapter 17, this volume). Although from some perspectives, attention is considered a prerequisite to stimulus control, in TEAB attention is stimulus control (e.g., Ray, 1969). The behavioral index of attention is whether the organism is responding to the nominal stimuli being presented. Thus, attending to a stimulus means responding in its presence and not in its absence, and such differential responding also defines stimulus control. According to this analysis, an instructor does not get the class's attention to start the day's activities; responding to the day's activities is what having the class's attention means.

Correlating stimuli with different reinforcement or punishment contingencies establishes discriminative stimulus control. It sometimes is labeled

discrimination, although care is taken in TEAB to ensure that the term describes an environment–behavior relation and not an action initiated by the organism. Discriminations have been established in two ways. The conventional technique is simply to expose the organism to the discrimination task until the behavior comes under the control of the different discriminative stimuli. Terrace (1963) reported differences in the number of responses made to a stimulus correlated with extinction (S−) as a function of how the discrimination was trained, specifically, how the S− and correlated period of nonreinforcement was introduced. The typical, sudden introduction of the S− after responding had been well established in the presence of another stimulus resulted in many (unreinforced) responses during the S− presentations, responses that Terrace labeled as errors. Introducing the S− in a different way changes the behavior it controls. Terrace introduced the S− simultaneously with the commencement of S+ training, but at low intensity (the S− was a colored light transilluminating the response key, initially for very brief time periods. Over successive sessions, both the intensity and the duration of the S− were increased gradually as a function of the pigeon's behavior in the presence of the S−. This procedure yielded few responses to the S− throughout training and during the steady-state S+–S− discriminative performance. Terrace (1966) suggested that the S− functioned differently when established with, as opposed to without, errors; however, it was unclear whether the fading procedure or the absence of responses to the S− was responsible for these differences. Subsequent research qualified some of Terrace's suggestions (e.g., Rilling, 1977).

Stimulus Generalization

Stimulus generalization refers to changes or gradations in responding as a function of changes or gradations in the stimulus with which the reinforcement or punishment contingency originally was correlated. In a typical procedure, a discrimination is established (generalization gradients are more reliable when a discriminative training procedure is used) between S+ (e.g., a horizontal line projected on a response key) and S− (e.g., a vertical line). In a test of stimulus generalization, typically conducted in the absence of reinforcement, lines differing in degree of tilt are presented in mixed order, and responding to each is recorded. The result is a gradient, with responding relatively high in the presence of stimuli most like the S+ in training and lowest in the presence of stimuli most like the S−. The shape of the gradient indexes stimulus generalization. A flat gradient suggests all stimuli are responded to similarly, that is, significant generalization or minimal discrimination. A steep gradient (that drops sharply between the S+ and the next-most-similar stimuli, e.g.) indicates that the stimuli differentially control responding, that is, significant discrimination or minimal generalization. The peak, that is, the highest point, of the gradient, is often not at the original training stimulus but rather shifted to the next stimulus in the direction opposite the S−. This *peak shift,* as it is labeled, has been suggested to reflect aversive properties of the S− in that it did not occur when discriminations were trained without errors (Terrace, 1966).

Stimulus generalization gradients also can be observed around the S−. Their assessment poses a difficulty if the S+ and S− are on the same continuum: The gradients around both the S+ and the S− are confounded by the fact that movement away from the S− constitutes movement toward the S+ and vice versa. The solution is to use as the S+ and S− orthogonal stimuli, that is, stimuli that are on different stimulus dimensions, for example, color and line tilt. This way, changes away from, for example, the line tilt correlated with S−, are not changes toward the key color correlated with the S+. Inhibitory generalization gradients typically are V shaped, with the lowest responding in the presence of the S− and increasing with increasing disparity between the test stimulus and the S−. These gradients, sometimes labeled *inhibitory generalization gradients,* have been interpreted to indicate that extinction, or nonreinforcement, involves the learning of other behavior rather than simply eliminating nonreinforced responding (Hearst, Besley, & Farthing, 1970).

Conditional Stimulus Control

The three-term contingency discussed in the preceding sections can itself be brought under stimulus

control, giving rise to a four-term contingency. Here, the stimuli defining the three-term contingency are conditional on another, superordinate set of stimuli, defining the fourth term. Conditional stimulus control has been studied widely using a procedure sometimes called *matching to sample* (see Sidman & Tailby, 1982). The procedure consists of three-element trials separated from one another by an ITI. In a typical arrangement, a pigeon is confronted by a three–response-key array. In the presence of a preparatory stimulus, a response turns on a sample stimulus, say a red or green key light, each with a probability of 0.5 on a given trial. A response to the transilluminated key turns on the two side stimuli (comparison component), one red and the other green. A peck to the key colored the same as the sample stimulus results in food access for 3 s, whereas a peck to the other key terminates the trial. After an intertrial interval, the cycle repeats. Thus, the red and green lights in the comparison component can be either an S+ or an S− conditional on the stimulus in the sample component. The percentage of choices of colors corresponding to the sample increases with exposure, reaching an asymptote near 100% correct. Variations on the procedure include (a) turning off the sample light during the choice component (zero-delay matching), (b) using sample and choice stimuli that differ in dimension (symbolic matching to sample), (c) using topographically different responses to the different sample stimuli (e.g., a key peck to one and a treadle press to the other), (d) using qualitatively different reinforcers for correct responses to either of the stimuli (differential outcomes procedure), and (e) imposing delays between the response to the sample and onset of the choice component (delayed matching to sample; see MacKay, 1991, for a review).

There are myriad possibilities for sample stimuli. Everything from simple colors to astonishingly complex visual arrays has been used to establish conditional stimulus control of responding. A particularly fruitful area of research involving conditional stimulus control is that of delayed matching to sample (see Chapter 18, this volume). Generally speaking, choice accuracy declines as delays increase. Indifference between the choices is reached with pigeons at around 30-s delays. The appropriate description of these gradients is a matter of interpretation. Those who are more cognitively oriented consider the gradients to reflect changes in memory, whereas those favoring a behavior-analytic interpretation generally describe them using action terms such as *remembering* or *forgetting*.

The conditional discrimination procedure involving both delayed presentations of choice components and the use of complex visual arrays as samples has given rise in part to the study of animal cognition, which has in turn led to often unfounded, and sometimes inexplicable, speculations about cognitive mechanisms underlying conditional stimulus control (and other behavioral phenomena) in nonhuman animals. The conceptual issues related to the interpretation of behavioral processes involving stimulus control in terms of memory or other cognitive mechanisms is beyond the scope of this chapter. Branch (1977), Watkins (1990), and many others have offered perspectives on these issues that are consistent with TEAB.

Temporal Discriminative Stimulus Control of Responding and Timing

Every schedule of reinforcement, positive or negative, involves time. It is a direct variable in interval schedules and an indirect one in ratio schedules. Early research on FI schedules suggested that the passage of time functioned as an S+ (e.g., Dews, 1970). The discriminative properties of time were also borne out in conditional discrimination experiments in which the reinforced response was conditional on the passage of one time interval versus another (e.g., Stubbs, 1968) and in experiments involving the peak interval procedure, in which occasional reinforcers are deleted from a series of FIs to reveal where responding peaks before waning. Research on temporal control in turn has given rise to different quantitative theories of timing, notably scalar expectancy theory (Gibbon, 1977) and the behavioral theory of timing (Killeen & Fetterman, 1988). Both theories integrate significant amounts of data generated using the aforementioned procedures, and both have had considerable heuristic value. The behavioral theory of timing focuses more directly on environmental and behavioral events in accounting for the discriminative properties of time.

Concept Learning

One definition of a concept is in terms of stimulus control. A concept may be said to exist when a similar response is controlled by common elements of otherwise dissimilar stimuli. Human concepts often are verbal in nature, for example, abstract configurations of stimuli that evoke words such as *love, esoteric, liberating,* and so forth. Despite their complexity, concepts are considered in TEAB to be on a continuum with other types of stimulus control of behavior. The classic demonstration of stimulus control of responding by an abstract stimulus was that of Herrnstein, Loveland, and Cable (1976). An S+–S− discrimination was established using a multiple schedule in which responses in one component were reinforced according to a VI 30-s schedule and extinguished in the other. The S+ in each of three experiments was, respectively, one of a variety of slides (more than 1,500 different ones—half positive and half negative in terms of containing the concept under study—were used in each of the three experiments) that were pictures of trees, water, or a particular person. In each experiment, the S− was the absence of these features in an otherwise parallel set of slides. Response rates were higher in the presence of the concept under investigation than in its absence. The basic results of Herrnstein et al. have been replicated systematically many times, using a variety of types of visual stimuli (e.g., Wasserman, Young, & Peissig, 2002).

The general topic of concepts and concept learning as instances of stimulus control has been approached in a different, but equally fruitful way by Sidman (e.g., 1986; Sidman & Tailby, 1982). Consider three groups of unrelated stimuli, A, B, and C, presented on a computer screen. Different patterns make up A; different shapes, B; and nonsense syllables, C. The question posed by Sidman and Tailby (1982) was how these structurally different groups of stimuli might all come to control similar responses to them, that is, become equivalent to one another—to function as a stimulus controlling the same response; that is, as a concept.

Sidman and Tailby (1982) turned to mathematics for a definition of equivalence and to the conditional discrimination procedure (outlined earlier) for its analysis. An equivalence relation in mathematics requires a demonstration of three properties: reflexivity, symmetry, and transitivity. Reflexivity is established by showing, in the absence of reinforcement, generalized identity matching (i.e., selecting the comparison stimulus that is identical to the sample). In normally developing humans, the tests for symmetry and transitivity often are combined. One such test consists of teaching the relation between A and B and that between A and C, using the conditional discrimination procedure described previously (e.g., given Sample A, select B from among the available comparison stimuli). In subsequent no-feedback test trials, if C is selected after a B sample and B is selected after a C sample, then these emergent (untrained) transitive relations require that the trained A–B and A–C relations be symmetric (B–A and C–A, respectively).

Stimulus equivalence suggests a mechanism whereby new stimulus relations can develop in the absence of direct reinforcement. Sidman (1986) suggested that these emergent relations could address criticisms of the inflexibility of a behavior-analytic approach that relies on direct reinforcement to establish new responses. In addition, if different sets of equivalence relations are themselves equated through training a connecting relation (Sidman, Kirk, & Wilson-Morris, 1985), then the number of equivalence relations established without training increases exponentially. As Sidman observed, both of these outcomes of stimulus equivalence are important advancements in accounting for the acquisition of verbal behavior within a behavior-analytic framework. By expanding the analysis of stimulus equivalence to a five-term contingency, Sidman also attempted to account for meaning in context (see Volume 2, Chapters 1, 6, and 18, this handbook).

Rules and Instructions

An important source of discriminative stimulus control of human behavior is verbal behavior (Skinner, 1957). The analysis of this discriminative function of verbal behavior has most frequently taken the form in TEAB of an analysis of how rules and instructions (the two terms are used interchangeably here, but see also Catania [1998] for suggestions concerning the rules for describing such control of

behavior) act in concert with contingencies to control human behavior. The control by instructions or rules is widely, but not universally, considered a type of discriminative control over responding (e.g., Blakely & Schlinger, 1987).

In human interactions, instructions may be spoken, written, or both. The effectiveness of instructions in controlling behavior varies in part as a function of their specificity and their congruency with the contingencies to which they refer. Galizio (1979), for example, elegantly showed how congruent instructions complement contingencies and incongruent ones can lead to ignoring the instruction. Incongruence does not universally have this effect, however. In some experiments, inaccurate instructions have been found to exert control over responding at the expense of the actual contingencies in effect.

Galizio's (1979) results, however, may be more a qualification than the rule in explicating the role of instructions in controlling human behavior. In many situations in which explicit losses are not incurred for following rules, humans often behave in stereotyped ways that suggest they are following either an instruction or their interpretation of an instruction. This outcome is not surprising given the long extra-experimental history of reinforced rule following. Even in the absence of explicit rules, some observers have postulated that humans construct their own rules. Such an analysis, however, is a quagmire—once private events such as self-generated rules are postulated to control responding in some situations, it becomes difficult to exclude their possible role in every situation. Nonetheless, in one study of how self-generated rules might control behavior, Catania, Matthews, and Shimoff (1982) had college students respond on two buttons; one reinforced high rate responding, and the other reinforced lower rate responding. The task was interrupted from time to time, and the students were asked to guess (by completing a series of structured sentences) what the schedule requirements were on the buttons. Stating the correct rule was shaped by reinforcing approximations to the correct description with points. Of interest was the relation between the shaped rule and responding in accord with the schedule in effect on either button. In general, the shaped rules functioned as a discriminative stimulus controlling responding under the two schedules.

THE FIVE PILLARS REDUX

Methods, reinforcement, punishment, control by stimuli correlated with reinforcers and punishers, and contextual and stimulus control—these are the five pillars of TEAB, the foundation on which the analyses and findings described in other chapters of this handbook are constructed. A review of these pillars balanced several factors with one another. The first was differing views as to what is fundamental. As with any science, inconsistencies in findings and differences in interpretation are commonplace. They are, however, the fodder for further growth in the science. The second was depth versus breadth of the topics. The relative space devoted to the four pillars representing empirical findings in TEAB reflects, more or less, the relative research activity making up each of those pillars. Each pillar is, of course, deeper than can be developed within the space constraints assigned. Important material was truncated to attain the breadth of coverage expected of an overview. The third was classic and contemporary research. Both have a role in defining foundations; the former lay the groundwork for contemporary developments, which in turn herald the future of TEAB.

Finally, the metaphorical nature of the five pillars needs to be taken a step further, for these are not pillars of stone. Rather, the material of these pillars is organic, subject to the same contingencies that they seek to describe. Research areas and problems come and go for a host of reasons. They are subject to the vicissitudes of life: Researchers come into their own, move, change, retire, or die (physically or metaphorically; sometimes both, but sometimes at different times); agency funding and university priorities change. Dead ends are reached. Marvelous discoveries captivate entire generations of scientists, or maybe just one scientist. Changes in TEAB will change both the content and, over time, perhaps the very pillars themselves. Indeed, it is highly likely that the research described in this handbook eventually will rewrite this chapter. As TEAB and the pillars that support it continue to

evolve, TEAB will contribute even more to an understanding of the behavior of organisms.

References

Allyon, T., & Azrin, N. H. (1968). *The token economy*. New York, NY: Appleton-Century-Crofts.

Arbuckle, J. L., & Lattal, K. A. (1987). A role for negative reinforcement of response omission in punishment? *Journal of the Experimental Analysis of Behavior, 48*, 407–416. doi:10.1901/jeab.1987.48-407

Azrin, N. H. (1956). Some effects of two intermittent schedules of immediate and non-immediate punishment. *Journal of Psychology, 42*, 3–21. doi:10.1080/00223980.1956.9713020

Azrin, N. H. (1961). Time-out from positive reinforcement. *Science, 133*, 382–383. doi:10.1126/science.133.3450.382

Azrin, N. H., & Hake, D. F. (1969). Positive conditioned suppression: Conditioned suppression using positive reinforcers as the unconditioned stimuli. *Journal of the Experimental Analysis of Behavior, 12*, 167–173. doi:10.1901/jeab.1969.12-167

Azrin, N. H., Hake, D. F., Holz, W. C., & Hutchinson, R. R. (1965). Motivational aspects of escape from punishment. *Journal of the Experimental Analysis of Behavior, 8*, 31–44. doi:10.1901/jeab.1965.8-31

Azrin, N. H., & Holz, W. C. (1966). Punishment. In W. K. Honig (Ed.), *Operantbehavior: Areas of research and application* (pp. 380–447). New York, NY: Appleton-Century-Crofts.

Azrin, N. H., Holz, W. C., & Hake, D. F. (1963). Fixed-ratio punishment. *Journal of the Experimental Analysis of Behavior, 6*, 141–148. doi:10.1901/jeab.1963.6-141

Azrin, N. H., Holz, W. C., Hake, D. F., & Allyon, T. (1963). Fixed-ratio escape reinforcement. *Journal of the Experimental Analysis of Behavior, 6*, 449–456. doi:10.1901/jeab.1963.6-449

Azrin, N. H., Hutchinson, R. R., & Hake, D. F. (1966). Extinction-induced aggression. *Journal of the Experimental Analysis of Behavior, 9*, 191–204. doi:10.1901/jeab.1966.9-191

Bachrach, A. (1960). *Psychological research: An introduction.* New York, NY: Random House.

Baer, D. M. (1981). The imposition of structure on behavior and the demolition of behavioral structures. In D. J. Bernstein (Ed.), *Response structure and organization* (pp. 217–254). Lincoln: University of Nebraska Press.

Baer, D. M., Wolf, M. M., & Risley, T. R. (1968). Some current dimensions of applied behavior analysis. *Journal of Applied Behavior Analysis, 1*, 91–97. doi:10.1901/jaba.1968.1-91

Baron, A. (1991). Avoidance and punishment. In I. Iversen & K. A. Lattal (Eds.), *Experimental analysis of behavior: Part1* (pp. 173–217). Amsterdam, the Netherlands: Elsevier.

Baron, A. (1999). Statistical inference in behavior analysis: Friend or foe? *Behavior Analyst, 22*, 83–85.

Baron, A., & Galizio, M. (2005). Positive and negative reinforcement: Should the distinction be preserved? *Behavior Analyst, 28*, 85–98.

Baum, W. M. (1973). The correlation-based law of effect. *Journal of the Experimental Analysis of Behavior, 20*, 137–153. doi:10.1901/jeab.1973.20-137

Baum, W. M. (1974). On two types of deviation from the matching law: Bias and undermatching. *Journal of the Experimental Analysis of Behavior, 22*, 231–242. doi:10.1901/jeab.1974.22-231

Baum, W. M. (1989). Quantitative description and molar description of the environment. *Behavior Analyst, 12*, 167–176.

Blackman, D. (1968). Conditioned suppression or facilitation as a function of the behavioral baseline. *Journal of the Experimental Analysis of Behavior, 11*, 53–61. doi:10.1901/jeab.1968.11-53

Blackman, D. E. (1977). Conditioned suppression and the effects of classical conditioning on operant behavior. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 340–363). New York, NY: Prentice Hall.

Blakely, E., & Schlinger, H. (1987). Rules: Function-altering contingency-specifying stimuli. *Behavior Analyst, 10*, 183–187.

Blakely, E., & Schlinger, H. (1988). Determinants of pausing under variable-ratio schedules: Reinforcer magnitude, ratio size, and schedule configuration. *Journal of the Experimental Analysis of Behavior, 50*, 65–73. doi:10.1901/jeab.1988.50-65

Bonem, M., & Crossman, E. K. (1988). Elucidating the effects of reinforcer magnitude. *Psychological Bulletin*, *104*, 348–362. doi:10.1037/0033-2909.104.3.348

Boren, J. J., & Devine, D. D. (1968). The repeated acquisition of behavioral chains. *Journal of the Experimental Analysis of Behavior, 11*, 651–660. doi:10.1901/jeab.1968.11-651

Branch, M. N. (1977). On the role of "memory" in behavior analysis. *Journal of the Experimental Analysis of Behavior, 28*, 171–179. doi:10.1901/jeab.1977.28-171

Breland, K., & Breland, M. (1961). The misbehavior of organisms. *American Psychologist, 16*, 681–684. doi:10.1037/h0040090

Brinker, R. P., & Treadway, J. T. (1975). Preference and discrimination between response-dependent and response-independent schedules of reinforcement.

Journal of the Experimental Analysis of Behavior, 24, 73–77. doi:10.1901/jeab.1975.24-73

Brown, P. L., & Jenkins, H. M. (1968). Autoshaping the pigeon's key-peck. *Journal of the Experimental Analysis of Behavior, 11*, 1–8. doi:10.1901/jeab.1968.11-1

Bruzek, J. L., Thompson, R. H., & Peters, L. C. (2009). Resurgence of infant caregiving responses. *Journal of the Experimental Analysis of Behavior, 92*, 327–343. doi:10.1901/jeab.2009-92-327

Catania, A. C. (1963). Concurrent performances: A baseline for the study of reinforcement magnitude. *Journal of the Experimental Analysis of Behavior, 6*, 299–300. doi:10.1901/jeab.1963.6-299

Catania, A. C. (1998). The taxonomy of verbal behavior. In K. A. Lattal & M. Perone (Eds.), *Handbook of research methods in human operant behavior* (pp. 405–433). New York, NY: Plenum Press.

Catania, A. C., Matthews, B. A., & Shimoff, E. (1982). Instructed versus shaped human verbal behavior: Interactions with nonverbal responding. *Journal of the Experimental Analysis of Behavior, 38*, 233–248. doi:10.1901/jeab.1982.38-233

Catania, A. C., & Reynolds, G. S. (1968). A quantitative analysis of responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior, 11*, 327–383. doi:10.1901/jeab.1968.11-s327

Church, R. M., & Raymond, G. A. (1967). Influence of the schedule of positive reinforcement on punished behavior. *Journal of Comparative and Physiological Psychology, 63*, 329–332. doi:10.1037/h0024382

Critchfield, T. S., Paletz, E. M., MacAleese, K. R., & Newland, M. C. (2003). Punishment in human choice: Direct or competitive suppression? *Journal of the Experimental Analysis of Behavior, 80*, 1–27. doi:10.1901/jeab.2003.80-1

Das Graças de Souza, D. D., de Moraes, A. B. A., & Todorov, J. C. (1984). Shock intensity and signaled avoidance responding. *Journal of the Experimental Analysis of Behavior, 42*, 67–74. doi:10.1901/jeab.1984.42-67

Davison, M. (1999). Statistical inference in behavior analysis: Having my cake and eating it. *Behavior Analyst*, *22*, 99–103.

Davison, M., & Baum, W. M. (2006). Do conditional reinforcers count? *Journal of the Experimental Analysis of Behavior, 86*, 269–283. doi:10.1901/jeab.2006.56-05

Davison, M. C., & Tustin, R. D. (1978). The relation between the generalized matching law and signal detection theory. *Journal of the Experimental Analysis of Behavior, 29*, 331–336. doi:10.1901/jeab.1978.29-331

DeGrandpre, R. J., Bickel, W. K., Hughes, J. R., Layng, M. P., & Badger, G. (1993). Unit price as a useful metric in analyzing effects of reinforcer magnitude. *Journal of the Experimental Analysis of Behavior, 60*, 641–666. doi:10.1901/jeab.1993.60-641

de Lorge, J. (1971). The effects of brief stimuli presented under a multiple schedule of second-order schedules. *Journal of the Experimental Analysis of Behavior, 15*, 19–25. doi:10.1901/jeab.1971.15-19

Deluty, M. Z. (1976). Choice and the rate of punishment in concurrent schedules. *Journal of the Experimental Analysis of Behavior, 25*, 75–80. doi:10.1901/jeab.1976.25-75

Dews, P. B. (1970). The theory of fixed-interval responding. In W. N. Schoenfeld (Ed.), *The theory of reinforcement schedules* (pp. 43–61). New York, NY: Appleton-Century-Crofts.

Dinsmoor, J. A. (1962). Variable-interval escape from stimuli accompanied by shocks. *Journal of the Experimental Analysis of Behavior, 5*, 41–47. doi:10.1901/jeab.1962.5-41

Dinsmoor, J. A. (1983). Observing and conditioned reinforcement. *Behavioral and Brain Sciences, 6*, 693–728. doi:10.1017/S0140525X00017969

Donahoe, J. W. (2003). Selectionism. In K. A. Lattal & P. N. Chase (Eds.), *Behavior theory and philosophy* (pp. 103–128). New York, NY: Kluwer Academic.

Eckerman, D. A., Hienz, R. D., Stern, S., & Kowlowitz, V. (1980). Shaping the location of a pigeon's peck: Effect of rate and size of shaping steps. *Journal of the Experimental Analysis of Behavior, 33*, 299–310. doi:10.1901/jeab.1980.33-299

Escobar, R., & Bruner, C. A. (2009). Observing responses and serial stimuli: Searching for the reinforcing properties of the S−. *Journal of the Experimental Analysis of Behavior, 92*, 215–231. doi:10.1901/jeab.2009.92-215

Estes, W. K., & Skinner, B. F. (1941). Some quantitative properties of anxiety. *Journal of Experimental Psychology, 29*, 390–400. doi:10.1037/h0062283

Fantino, E. (1969). Conditioned reinforcement, choice, and the psychological distance to reward. In D. P. Hendry (Ed.), *Conditioned reinforcement* (pp. 163–191). Homewood, IL: Dorsey Press.

Fantino, E. (1977). Conditioned reinforcement: Choice and information. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 313–339). New York, NY: Prentice Hall.

Fantino, E. (1991). Behavioral ecology. In I. Iversen & K. A. Lattal (Eds.), *Experimental analysis of behavior: Part 2* (pp. 117–153). Amsterdam, the Netherlands: Elsevier.

Fantino, E., & Silberberg, A. (2010). Revisiting the role of bad news in maintaining human observing behavior. *Journal of the Experimental Analysis of Behavior, 93*, 157–170. doi:10.1901/jeab.2010.93-157

Farley, J. (1980). Reinforcement and punishment effects in concurrent schedules: A test of two models. *Journal of the Experimental Analysis of Behavior*, *33*, 311–326. doi:10.1901/jeab.1980.33-311

Felton, M., & Lyon, D. O. (1966). The post-reinforcement pause. *Journal of the Experimental Analysis of Behavior, 9*, 131–134. doi:10.1901/jeab.1966.9-131

Ferster, C. B., & Skinner, B. F. (1957). *Schedules of reinforcement.* New York, NY: Appleton-Century-Crofts. doi:10.1037/10627-000

Freeman, T. J., & Lattal, K. A. (1992). Stimulus control of behavioral history. *Journal of the Experimental Analysis of Behavior, 57*, 5–15. doi:10.1901/jeab.1992.57-5

Galizio, M. (1979). Contingency-shaped and rule-governed behavior: Instructional control of human loss avoidance. *Journal of the Experimental Analysis of Behavior, 31*, 53–70. doi:10.1901/jeab.1979.31-53

Gibbon, J. (1977). Scalar expectancy theory and Weber's law in animal timing. *Psychological Review, 84*, 279–325. doi:10.1037/0033-295X.84.3.279

Gibson, D. A. (1966). A quick and simple method for magazine training the pigeon. *Perceptual and Motor Skills, 23*, 1230. doi:10.2466/pms.1966.23.3f.1230

Gibson, D. A. (1968). *Conditioned punishment by stimuli signalling time out from positive reinforcement.* Unpublished doctoral dissertation, University of Alabama, Tuscaloosa.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics.* New York, NY: Wiley.

Green, L., & Freed, D. E. (1998). Behavioral economics. In W. O'Donohue (Ed.), *Learning and behavior therapy* (pp. 274–300). Needham Heights, MA: Allyn & Bacon.

Hake, D. F., & Azrin, N. H. (1965). Conditioned punishment. *Journal of the Experimental Analysis of Behavior, 8*, 279–293. doi:10.1901/jeab.1965.8-279

Hall, G. A., & Lattal, K. A. (1990). Variable-interval schedule performance under open and closed economies. *Journal of the Experimental Analysis of Behavior, 54*, 13–22. doi:10.1901/jeab.1990.54-13

Hearst, E., Besley, S., & Farthing, G. W. (1970). Inhibition and the stimulus control of operant behavior. *Journal of the Experimental Analysis of Behavior, 14*, 373–409. doi:10.1901/jeab.1970.14-s373

Herrnstein, R. J. (1961). Relative and absolute strength of response as a function of frequency of reinforcement. *Journal of the Experimental Analysis of Behavior, 4*, 267–272. doi:10.1901/jeab.1961.4-267

Herrnstein, R. J. (1969). Method and theory in the study of avoidance. *Psychological Review*, *76*, 49–69.

Herrnstein, R. J. (1970). On the law of effect. *Journal of the Experimental Analysis of Behavior, 13*, 243–266. doi:10.1901/jeab.1970.13-243

Herrnstein, R. J., & Hineline, P. N. (1966). Negative reinforcement as shock-frequency reduction. *Journal of the Experimental Analysis of Behavior, 9*, 421–430. doi:10.1901/jeab.1966.9-421

Herrnstein, R. J., Loveland, D. H., & Cable, C. (1976). Natural concepts in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes, 2*, 285–302. doi:10.1037/0097-7403.2.4.285

Hoffman, H. S. (1966). The analysis of discriminated avoidance. In W. K. Honig (Ed.), *Operant behavior: Areas of research and application* (pp. 499–530). New York, NY: Appleton-Century-Crofts.

Holz, W. C. (1968). Punishment and rate of positive reinforcement. *Journal of the Experimental Analysis of Behavior, 11*, 285–292. doi:10.1901/jeab.1968.11-285

Holz, W. C., & Azrin, N. H. (1961). Discriminative properties of punishment. *Journal of the Experimental Analysis of Behavior, 4*, 225–232. doi:10.1901/jeab.1961.4-225

Hoyert, M. S. (1992). Order and chaos in fixed-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior, 57*, 339–363. doi:10.1901/jeab.1992.57-339

Hull, C. L. (1943). *Principles of psychology*. New York, NY: Appleton-Century-Crofts.

Hursh, S. R. (1980). Economic concepts for the analysis of behavior. *Journal of the Experimental Analysis of Behavior, 34*, 219–238. doi:10.1901/jeab.1980.34-219

Kaufman, A., & Baron, A. (1968). Suppression of behavior by timeout punishment when suppression results in loss of positive reinforcement. *Journal of the Experimental Analysis of Behavior, 11*, 595–607. doi:10.1901/jeab.1968.11-595

Kazdin, A. E. (1982). *Single-case research designs: Methods for clinical and applied settings.* New York, NY: Oxford University Press.

Kelleher, R. T. (1966). Chaining and conditioned reinforcement. In W. K. Honig (Ed.), *Operant behavior: Areas of research and application* (pp. 160–212). New York, NY: Appleton-Century-Crofts.

Kelleher, R. T., & Gollub, L. R. (1962). A review of conditioned reinforcement. *Journal of the Experimental Analysis of Behavior, 5*, 543–597. doi:10.1901/jeab.1962.5-s543

Keller, F. S., & Schoenfeld, W. N. (1950). *Principles of psychology*. New York, NY: Appleton-Century-Crofts.

Kelly, D. D. (1973). Suppression of random-ratio and acceleration of temporally spaced responding by the same prereward stimulus in monkeys. *Journal of the Experimental Analysis of Behavior, 20*, 363–373. doi:10.1901/jeab.1973.20-363

Killeen, P. R., & Fetterman, J. G. (1988). A behavioral theory of timing. *Psychological Review, 95*, 274–295. doi:10.1037/0033-295X.95.2.274

Kupfer, A. S., Allen, R., & Malagodi, E. F. (2008). Induced attack during fixed-ratio and matched-time schedules of food presentation. *Journal of the Experimental Analysis of Behavior, 89*, 31–48. doi:10.1901/jeab.2008.89-31

Lattal, K. A. (1974). Combinations of response-reinforcer dependence and independence. *Journal of the Experimental Analysis of Behavior*, *22*, 357–362. doi:10.1901/jeab.1974.22-357

Lattal, K. A. (1975). Reinforcement contingencies as discriminative stimuli. *Journal of the Experimental Analysis of Behavior, 23*, 241–246. doi:10.1901/jeab.1975.23-241

Lattal, K. A. (1979). Reinforcement contingencies as discriminative stimuli: II. Effects of changes in stimulus probability. *Journal of the Experimental Analysis of Behavior, 31*, 51–22.

Lattal, K. A. (1987). Considerations in the experimental analysis of reinforcement delay. In M. L. Commons, J. Mazur, J. A. Nevin, & H. Rachlin (Eds.), *Quantitative studies of operant behavior: The effect of delay and of intervening events on reinforcement value* (pp. 107–123). New York, NY: Erlbaum.

Lattal, K. A. (1989). Contingencies on response rate and resistance to change. *Learning and Motivation, 20*, 191–203. doi:10.1016/0023-9690(89)90017-9

Lattal, K. A. (1991). Scheduling positive reinforcers. In I. H. Iversen & K. A. Lattal (Eds.), *Experimental analysis of behavior: Part I* (pp. 87–134). Amsterdam, the Netherlands: Elsevier.

Lattal, K. A. (2010). Delayed reinforcement of operant behavior. *Journal of the Experimental Analysis of Behavior, 93*, 129–139. doi:10.1901/jeab.2010.93-129

Lattal, K. A., & Boyer, S. S. (1980). Alternative reinforcement effects on fixed-interval responding. *Journal of the Experimental Analysis of Behavior, 34*, 285–296. doi:10.1901/jeab.1980.34-285

Lattal, K. A., & Bryan, A. J. (1976). Effects of concurrent response-independent reinforcement on fixed-interval schedule performance. *Journal of the Experimental Analysis of Behavior, 26*, 495–504. doi:10.1901/jeab.1976.26-495

Lattal, K. A., Freeman, T. J., & Critchfield, T. (1989). Dependency location in interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior, 51*, 101–117. doi:10.1901/jeab.1989.51-101

Lattal, K. A., & Griffin, M. A. (1972). Punishment contrast during free-operant avoidance. *Journal of the Experimental Analysis of Behavior*, *18*, 509–516. doi:10.1901/jeab.1972.18-509

Lea, S. E. G. (1986). Foraging and reinforcement schedules in the pigeon: Optimal and non-optimal aspects of choice. *Animal Behaviour, 34*, 1759–1768. doi:10.1016/S0003-3472(86)80262-7

Leander, J. D. (1973). Shock intensity and duration interactions on free-operant avoidance behavior. *Journal of the Experimental Analysis of Behavior, 19*, 481–490. doi:10.1901/jeab.1973.19-481

Lieving, G. A., & Lattal, K. A. (2003). Recency, repeatability, and reinforcer retrenchment: An experimental analysis of resurgence. *Journal of the Experimental Analysis of Behavior, 80*, 217–233. doi:10.1901/jeab.2003.80-217

Logue, A. W., & de Villiers, P. A. (1978). Matching in concurrent variable-interval avoidance schedules. *Journal of the Experimental Analysis of Behavior, 29*, 61–66. doi:10.1901/jeab.1978.29-61

LoLordo, V. M. (1971). Facilitation of food-reinforced responding by a signal for response-independent food. *Journal of the Experimental Analysis of Behavior, 15*, 49–55. doi:10.1901/jeab.1971.15-49

Lund, C. A. (1976). Effects of variations in the temporal distribution of reinforcements on interval schedule performance. *Journal of the Experimental Analysis of Behavior, 26*, 155–164. doi:10.1901/jeab.1976.26-155

Mackay, H. A. (1991). Conditional stimulus control. In I. Iversen & K. A. Lattal (Eds.), *Experimental analysis of behavior: Part 1* (pp. 301–350). Amsterdam, the Netherlands: Elsevier.

Madden, G. J. (2000). A behavioral economics primer. In W. Bickel & R. K. Vuchinich (Eds.), *Reframing health behavior change with behavioral economics* (pp. 3–26). Mahwah, NJ: Erlbaum.

Madden, G. J., & Bickel, W. K. (Eds.). (2010). *Impulsivity: The behavioral and neurological science of discounting.* Washington, DC: American Psychological Association. doi:10.1037/12069-000

Marr, M. J. (1992). Behavior dynamics: One perspective. *Journal of the Experimental Analysis of Behavior, 57*, 249–266. doi:10.1901/jeab.1992.57-249

Marr, M. J. (2006). Through the looking glass: Symmetry in behavioral principles? *Behavior Analyst, 29*, 125–128.

Mazur, J. E. (1986). Choice between single and multiple delayed reinforcers. *Journal of the Experimental Analysis of Behavior, 46*, 67–77. doi:10.1901/jeab.1986.46-67

McDowell, J. J. (1986). On the falsifiability of matching theory. *Journal of the Experimental Analysis of Behavior, 45*, 63–74. doi:10.1901/jeab.1986.45-63

McDowell, J. J. (1989). Two modern developments in matching theory. *Behavior Analyst, 12*, 153–166.

McKearney, J. W. (1972). Maintenance and suppression of responding under schedules of electric shock presentation. *Journal of the Experimental Analysis of Behavior, 17*, 425–432. doi:10.1901/jeab.1972.17-425

Michael, J. (1974). Statistical inference for individual organism research: Mixed blessing or curse? *Journal*

of Applied Behavior Analysis, 7, 647–653. doi:10.1901/jaba.1974.7-647

Michael, J. (1975). Positive and negative reinforcement: A distinction that is no longer necessary; or a better way to talk about bad things. *Behaviorism, 3*, 33–44.

Michael, J. (1982). Distinguishing between discriminative and motivational functions of stimuli. *Journal of the Experimental Analysis of Behavior, 37*, 149–155. doi:10.1901/jeab.1982.37-149

Moore, J., & Fantino, E. (1975). Choice and response contingencies. *Journal of the Experimental Analysis of Behavior, 23*, 339–347. doi:10.1901/jeab.1975.23-339

Morse, W. H., & Kelleher, R. T. (1977). Determinants of reinforcement and punishment. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 98–124). New York, NY: Prentice Hall.

Neuringer, A. J. (1970). Superstitious key pecking after three peck-produced reinforcements. *Journal of the Experimental Analysis of Behavior, 13*, 127–134. doi:10.1901/jeab.1970.13-127

Neuringer, A. (2002). Operant variability: Evidence, functions, and theory. *Psychonomic Bulletin and Review*, *9*, 672–705. doi:10.3758/BF03196324

Nevin, J. A. (1969). Signal detection theory and operant behavior: A review of David M. Green and John A. Swets'*Signal detection theory and psychophysics. Journal of the Experimental Analysis of Behavior*, *12*, 475–480. doi:10.1901/jeab.1969.12-475

Nevin, J. A. (1974). Response strength in multiple schedules. *Journal of the Experimental Analysis of Behavior, 21*, 389–408. doi:10.1901/jeab.1974.21-389

Nevin, J. A., Mandell, C., & Atak, J. R. (1983). The analysis of behavioral momentum. *Journal of the Experimental Analysis of Behavior, 39*, 49–59. doi:10.1901/jeab.1983.39-49

Nevin, J. A., Tota, M. E., Torquato, R. D., & Shull, R. L. (1990). Alternative reinforcement increases resistance to change: Pavlovian or operant contingencies? *Journal of the Experimental Analysis of Behavior, 53*, 359–379. doi:10.1901/jeab.1990.53-359

Ono, K. (2004). Effects of experience on preference between forced and free choice. *Journal of the Experimental Analysis of Behavior, 81*, 27–37. doi:10.1901/jeab.2004.81-27

Palya, W. L. (1992). Dynamics in the fine structure of schedule-controlled behavior. *Journal of the Experimental Analysis of Behavior, 57*, 267–287. doi:10.1901/jeab.1992.57-267

Pear, J. J., & Legris, J. A. (1987). Shaping by automated tracking of an arbitrary operant response. *Journal of the Experimental Analysis of Behavior, 47*, 241–247. doi:10.1901/jeab.1987.47-241

Peele, D. B., Casey, J., & Silberberg, A. (1984). Primacy of interresponse time reinforcement in accounting for rate differences under variable-ratio and variable-interval schedules. *Journal of Experimental Psychology: Animal Behavior Processes, 10*, 149–167. doi:10.1037/0097-7403.10.2.149

Perone, M., & Baron, A. (1980). Reinforcement of human observing behavior by a stimulus correlated with extinction or increased effort. *Journal of the Experimental Analysis of Behavior, 34*, 239–261. doi:10.1901/jeab.1980.34-239

Perone, M., & Galizio, M. (1987). Variable-interval schedules of time out from avoidance. *Journal of the Experimental Analysis of Behavior, 47*, 97–113. doi:10.1901/jeab.1987.47-97

Pietras, C. J., & Hackenberg, T. D. (2005). Response-cost punishment via token loss with pigeons. *Behavioural Processes, 69*, 343–356. doi:10.1016/j.beproc.2005.02.026

Platt, J. R. (1973). Percentile reinforcement: Paradigms for experimental analysis of response shaping. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in theory and research* (Vol. 7, pp. 271–296). New York, NY: Academic Press.

Premack, D. (1959). Toward empirical behavior laws: 1. Positive reinforcement. *Psychological Review, 66*, 219–233. doi:10.1037/h0040891

Rachlin, H., & Green, L. (1972). Commitment, choice and self-control. *Journal of the Experimental Analysis of Behavior, 17*, 15–22. doi:10.1901/jeab.1972.17-15

Rasmussen, E. B, & Newlin, C. (2008). Asymmetry of reinforcement and punishment in human choice. *Journal of the Experimental Analysis of Behavior, 89*, 157–167. doi:10.1901/jeab.2008.89-157

Ray, B. A. (1969). Selective attention: The effects of combining stimuli which control incompatible behavior. *Journal of the Experimental Analysis of Behavior, 12*, 539–550. doi:10.1901/jeab.1969.12-539

Rescorla, R. A., & Skucy, J. C. (1969). Effect of response-independent reinforcers during extinction. *Journal of Comparative and Physiological Psychology, 67*, 381–389. doi:10.1037/h0026793

Richards, J. B., Mitchell, S. H., de Wit, H., & Seiden, L. S. (1997). Determination of discount functions in rats with an adjusting-amount procedure. *Journal of the Experimental Analysis of Behavior, 67*, 353–366. doi:10.1901/jeab.1997.67-353

Rilling, M. (1977). Stimulus control and inhibitory processes. In W. K. Honing & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 432–480). Englewood Cliffs, NJ: Prentice-Hall.

Schuster, R., & Rachlin, H. (1968). Indifference between punishment and free shock: Evidence for the negative

law of effect. *Journal of the Experimental Analysis of Behavior, 11*, 777–786. doi:10.1901/jeab.1968.11-777

Shnidman, S. R. (1968). Extinction of Sidman avoidance behavior. *Journal of the Experimental Analysis of Behavior, 11*, 153–156. doi:10.1901/jeab.1968.11-153

Sidman, M. (1953). Two temporal parameters of the maintenance of avoidance behavior by the white rat. *Journal of Comparative and Physiological Psychology, 46*, 253–261. doi:10.1037/h0060730

Sidman, M. (1960). *Tactics of scientific research*. New York, NY: Basic Books.

Sidman, M. (1966). Avoidance behavior. In W. Honig (Ed.), *Operant behavior: Areas of research and application* (pp. 448–498). New York, NY: Appleton-Century-Crofts.

Sidman, M. (1986). Functional analysis of emergent verbal classes. In T. Thompson & M. D. Zeiler (Eds.), *Analysis and integration of behavioral units* (pp. 213–245). Hillsdale, NJ: Erlbaum.

Sidman, M., Kirk, B., & Wilson-Morris, M. (1985). Six-member stimulus classes generated by conditional-discrimination procedures. *Journal of the Experimental Analysis of Behavior, 43*, 21–42. doi:10.1901/jeab.1985.43-21

Sidman, M., & Tailby, W. (1982). Conditional discrimination vs. matching to sample: An expansion of the testing paradigm. *Journal of the Experimental Analysis of Behavior, 37*, 5–22. doi:10.1901/jeab.1982.37-5

Siegel, P. S., & Milby, J. B. (1969). Secondary reinforcement in relation to shock termination: Second chapter. *Psychological Bulletin*, *72*, 146–156. doi:10.1037/h0027781

Skinner, B. F. (1935). The generic nature of the concepts of stimulus and response. *Journal of General Psychology, 12*, 40–65. doi:10.1080/00221309.1935.9920087

Skinner, B. F. (1938). *Behavior of organisms*. New York, NY: Appleton-Century-Crofts.

Skinner, B. F. (1948). "Superstition" in the pigeon. *Journal of Experimental Psychology, 38*, 168–172. doi:10.1037/h0055873

Skinner, B. F. (1953). *Science and human behavior*. New York, NY: Macmillan.

Skinner, B. F. (1956). A case history in scientific method. *American Psychologist, 11*, 221–233. doi:10.1037/h0047662

Skinner, B. F. (1957). *Verbal behavior*. New York, NY: Appleton-Century-Crofts. doi:10.1037/11256-000

Skinner, B. F. (1966). What is the experimental analysis of behavior? *Journal of the Experimental Analysis of Behavior, 9*, 213–218. doi:10.1901/jeab.1966.9-213

Skinner, B. F. (1981). Selection by consequences. *Science, 213*, 501–504. doi:10.1126/science.7244649

Staddon, J. E. R. (1968). Spaced responding and choice: A preliminary analysis. *Journal of the Experimental Analysis of Behavior, 11*, 669–682. doi:10.1901/jeab.1968.11-669

Staddon, J. E. R. (1979). Operant behavior as adaptation to constraint. *Journal of Experimental Psychology: General, 108*, 48–67. doi:10.1037/0096-3445.108.1.48

Staddon, J. E. R., & Simmelhag, V. (1971). The "superstition" experiment: A re-examination of its implications for the principles of adaptive behavior. *Psychological Review, 78*, 3–43. doi:10.1037/h0030305

Stubbs, A. (1968). The discrimination of stimulus duration by pigeons. *Journal of the Experimental Analysis of Behavior, 11*, 223–238. doi:10.1901/jeab.1968.11-223

Terrace, H. S. (1963). Discrimination learning with and without "errors." *Journal of the Experimental Analysis of Behavior, 6*, 1–27. doi:10.1901/jeab.1963.6-1

Terrace, H. S. (1966). Stimulus control. In W. Honig (Ed.), *Operant behavior: Areas of research and application* (pp. 271–344). New York, NY: Appleton-Century-Crofts.

Thorndike, E. L. (1911). *Animal intelligence*. New York, NY: Macmillan.

Timberlake, W., & Allison, J. (1974). Response deprivation: An empirical approach to instrumental performance. *Psychological Review, 81*, 146–164. doi:10.1037/h0036101

Timberlake, W., & Lucas, G. A. (1985). The basis of superstitious behavior: Chance contingency, stimulus substitution, or appetitive behavior? *Journal of the Experimental Analysis of Behavior, 44*, 279–299. doi:10.1901/jeab.1985.44-279

Uhl, C. N., & Garcia, E. E. (1969). Comparison of omission with extinction in response elimination in rats. *Journal of Comparative and Physiological Psychology, 69*, 554–562. doi:10.1037/h0028243

Verhave, T. (1962). The functional properties of a time out from an avoidance schedule. *Journal of the Experimental Analysis of Behavior, 5*, 391–422. doi:10.1901/jeab.1962.5-391

Wasserman, E. A., Young, M. E., & Peissig, J. J. (2002). Brief presentations are sufficient for pigeons to discriminate arrays of same and different stimuli. *Journal of the Experimental Analysis of Behavior, 78*, 365–373. doi:10.1901/jeab.2002.78-365

Watkins, M. J. (1990). Mediationism and the obfuscation of memory. *American Psychologist, 45*, 328–335. doi:10.1037/0003-066X.45.3.328

Weiner, H. (1962). Some effects of response cost upon human operant behavior. *Journal of the Experimental Analysis of Behavior, 5*, 201–208. doi:10.1901/jeab.1962.5-201

Weiner, H. (1969). Conditioning history and the control of human avoidance and escape responding. *Journal*

of the Experimental Analysis of Behavior, 12, 1039–1043. doi:10.1901/jeab.1969.12-1039

Williams, B. A. (1983). Revising the principle of reinforcement. *Behaviorism, 11*, 63–88.

Williams, B. A. (1994). Conditioned reinforcement: Experimental and theoretical issues. *Behavior Analyst, 17*, 261–285.

Wyckoff, L. B. (1952). The role of observing responses in discrimination learning. *Psychological Review, 59*, 431–442. doi:10.1037/h0053932

Zeiler, M. D. (1968). Fixed and variable schedules of response-independent reinforcement. *Journal of the Experimental Analysis of Behavior, 11*, 405–414. doi:10.1901/jeab.1968.11-405

Zeiler, M. D. (1976). Positive reinforcement and the elimination of reinforced responses. *Journal of the Experimental Analysis of Behavior, 26*, 37–44. doi:10.1901/jeab.1976.26-37

Zeiler, M. D. (1977a). Elimination of reinforced behavior: Intermittent schedules of not-responding. *Journal of the Experimental Analysis of Behavior, 27*, 23–32. doi:10.1901/jeab.1977.27-23

Zeiler, M. D. (1977b). Schedules of reinforcement: The controlling variables. In W. K. Honig & J. E. R. Staddon (Eds.), *Handbook of operant behavior* (pp. 201–232). New York, NY: Prentice Hall.

Zeiler, M. D. (1984). Reinforcement schedules: The sleeping giant. *Journal of the Experimental Analysis of Behavior, 42*, 485–493. doi:10.1901/jeab.1984.42-485

Zeiler, M. D. (1992). On immediate function. *Journal of the Experimental Analysis of Behavior, 57*, 417–427. doi:10.1901/jeab.1992.57-417

Zimmerman, J. (1969). Meanwhile . . . back at the key: Maintenance of behavior by conditioned reinforcement and response-independent primary reinforcement. In D. P. Hendry (Ed.), *Conditioned reinforcement* (pp. 91–124). Homewood, IL: Dorsey Press.