CHAPTER 4

OPERANT EXTINCTION: ELIMINATION AND GENERATION OF BEHAVIOR

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In recounting his early research agenda, Skinner (1956) described the serendipitous event that led to the discovery of operant extinction curves. The pellet dispenser on his apparatus jammed, leaving lever pressing unreinforced. The cumulative record obtained under this defective procedure was nonetheless orderly. Lever pressing did not stop immediately when reinforcement was withdrawn. Rather, it continued for a while, decreasing as exposure to the new contingency proceeded. As Skinner noted, the record was one of "pure behavior" (p. 226), uninterrupted by food delivery or consumption. He recalled, too, his excitement on observing this first extinction curve, suggesting to him that he "had made contact with Pavlov at last!" (p. 226).

Skinner's serendipitous finding not only made contact with Pavlov, but it turned out to be one of the most reliable effects in the study of learned behavior. Furthermore, the effect has considerable generality. Extinction is found across classical and operant conditioning, in basic and applied research, and in practice. It also is widespread in the animal kingdom, having been reported in organisms ranging from invertebrates (e.g., Abramson, Armstrong, Feinman, & Feinman, 1988) to *Homo sapiens*.

The effects of extinction, however, are neither unidimensional nor simple. Eliminating reinforcement can diminish not only the previously reinforced response, but also others that are related to it. Although responding is eliminated in the sense that it is no longer observed, the extinguished response is quickly reestablished under appropriate circumstances, leading some to describe extinction in terms of discriminative stimulus control and others to consider it as evidence for a learning–performance distinction (e.g., Hull, 1943). Skinner's subsequent research on extinction (e.g., 1933b) revealed something of its synergistic relation to other contingencies of reinforcement. When he alternated periods of reinforcement and nonreinforcement, the result was the familiar scalloped pattern of responding, and the fixed-interval (FI) schedule was born—a direct descendant of operant extinction. Its sibling, the variable-interval (VI) schedule, was created by substituting variable for fixed interreinforcer intervals (IRIs). Other analyses of the synergistic relation between extinction and other events in the organism's proximal and distal histories have elaborated the generative effects of extinction. This chapter is a review of research from basic and applied behavior analysis bearing on both the eliminative and generative effects of the extinction of operant behavior.

HISTORY OF THE STUDY OF EXTINCTION

The physiologist Sherrington (1906) used *extinction* as a synonym for *elimination*. He suggested that the extinction of a reflex could be achieved either by changing the physical properties of the stimuli or by interrupting the nerve connection. Pavlov (1927) was the first to give a precise definition of *extinction* in terms of both a procedure and an effect or result. He noted that the "phenomenon of a rapid and more or less smoothly progressive weakening of the conditioned reflex to a conditioned stimulus which is repeated a number of times without reinforcement

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may appropriately be termed **experimental extinction of conditioned reflexes**" (p. 49). For Pavlov, in extinction the "positive conditioned stimulus itself becomes . . . negative or inhibitory" (p. 48), which he contrasted to external inhibition, in which some other stimulus reduces the probability of the conditioned reflex. Thus, for Pavlov, as for many who subsequently studied it, extinction was an active process whereby the response previously established by reinforcement was inhibited.

As Pavlov's research became accessible in the United States (e.g., Watson, 1916; Yerkes & Morgulis, 1909), the term *extinction* began to appear in psychology textbooks. Pavlov's definition of *extinction,* however, was not clarified for English speakers until Anrep's translation of Pavlov's work appeared in 1927 (Humphrey, 1930). For example, Watson (1924, p. 29) mentioned briefly that a conditioned reflex could be extinguished under two conditions: the lack of practice and the very rapid repetition of the stimulus. After the procedural definition of extinction was clarified, it became more broadly integrated into research on learning, although others continued to equate extinction with fatigue or negative adaptation (e.g., Symonds, 1927; Winsor, 1930).

Following Pavlov's lead, Hull (e.g., 1929) suggested that the conditioned reflex was composed of an excitatory or positive phase during conditioning and an inhibitory or negative phase during extinction. Skinner (1933a, 1933b) described extinction simply as a decrease in the strength of the conditioned reflex by removing the consequence of the conditioned response. He subsequently (Skinner, 1935) distinguished respondent, or Pavlovian, and operant conditioning, in part on the basis of a distinction between involuntary and voluntary behavior.

Although Skinner (1938) applied Pavlov's terminology to voluntary, or emitted, behavior, he rejected the concept of inhibition: "Extinction of a conditioned reflex of Type R occurs when the response is no longer followed by the reinforcing stimulus. The change is merely a decrease in [the] previously reinforced response" (p. 74). Thus, for Skinner, rather than the distinct learning process that is implied by assigning inhibitory properties to extinction, the effects of extinction were a reflection of the effects of reinforcement. This was the basis of Skinner's concept of the reflex reserve, whereby reinforcement builds the reserve that then is depleted as a function of the previous conditions of reinforcement when such reinforcement is discontinued. Skinner later dropped the reflex reserve, but the notion of resistance to extinction as an index of the effects of reinforcement on operant behavior persists (e.g., Nevin, 1974, 1979).

In an early application of extinction to socially relevant problems, Fuller (1949) first established raising to a vertical position the right arm of a vegetative 18-year-old man by reinforcing such movements with a warm sugar–milk solution squirted into the man's mouth. After four training sessions, reinforcement was discontinued, but responding was maintained for the first 30 min of extinction. Thereafter, "the rate decreased until by the seventieth minute . . . it approached zero" (p. 590). Fuller also observed that during extinction "*S*'s movements gradually became more generalized; the left arm, which had moved very little in the last two sessions, moved more frequently after the rate of movement of the right arm noticeably decreased" (p. 590). After Fuller's demonstration, applied extinction research continued to examine the degree to which extinction effects reported with nonhumans could be replicated and extended with human participants (e.g., Bijou, 1957, 1958; Mech, 1952).

Contemporary research on extinction in both research and application has strengthened, questioned, and qualified some of the historical findings and assumptions about the nature of extinction. Before turning to these contemporary developments, however, a consideration of the definitions of extinction is in order.

DEFINITIONS AND GENERAL CHARACTERISTICS OF EXTINCTION

The term *extinction* refers to both procedures and the effects of those procedures. The extinction procedure can both eliminate and generate behavior. Neither effect typically is permanent. Rather, they are circumstantial. In this section the general characteristics of extinction are addressed.

Procedural Dimensions

A general procedural definition of *extinction* is the discontinuation of the reinforcement of a response. With responding that has been positively reinforced, this conventionally means removing the previously established positive reinforcer. Another way of discontinuing positive reinforcement, however, is to remove the response–positive reinforcer dependency. The reinforcer continues to occur, albeit independently of responding (Rescorla & Skucy, 1969). With responding that has been negatively reinforced, three extinction procedures have been used: (a) The negative reinforcer (i.e., the stimulus previously avoided or escaped from; cf. Catania, 1991; Cooper, Heron, & Heward, 2007) is made noneliminable, that is, responses do not terminate or postpone it; (b) the negative reinforcer is terminated intermittently, independently of responding; and (c) the negative reinforcer is removed by, for example, turning off a shock generator after training on a free-operant avoidance schedule. Each of these procedures are elaborated and discussed in the sections that follow.

Procedurally, too, extinction often is a chronic preparation. That is, once implemented, it remains in effect for an indefinite period or until some behavioral criterion of response elimination is reached. Extinction, however, also may be more acute and local. In an FI schedule, for example, the initial part of each individual FI is always extinction in that responding is never reinforced during that time. As is discussed later, reducing the rate of reinforcement programmed by a schedule (so-called schedule leaning or thinning) also can be considered an instance of local extinction because the likelihood that responses previously meeting the reinforcement criterion now go unreinforced is increased.

A final procedural consideration is the term *extinction* applied to punishment. In line with the preceding discussion, either the elimination of a punisher or the removal of the dependency between a response and a punisher could be construed as extinction. Doing so, however, invites confusion in light of the long history of using extinction in the context of reinforced responding (cf. Catania, 1991). For that reason, punishment is not considered in this chapter (see Volume 1, Chapter 21, this handbook).

Functional Dimensions

Procedural definitions describe only operations, not the functional outcomes that are critical to any useful definition of extinction. Both Pavlov's and Skinner's definitions included a statement of the functional effects: Responding is reduced or eliminated when the procedure is implemented. As used here, *elimination* means reducing responding to zero or near zero in the context in which it previously was reinforced. It does not mean that the probability of the response has been permanently reduced to zero such that when contexts or circumstances change, there is little to no chance that the extinguished behavior will recur if extinction subsequently is discontinued.

The applied technique of planned ignoring (e.g., Buck, 1992) illustrates the types of problems that ensue from using a procedural as opposed to a functional definition of extinction. In planned ignoring, the problem behavior of a child evokes no reaction from the caregiver. The procedure assumes a priori that some aspect of the caregiver's behavior is responsible for the misbehavior in the first place. The failure of such a treatment, based on a procedural definition of extinction, led to an emphasis in treatment on a functional definition of extinction and a focus on eliminating the de facto (functional) reinforcer (Iwata, Pace, Cowdery, & Miltenberger, 1994).

Response Generation and Functional Dimensions of Extinction

The effect of extinction depends on where one is looking. Conventionally, the previously reinforced response is the focus, and its decrease functionally defines extinction. As measurement has extended from the recording of a single operant to variations in operant topography (e.g., Antonitis, 1951), to multiple operants (e.g., Lowry & Lachter, 1977), or to behavior in addition to the operant (e.g., Kelly & Hake, 1970), the generative function of extinction has become more evident. Generative effects such as extinction-induced variability, extinction-induced responding, and reinforcement of alternative behavior were discovered as a result of examining the effects of extinction on extended and other classes of behavior.

The generative function of extinction may come into play in different ways in application. First, there is no guarantee that alternative behavior generated by extinction will be more adaptive or socially appropriate than the response being extinguished. This is especially true if no specific alternative response is selected for reinforcement. Lieving, Hagopian, Long, and O'Connor (2004), for example, demonstrated that extinction of one form of disruptive behavior resulted in the emergence of other, sometimes more severe forms of disruption. Second, extinction may generate new responses that then can be reinforced (e.g., Grow, Kelley, Roane, & Shillingsburg, 2008). In procedures involving the differential reinforcement of successive approximations (shaping), for example, the variability created by extinction may generate the desired successive approximation to the terminal response. If, however, the desired alternative response is not one generated by extinction, then the generated responses may compete with the selected alternative response.

Stability and Functional Dimensions of Extinction

Even though extinction decreases the frequency of the previously reinforced response, it often maintains the structure of that previously reinforced response. That is, even though extinguished, the form of the response may remain stable or intact, at least in the short term but often in the longer term (Rescorla, 1996; see Volume 1, Chapter 13, this handbook). Responses completely eliminated by extinction in one context, for example, often recur under other conditions (see, e.g., Reinstatement and Resurgence sections; Lerman, Kelley, Van Camp & Roane, 1999; Uhl & Garcia, 1969). Nevin (1967), for example, trained pigeons to peck the brighter of two keys presented simultaneously during a discrete-trials procedure. When intermittent food delivery following correct choices was discontinued, key pecking decreased, but the accuracy of the responses that did occur was unchanged.

An experiment by Neuringer, Kornell, and Olufs (2001) suggests a possible rapprochement between the seemingly contradictory functions of extinction in maintaining response stability or integrity over time while also increasing response variability. They reinforced three-response sequences of rats only if the sequence had been emitted less than 5% of the time, weighted for recency. When reinforcement of these response sequences was discontinued, response rates and sequences completed per minute decreased, but the probability of each of the 27 possible sequences remained nearly constant. There was, however, a small but consistent increase in the probability of the least likely sequences relative to their baseline levels during the reinforcement baseline. Neuringer et al. observed that the result of extinguishing the response sequences was

> to significantly raise variability but not so much as to affect the hierarchies. It is as if the subjects generally bet on what had worked in the past but occasionally probed to see whether anything better might appear by doing something completely different, a combination of conservative and radical behavioral strategies. The combination is presumably functional in a world in which reinforcers are sometimes intermittent and other times depleted . . . but the two cases may be difficult for an animal to discriminate; therefore, the combination of conservative and radical strategies. (p. 92)

But what of some applied situations in which extinction does appear to eliminate the target response permanently? Most likely, other responses have been reinforced as the extinction procedure was implemented. Thus, a differential-reinforcement-of-alternative-behavior contingency may be responsible for the elimination of the response rather than such elimination being a direct outcome of extinction. Athens and Vollmer (2010), for example, reduced responding during differential reinforcement procedures, in the absence of programmed extinction for problem behavior. For all participants, problem behavior was reduced or eliminated when the (alternative) reinforcement contingency favored compliance or appropriately requesting a desired outcome, even though problem behavior would have been reinforced.

ELIMINATIVE EFFECTS OF EXTINCTION

The most consistent effect of the extinction procedures defined above is a reduction of response rates to low levels, often eventually to zero. The following sections delineate the dimensions of these eliminative effects.

Extinction of Positively Reinforced Responding by Removing the Positive Reinforcer

Because positive reinforcement is the most common behavioral process, it is not surprising that the effects of extinction in eliminating behavior previously maintained by positive reinforcement have been those most commonly studied. In this section we review such extinction effects.

Methodological considerations. Three methods have been used to evaluate the functional relations between different parameters of positive reinforcement and operant extinction. In early experiments, different groups of subjects were exposed to different values of the selected parameter of reinforcement. Following Skinner (1938) and Sidman (1960), a second method appeared in which each of a few subjects were exposed during successive conditions to different values of the selected parameter, each followed by extinction. One difficulty with this latter design is a temporal confound such that resistance to extinction may diminish with repeated exposure to it. This effect amounts to the formation of a discrimination across conditions on the basis of the presence or absence of reinforcement. Thus, the effects on extinction of the second-studied parameter may be confounded by a prior history of extinction, which in turn may decrease responding independently of the effects of the second parameter. A third method is the multiple-schedule or alternating-treatments design (Volume 1, Chapter 5, this handbook). In it, two or more different conditions of reinforcement, each correlated with distinct stimuli, alternate within or across successive sessions. It thus is possible to compare the relative changes in responding when extinction is imposed more or less simultaneously in all components. A potential limitation of using multiple schedules is that the order of the components during extinction can affect the course of extinction. That is, as responding diminishes in the first-presented component, associated with one of the reinforcement conditions, such reduction may affect responding in the second component, associated with the other reinforcement condition, independent of the reinforcement parameter under study. For example, the results might reveal Parameter 1 to be more resistant to extinction if it appeared first but Parameter 2 to be more resistant if it appeared first. There is no uniform solution to such potential order effects in comparing the effects of different parameters on resistance to extinction. Rather, they are simply a drawback of the design that must be weighed relative to its merits and in comparison with other procedures for examining the effects of different reinforcement parameters on extinction.

Extinction of schedule-maintained responding. One of the earliest reported effects of intermittent reinforcement was that it resulted in relatively greater resistance to extinction than did continuous reinforcement (CRF). This effect is variously described as "Humphreys' paradox," or the partial reinforcement extinction effect. Humphreys (1939) first demonstrated it with Pavlovian conditioning, but it subsequently was replicated with operant behavior in both laboratory (e.g., Notterman, Schoenfeld, & Bersh, 1952; Zarcone, Branch, Hughes, & Pennypacker, 1997) and applied research (Lerman, Iwata, Shore, & Kahng, 1996). The effect depends on whether responding is measured in absolute or relative terms (e.g., Lerman et al., 1996) and has been accounted for in different ways (see Nevin, 1988).

Response patterning during extinction reflects the schedule under which the operant response was maintained before extinction (Reynolds, 1968), although systematic research on this subject is limited. Reynolds (1968) noted that responding in extinction after VI training tends to occur regularly but at progressively lower rates as extinction proceeds. By contrast, extinction after fixed-ratio (FR) or variable-ratio (VR) training is characterized by progressively decreasing bursts of responses followed by progressively longer periods of nonresponding. During extinction after FI training, responding tends to occur in positively accelerated patterns but with longer periods of pausing and increasingly shallow scallops (or break-and-run patterns, if the FI schedule has been in effect for an extended period; cf. Schneider, 1969) as time in extinction proceeds.

Extinction within conditions/schedules of reinforcement. Response shaping is one of the most common procedures for establishing a target response. In shaping, reinforcement and extinction occur within a dynamic framework whereby the criteria for reinforcement are constantly in flux, changing as behavior approaches the criterion response. Over time, previous criterion responses are no longer sufficient for reinforcement and undergo extinction as closer approximations to the target response are reinforced (cf. Athens, Vollmer, & St. Peter Pipkin, 2007; Galbicka, 1994; Platt, 1973; Smeets, Lancioni, Ball, & Oliva, 1985).

Periods of nonreinforcement occur when responding is reinforced intermittently (local extinction). These periods of local extinction are inherent in schedules of reinforcement such as FI and FR, in which responding is reinforced only after a fixed point in time or a fixed number of responses, respectively. This reinforcement pattern results in oscillations between distinct periods of responding and its absence, yielding the pause–respond pattern reported with both FI and FR (Felton & Lyon, 1966; Ferster & Skinner, 1957; Schneider, 1969).

Alternating periods of extinction and reinforcement characterize other schedules as well, albeit more subtly. Catania and Reynolds (1968), for example, noted that the smallest IRI on a VI schedule denotes a period of absolute nonreinforcement. As a result, the postreinforcement pause corresponds to the minimum IRIs, such that longer minimum intervals result in longer mean postreinforcement pauses on VI schedules. Blakely and Schlinger (1988) reported parallel findings for VR schedules: The postreinforcement pause varied as a function of the smallest ratio requirement within the VR.

In differential-reinforcement-of-low-rate (DRL) schedules, a response is never followed by a reinforcer until after the specified value of the DRL has lapsed. As a result, the responses (and reinforcers, too) could serve as discriminative stimuli for periods of nonreinforcement (an S−), thereby contributing, along with the differential reinforcement of long interresponse times, to the relatively low response rates that characterize performance on this schedule.

Other parameters of reinforcement and extinction. Responding previously maintained on multiple schedules of positive reinforcement is more resistant to extinction when reinforcers are more frequent, of larger magnitude, and less delayed from the responses that produce them (Cohen, Riley, & Weigle, 1993; Nevin, 1974, 1979). Using a multiple schedule in which different components arranged different numbers of reinforcers, Hearst (1961), for example, found that responding during extinction was a monotonically increasing function of the number of reinforcers (Experiment 1). Also using a multiple schedule, Shettleworth and Nevin (1965) found that responding during extinction was more frequent after training with 9-s access to the reinforcer than after 1-s access.

A somewhat different picture of the effects on extinction of different parameters of reinforcement emerges, however, when extinction follows training on single reinforcement schedules instead of components of a multiple schedule. Cohen et al. (1993) maintained responding of rats and pigeons on VI, FI, FR, or VR schedules. Over successive sessions, responding was stabilized at a given reinforcement rate, followed by extinction. The sequence of schedule-maintained responding followed by extinction was repeated, using different reinforcement rates with the specified schedule. Cohen et al. found no systematic relation between resistance to extinction and reinforcement rate with any of the schedules. Lerman, Kelley, Vorndran, Kuhn, and LaRue (2002) did not find systematic differences in the effects of reinforcer magnitude on problem behavior either during training or during extinction. Using a reversal design, Fisher (1979) found reliable effects of reinforcer magnitude on resistance to extinction but in the opposite direction to that reported under multiple schedules of reinforcement. That is, when toothbrushing was reinforced with either one or five tokens, the responding of 11 of 13 participants was more resistant to extinction after reinforcement with one token than it was after five tokens. This finding, however, is difficult to interpret because for each participant, the larger magnitude reinforcer always preceded the smaller magnitude reinforcer.

Little other applied research has examined parameters of reinforcement affecting resistance to extinction during the treatment of problem behavior. This relative paucity may be related in part to difficulties in controlling reinforcement parameters. For example, it may be difficult to manipulate experimentally the number of reinforcers delivered for problem behavior in a controlled way, because problem behavior typically has a long history of extraexperimental reinforcement before it is referred for intervention. The additional reinforcers provided in an experimental arrangement, in relation to the larger context of the extraexperimental history, may be insufficient to produce systematic changes in resistance to extinction (Lerman & Iwata, 1996).

Repeated exposure to extinction. When successive reconditioning and exposure to extinction occurs, responding generally decreases more rapidly across replications. Reductions in responding (i.e., diminishing resistance to extinction) during successive periods of extinction have been reported in pigeons after both continuous and intermittent reinforcement (e.g., Anger & Anger, 1976; Bullock, 1960; Jenkins, 1961). For example, Bullock exposed different pigeons to 18 sessions of either an FR 20 or an FI 26-s schedule of reinforcement. Within each of these sessions, after 20 reinforcers were delivered, responding was extinguished for 60 min and then the session terminated. Responding during extinction decreased monotonically across successive extinction sessions for each pigeon. Anger and Anger (1976) repeated, either six or 12 times, a cycle composed of two daily sessions of conditioning followed by eight daily sessions of extinction. They used a discrete-trial modified autoshaping procedure in which the first key peck during each trial both ended the trial and was reinforced with a probability of .20. Response rates decreased across successive exposures to the extinction cycles, but the decrease occurred only during the first sessions of extinction in each cycle. During the last extinction sessions in each cycle, after first decreasing from that occurring during the previous reinforcement portion of the cycle, responding increased slightly across successive cycles. These findings suggest that the absence of reinforcement during extinction serves as a discriminative stimulus controlling behavior other than the defined response. As extinction progresses, however, the discriminative control of not responding exerted by the absence of reinforcement may asymptote or even diminish, as reflected by the increases in responding during later sessions of each cycle. This analysis is hypothetical, however, because the other behavior is not measured.

The effects of repeated exposures to extinction have not been examined systematically in applied research. Lerman et al. (1996) speculated that repeated exposures to extinction may have been responsible for the decrease in responding for one of their three participants, but they did not have evidence of this effect with the other two. Although the applied literature is replete with examples of extinction in reversal designs, extinction typically is combined with some other treatment procedure, such as differential reinforcement. The use of extinction as part of a treatment package thus makes it difficult to determine the extent to which the repetition of extinction is a causal variable in response reduction.

Sudden versus gradual introduction of extinction. Following earlier research by Skinner (1938, pp. 203–206) and Schlosberg and Solomon (1943), Terrace (1963) reported differences in the number of responses made to an S− as a function of how the stimulus and accompanying periods of nonreinforcement were introduced. For one group of pigeons, sudden introduction of the S− after responding had been well established in the presence of an S+ resulted in many (unreinforced) responses during the S− presentations. For a second group, the S− was introduced simultaneously with the commencement of training to respond in the presence of the S+, but at low intensity and initially for very brief durations. Over successive presentations, the duration and brightness of the S− was increased gradually, and care was taken to not reinforce responses in S− by immediately presenting the S+ after such responses. The method yielded few responses to the S− throughout training and during the steady-state S+–S− discriminative performance.

The more general term used to describe this procedure is *fading* or *stimulus fading*, and it can refer to either the fading in or the fading out of stimuli, including reinforcers. The procedure commonly is used in applied behavior analysis, particularly when teaching new skills to learners with disabilities. Sidman and Stoddard (1967) obtained results with children similar to those found with pigeons by Terrace and others (e.g., Rilling, 1977). Birkan, McClannahan, and Krantz (2007) used a fading procedure to teach a young child with autism to read printed words aloud. In their procedure, photographs of corresponding objects were displayed behind the printed words and gradually faded until the participant could read the words presented alone.

Terrace (1966) observed that establishing a discrimination between an S+ and an S− by using a fading procedure resulted in an S− that differed functionally from one that was established without fading (i.e., by extinguishing responding through contact with nonreinforcement). He suggested that allowing unreinforced responses to S− increased behavioral contrast, inhibitory stimulus control, aggression toward a target animal, and escape or avoidance of the S−, effects that were either not present or greatly diminished when the S− was established using a fading procedure. Rilling (1977) qualified some of these differences, replicating some, but not others. Thus, the nature and differential effects of fading continue to invite further experimental analysis.

Schedule leaning or thinning and extinction. The gradual reduction over time in the number of reinforcers delivered is labeled *schedule leaning* or *thinning*, the former more commonly used in basic research; the latter, in applied research. Schedule leaning or thinning may be considered a type of fading in which the rate of reinforcement scheduled for some response is reduced gradually. Unlike Terrace's (1963) stimulus fading, there are no changes in the accompanying stimuli as the rate of reinforcement is reduced. Nor are the gradual changes in reinforcement rate necessarily related to changes, or the absence thereof, in behavior. In applied research, the reinforcement rate rarely is thinned to extinction. Reducing that rate, however, can be considered as implementing periods of local extinction in that previously reinforced responses go unreinforced as the reinforcement frequency decreases. Such thinning typically maintains response rates similar to those established during the initial intervention, despite the diminishing reinforcement (e.g., Hagopian, Fisher, & Legacy, 1994; Kahng, Iwata, DeLeon, & Wallace, 2000; Lalli, Casey, & Kates, 1997; Marcus & Vollmer, 1996).

The gradual reduction in reinforcement rate toward the total elimination of reinforcement also has been suggested to reduce undesirable generative effects of extinction such as extinction bursts and extinction-induced problem behavior (see the Generative Effects of Extinction section). Lerman, Iwata, and Wallace (1999), for example, found that extinction bursts and aggression were attenuated when extinction initially was implemented as part of a treatment package that provided reinforcement for behavior other than the extinguished response, as opposed to extinction as the sole intervention. Relatedly, Vollmer et al. (1998) found that time-based reinforcement schedules reduced extinction-induced problem behavior compared with conventional extinction alone.

Given that reduced reliance on artificially arranged reinforcers is often a goal of applied behavior-change procedures, demonstrations of the maintenance of responding when reinforcement is reduced gradually (but not necessarily eliminated) are promising. Hanley, Iwata, and Thompson (2001) compared three methods of reducing the rate of reinforcement of communicative responses trained as alternatives to self-injurious behavior. When delays of reinforcement for communication were introduced, rates of communication decreased to near zero. Thinning from continuous reinforcement of communication to an FI 25-s schedule increased communication to socially unacceptable rates, but thinning to a multiple FR 1 extinction for communication resulted in maintenance of low, steady rates of communicative responding. St. Peter Pipkin, Vollmer, and Sloman (2010) gradually thinned the reinforcement rate of a laboratory analogue of appropriate responses by decreasing the percentage of these responses that were reinforced but without accompanying stimulus changes. Participants continued to respond appropriately as the schedule was thinned from FR 1 to VR 5; however, rates of appropriate responding decreased with reinforcement rate reductions.

Neither Hanley et al. (2001) nor St. Peter Pipkin et al. (2010) compared schedule thinning with conventional extinction. The body of research reviewed thus far suggests that nonreinforced responding would cease. Thus, sustained responding as a function of reinforcement thinning would depend on either the reduced reinforcement rate being sufficient to maintain responding or, if the reinforcers were completely eliminated, whether alternative reinforcers (e.g., what Herrnstein [1970] would call R_e) would come to substitute for the other reinforcers thus eliminated. For example, Kazdin and Polster (1973) maintained social greetings after a change from FR 1 to an intermittent reinforcement schedule. It is likely, however, that the greetings had come under the control of naturally occurring reinforcers in social interactions.

Extinction in combination with punishment. Skinner (1938, pp. 154–155) punished rats' lever pressing by having the response lever spring back when depressed, delivering a slap to the rat with each lever press. Responding first was reinforced with food. At the same time that food reinforcement was discontinued, the first few responses in extinction were punished. Then punishment too was removed. The rats' responding eventually recovered such that the overall responding was equivalent to rats exposed to extinction without punishment. By contrast, Hagopian, Fisher, Sullivan, Acquisto, and LeBlanc (1998) compared the outcomes of several clinical cases, four of which involved reinforcement of appropriate behavior and extinction and punishment of problem behavior in various combinations at different times over the course of treatment. In three of these four cases, the greatest reductions in problem behavior occurred when reinforcement of appropriate behavior was combined with extinction and punishment of problem behavior, suggesting that in some clinical cases, punishment may be a critical component of response reduction (cf. Azrin & Holz, 1966).

Extinction of Positively Reinforced Responding by Removing the Response–Positive Reinforcer Dependency

Removal of the response–positive reinforcer dependency after responding has been reinforced usually decreases responding (Rescorla & Skucy, 1969; Zeiler, 1968). The extent and speed with which responding decreases is in part a function of such variables as the delays between responding and delivery of the previously established reinforcer (Zeiler, 1968, but see Rescorla & Skucy, 1969), the reinforcement schedules changed from and to (Lachter, 1971), and other historical variables (Lattal, 1972; Zeiler, 1968). Removal of the response–reinforcer dependency has the disadvantage that responding can be adventitiously reinforced if it is followed closely by reinforcer delivery (Herrnstein, 1966). Its advantage is that by removing only the response–reinforcer dependency, the context during extinction does not change from reinforcer present to reinforcer absent (see Reinstatement section), thereby reducing the stimulus change occurring with extinction.

In applied behavior analysis, response reduction or elimination by removal of the response–reinforcer dependency is used frequently. Typically, the procedure decreases responding when the response–reinforcer dependency is either eliminated or degraded (cf. Lattal, 1974). Unlike nonhuman studies, in applied research removing the response–reinforcer dependency most often is concurrent with increases in the nominal reinforcer rate. Many such studies, for example, start the response-independent phase by providing continuous access to the reinforcer (Hagopian et al., 1994). As a result, response rate decreases obtained when the response–reinforcer dependency is removed under such conditions could be the result of some combination of extinction and the abolishing operation of satiation (e.g., continuous attention to forestall attention-maintained problem behavior). (This confounding typically is not a problem in basic research, however, because removing the response–reinforcer dependency is not accompanied by increases in reinforcement rate.)

Kahng, Iwata, Thompson, and Hanley (2000) investigated the relative contributions of satiation and extinction in reducing problem behavior during response-independent stimulus deliveries. Participants were three adults with severe or profound intellectual disabilities whose problem behavior was maintained by attention or bits of food. Brief periods of extinction (withholding of the reinforcer) were implemented after periods in which the reinforcer was delivered independently of responding on escalating fixed-time (FT) schedules. Kahng et al. reasoned that if response reduction during the FT condition resulted from extinction, responding would remain at low or zero levels once conventional extinction was introduced. If satiation were the determining variable, responding would increase when the reinforcer was withdrawn during conventional extinction. Suppression of responding for one subject was due to satiation (the one with the food reinforcer); for another, to extinction; and for the third, initially to satiation but later to extinction. This mixed outcome suggests that the effects of response-independent reinforcer delivery may be idiosyncratic across individuals, perhaps as a result of different reinforcement histories or treatment contexts.

Vollmer, Iwata, Zarcone, Smith, and Mazaleski (1993) examined the contributions of satiation and extinction to the reductive effects of FT schedules in a different way. Participants were three adults with severe or profound intellectual disabilities and self-injurious behavior that was maintained by social attention. During baseline, each response was followed by 10 s of attention, and participants responded at rates that yielded near-continuous access to reinforcers. When attention subsequently occurred independently of responding, response rates decreased dramatically, remaining at near-zero rates as the schedule was thinned from FT 10 s (given that the reinforcer access duration was 10 s, this schedule resulted in continuous access to the reinforcer) to FT 5 min. The reduction in problem behavior seemed to be the result of neither satiation nor extinction alone. Satiation was unlikely because participants continued to respond at high rates throughout baseline sessions of equal duration. For two of the three participants, response rates were higher during a differential-reinforcement-of-other-behavior (DRO) schedule than during FT. This outcome is noteworthy because fewer reinforcers were delivered during DRO than during FT, suggesting that extinction was not solely responsible for the decrease in responding during FT. Additionally, more extinction-induced behavior (e.g., aggression; see Extinction-Induced Behavior section) occurred during DRO than FT for two of the three participants.

Comparison of Positive Reinforcer Removal and Removal of the Response–Positive Reinforcer Dependency

A few experiments have examined the functional differences between extinction as stimulus removal and extinction as removal of the response–reinforcer dependency. Lattal (1972) compared the effects of a conventional extinction procedure to removal of the response–reinforcer dependency training on FI and VI schedules programmed as components of a multiple schedule with two outcomes. First, responding was more persistent after the response–reinforcer dependency was removed than after reinforcement was eliminated (cf. Rescorla & Skucy, 1969). Second, responding was more persistent after removal of the response–reinforcer dependency from the FI than after its removal from the VI schedule, but FI- and VI-maintained responding was reduced equally when food delivery was discontinued. Some combination of the discriminative stimulus properties of food delivery and adventitious reinforcement (Herrnstein, 1966) likely accounts for the more persistent responding when the response–reinforcer dependency is removed.

Extinction of Negatively Reinforced Responding by Making the Negative Reinforcer Noneliminable

This procedure parallels the extinction of positively reinforced responding by eliminating access to the positive reinforcer. Sidman (1966), for example, serendipitously found that shocks delivered independently of responding because of an equipment failure initially increased responding, but "eventually led to extinction" (p. 194). Davenport and Olson (1968) substantially reduced lever pressing by eliminating the response–shock removal contingency in a signaled avoidance procedure by presenting the shock at the end of the signal independent of responding.

In application, with the techniques of response flooding (Baum, 1970) and escape extinction, the negative reinforcer is noneliminable, that is, it continues to occur independently of whether the target response occurs or not. Escape extinction is effective in reducing food refusal. With one such procedure, called *nonremoval of the spoon,* the caregiver continues to present the food item until a bite is accepted and swallowed (e.g., Ahearn, Kerwin, Eicher, & Lukens, 2001; Patel, Piazza, Martinez, Volkert, & Santana, 2002). Thus, the food, presumably a negative reinforcer, is constantly present, independent of the problem behavior that previously resulted in its removal (escape). Such escape extinction has been suggested to be a critical component of establishing food acceptance (Piazza, Patel, Gulotta, Sevin, & Layer, 2003; Reed et al., 2004).

Extinction of Negatively Reinforced Responding by Response-Independent Termination of the Negative Reinforcer

This procedure parallels the removal of the response–positive reinforcer dependency (cf. Rescorla & Skucy, 1969). Hutton and Lewis (1979) delivered response-independent electric shocks to pigeons every 3 s. Pecking a transilluminated key occasionally suspended shocks and changed the key color for 2 min. The rate of the pigeons' escape responding decreased as the number of shock-free periods delivered independently of responding increased.

Applied behavior analysts sometimes also arrange for escape to occur independently of responding, a procedure often mislabeled *noncontingent escape.* This procedure typically involves demand removal on a time-based schedule (e.g., Vollmer, Marcus, & Ringdahl, 1995), and it typically results in immediate and substantial reduction in response rates. Disruption of the response–escape dependency through response-independent escape has several potential advantages over the escape extinction procedure described in the preceding section (see also Geiger, Carr, & LeBlanc, 2010). First, it ensures contact with the reinforcer maintaining the problem behavior, potentially reducing or preventing aggressive or emotional responding typically associated with escape extinction. Second, time-based delivery of escape reduces problem behavior even when response-dependent escape continues to occur (Lalli et al., 1997). Finally, removal of demands on a time-based schedule does not require problem behavior to occur to be effective and thus may be a preventive strategy.

Extinction of Negatively Reinforced Responding by Removing the Negative Reinforcer

One interpretation of this extinction procedure is that it is the extreme of the Hutton and Lewis (1979) procedure described in the preceding section. That is, removing the negative reinforcer is tantamount to continuously delivering all negative-reinforcer–free periods, independent of responding. Another interpretation is that eliminating the negative reinforcer by, for example, discontinuing shock delivery after training on a free-operant avoidance schedule may be considered an abolishing operation in the same way that allowing continuous access to a positive reinforcer abolishes it as a reinforcer.

Shnidman (1968) eliminated shock delivery after training of rats during 4-hr sessions. Free-operant (Sidman) avoidance schedules, in which each response postponed shock delivery in different conditions for 20 s or 40 s, or a discriminated avoidance procedure, in which a 5-s tone preceded shocks, were in effect in different conditions of the experiment. Once responding stabilized on each avoidance procedure, the shock was discontinued and responding declined to zero within a single 2- to 3-hr session. Shnidman suggested a comparison of extinction arranged by shock elimination and by rendering the response ineffective in terminating shocks, but this comparison was not undertaken. Ayres, Benedict, Glackenmeyer, and Matthews

(1974) compared extinction by shock elimination after training a head-poke or lever-press response under unsignaled (free-operant) or signaled (discriminated) avoidance schedules. Responding previously maintained under the free-operant avoidance schedule extinguished within a 2-hour session, regardless of the operant response topography, and was considerably lower than under the discriminated avoidance procedure. The finding that responding extinguished more rapidly under unsignaled than signaled avoidance was counter to that reported by Shnidman and may be the result of procedural differences between the two experiments.

Comparisons of Different Procedures for Extinguishing Negatively Reinforced Responding

After training college students to avoid a signaled air blast delivered behind the ear, Meyer (1970) compared responding during extinction implemented as air-blast removal or as unavoidable response-independent air-blast presentation after the signal. Responding was more resistant to extinction in the former condition. Responding during the signal when the air blast was unavoidable resulted in immediate contact with that contingency. By contrast, when the air blast was removed, continued responding during the signal continued to have the same effect as before (no air blast), thus prolonging responding. This finding was replicated in rats avoiding shocks in a shuttle box (Bolles, Moot, & Grossen, 1971) and in children avoiding the termination of a song (Moffat & McGown, 1974). Results from experiments in which unsignaled avoidance was used, however, are inconsistent with those obtained when the two extinction procedures are compared using discriminated avoidance. Coulson, Coulson, and Gardner (1970), for example, trained rats on an unsignaled avoidance procedure. In one extinction condition, shocks were presented at the same frequency as in the previous avoidance condition but independently of the rats' behavior. In another extinction condition, the shocks were never presented. Responding was more resistant to extinction when the shocks were presented independently of responding than when they were not presented (see also Powell, 1972). The shocks were suggested to function as a discriminative or eliciting stimulus for continued responding in this situation (Baron, 1991; Morse & Kelleher, 1977). Powell (1972) found that after training rats in an unsignaled avoidance procedure, responding during extinction (implemented as response-independent shock presentations) continued for long periods at a rate that was related directly to the frequency and intensity of the shocks.

The way in which the extinction procedure is structured results in different response patterns over the course of extinction, which can influence the choice of procedure in application (Geiger et al., 2010). Eliminating the negative reinforcer or breaking the response–reinforcer dependency through infrequent presentation of the negative reinforcer may be advantageous because these procedures typically reduce responding immediately, but they have the disadvantage of reduced exposure to the negative reinforcer (which can be problematic when that stimulus is an academic demand or the presentation of food). In contrast, extinction by making the negative reinforcer noneliminable may have advantages associated with increased exposure to the negative reinforcer, including better promoting the development of appropriate responses when combined with other procedures. The latter procedure may be limited in that continuous presentation may be more likely to evoke emotional responding (e.g., Lerman & Iwata, 1995).

Response-Elimination Procedures With Extinction-Like Properties

In this section, the discussion is confined to comparisons between conventional extinction of positively reinforced responding and schedules with extinction-like properties, unless otherwise noted. Conventional extinction is procedurally a period of nonreinforcement initiated independently of the organism's behavior. The period of extinction is indefinite and typically occurs in the presence of the same stimuli in effect when the response had been reinforced. Other procedures also involve the elimination of reinforcement but do so as a function of the organism's responding. Such responding results in a time-limited elimination of the opportunity for reinforcement. These response-produced periods of nonreinforcement sometimes are and sometimes are not correlated with distinct stimuli.

DRO. The DRO contingency is defined negatively in that reinforcement depends on the omission or nonoccurrence of the targeted operant response for a specified period of time. The label *DRO,* coined by Reynolds (1961), leaves the other response unspecified, making it an unmeasured hypothetical entity. Other terms have been proposed to describe DRO (Uhl & Garcia, 1969; Zeiler, 1977b), but none is without drawbacks. Reynolds's term is retained in this chapter.

Conventional extinction of positively reinforced responding and DRO are indistinguishable from one another from the time they are implemented until a pause sufficiently long to meet the DRO requirement occurs. Only after responding has extinguished to the point that such a pause occurs can DRO and extinction differentially affect the measured operant. Extinction therefore is a necessary feature of the DRO contingency.

Two temporal parameters define DRO: the interval by which each response delays a reinforcer (the response–reinforcer or R-S^R interval) and the interval between successive reinforcers in the absence of intervening responses (the reinforcer–reinforcer or S^R–S^R interval). In both basic and applied settings, the most common procedure is to equate these two intervals. That said, DROs have been arranged in other ways, such as with variable S^R–S^R intervals. For example, Lattal and Boyer (1980, Experiment 2) exposed pigeons concurrently to an FI schedule of key-peck reinforcement and a DRO schedule. The DRO was arranged such that the first 5-s pause after the lapse of a variable S^R–S^R interval resulted in food delivery. As the rate of reinforcement for pausing increased (in different conditions, from once every 300 s on average to once every 30 s on average), the amount of the session time allocated to key pecking decreased. Thus, key pecking was negatively punished by the response-dependent presentation of time-limited periods of nonreinforcement of key pecking (cf. Zeiler, 1977a).

Lattal and Boyer (1980, Experiment 1) found no systematic effect of the pause duration required for reinforcement (cf. Zeiler, 1977a) on response rates; however, Cowdery, Iwata, and Pace (1990) reported such an effect when applying a DRO procedure to eliminate self-injurious scratching by a 9-year-old boy. Initially, tokens exchangeable for snacks and play materials were dependent on the absence of scratching for 2 min. Scratching continued to be absent as the DRO intervals were increased to more than 4 min. The Cowdery et al. experiment, however, confounded changes in DRO duration and session duration. Thus, the changes attributed to the longer DRO could have been in part the result of longer exposure to treatment resulting from the fact that the longer DROs required longer treatment sessions.

Response-produced time-outs. Response-produced time-outs differ procedurally from conventional extinction because of their relative brevity and because the periods of nonreinforcement typically are correlated with an S–. The latter is most often, with pigeons, a darkening of the chamber; with rats, it often is removal (retraction from the chamber) of the operandum. In application, time out is a response-produced period of nonreinforcement accompanied by a stimulus change such as the withdrawal of the therapist, removal of the client from the situation, or presentation of another stimulus, as with a time-out ribbon (Foxx & Shapiro, 1978). The context in which response-dependent time outs are arranged determines their behavioral effects. Arranged in a context of positive reinforcement, the typical effect is response reduction or elimination. Response-dependent time outs from free-operant avoidance schedules function as positive reinforcers (e.g., Perone & Galizio, 1987; Plummer, Baer, & LeBlanc, 1977)

Applied research has suggested that response-dependent time out from positive reinforcement reduces problem behavior. Such effects are not strongly influenced by the time-out parameters, such as its duration or frequency (for a review, see Hobbs & Forehand, 1977), although it is possible that response rate and schedule of time out may interact, such that high-rate responses require more frequent use of time out (Calhoun & Lima, 1977). Response-dependent time outs often can be removed from treatment packages without negative side effects or reemergence of the target behavior (Iwata, Rolider, & Dozier, 2009). As such, response-produced time outs might function differently than conventional extinction.

Eliminating Responding With Extinction Compared With Other Response-Elimination Procedures

Among the first to compare operant extinction with other response elimination procedures were Holz and Azrin (1963), who examined the relative efficacy of different techniques in eliminating pigeons' key pecking in terms of whether the technique had an immediate, enduring, and irreversible effect and whether it produced complete suppression. The techniques compared were stimulus change (a change in key color from red to green for 60 min that occurred 30 min into a 2-hr session), eliminating reinforcement (extinction), satiation, physical restraint, and punishment. By their criteria, punishment was the most effective means of response elimination, and the only technique that received a response of "yes" to each of these effects. The response-reducing effects of conventional extinction were more gradual than those of satiation, which produced abrupt reductions in responding immediately on implementation. Holz and Azrin cited the gradual onset of effect as the greatest weakness of extinction as a means of response elimination. Since this initial evaluation, several studies have examined the relative effects of extinction and other procedures in eliminating responding.

Comparisons of DRO and conventional extinction. Comparisons of the relative efficacy of DRO and conventional extinction in reducing responding have yielded mixed results. Uhl and Garcia (1969) found no significant differences between the two, but Rescorla and Skucy (1969) found that conventional extinction reduced lever-press responding of rats to a lower level than did a DRO 5-s schedule after 5 days of training on a VI 2-min schedule. Zeiler (1971) reported the opposite outcome. After pigeons' key pecking stabilized on a multiple FR 25–FR 25 schedule of food reinforcement, pigeons were exposed to a multiple extinction DRO 30-s schedule. During the DRO, each response reset the 30-s IRI, and in the absence of responding, reinforcers were delivered every 30 s. For each pigeon, response rates were reduced more quickly and to lower levels in the DRO component. After 3-day periods when sessions were not conducted, more spontaneous recovery occurred in extinction than in the DRO component.

Other experiments have been no more definitive in yielding consistent across-experiment effects. Lowry and Lachter (1977) used a multiple schedule to compare pigeons' rates of key pecking under different response-reduction procedures. After a baseline in which VI 128-s schedules were in effect in each of four components, the VIs were replaced with an FT 32 s, a differential-reinforcement-of-alternative-behavior (DRA; extinction of pecking on the VI key while reinforcing responding on a second key on an FI 32-s schedule), DRO 32 s, and extinction. Response rates were lowest under the DRA and highest under FT. Similar to the findings of Uhl and Garcia (1969), extinction and DRO were equally effective in reducing responding.

Consistent with Rescorla and Skucy (1969), R. H. Thompson, Iwata, Hanley, Dozier, and Samaha (2003) found that extinction decreased responding more rapidly than did DRO with clinical populations. They suggested that responding continued during DRO because the reinforcer delivery occasioned responding by functioning as a discriminative stimulus for further responding (cf. Franks & Lattal, 1976). This account holds, however, only after the response contacts the DRO contingency; until that contact occurs, as has been noted, extinction and DRO are identical. By that point, too, as a function of the DRO duration, the reinforcer may begin to function as a discriminative stimulus for not responding, leaving the interpretation somewhat unclear.

The mixed findings concerning the relative efficacy of DRO and extinction in eliminating responding seem more likely to be the result of procedural and parametric differences between experiments. For example, both Rescorla and Skucy (1969) and Uhl and Garcia (1969) provided only a few days' training on the reinforcement schedule before implementing extinction or DRO, whereas Zeiler (1971) achieved stable responding under the baseline schedule before proceeding to the next condition. Zeiler did not specify whether the DRO or extinction components appeared first when the FR schedules were replaced, but the order of schedule presentation in the multiple schedule could affect the relative speeds with which responding in the two components decreased (see the Methodological Considerations section). Other variables contributing to the mixed outcomes may be the use of different species; parameters of the DRO schedule, which differed among the various experiments; and the use of within- versus between-subject designs.

The role of parametric differences was underlined by Rieg, Smith, and Vyse (1993). Using a between-subjects design with rats, they compared response reduction under extinction and DROs with different combinations of R–S^R and S^R–S^R intervals. S^R–S^R intervals of 10 and 20 s were scheduled after training on FI 10 and FI 20 s, respectively. These two intervals were combined with R–S^R intervals of 2, 6, and 18 s and 4, 12, and 36 s respectively, yielding R–S^R:S^R–S^R ratios of 0.2, 0.6, and 1.8. During the first few response-elimination sessions, the effects of the DROs and extinction did not differ. As these sessions progressed, however, the 1.8 ratio resulted in lower rates of responding under DRO than under extinction, and the 0.2 ratio resulted in higher rates of responding under DRO than under extinction. These results support the notion that before the first reinforcer is delivered under a DRO, the schedule is functionally equivalent to extinction. After the first reinforcer is delivered, if the R–S^R interval is relatively short, responding can be reestablished because the reinforcer may retain vestigial discriminative stimulus control of responding. If the R–S^R interval is relatively long, two processes may complement one another. First, the reinforcer may come to function as a discriminative stimulus for behavior other than the now-forbidden response. Second, other behavior can be adventitiously reinforced, making the schedule functionally similar to a DRA, which has been shown to control lower rates of responding than either DRO or extinction (e.g., Lowry & Lachter, 1977). Another possibility is that these DRO effects reflect delay of reinforcement gradients.

Comparison of DRO and removal of the response–reinforcer dependency. Davis and Bitterman (1971) compared the effects of DRO and a yoked VT schedule on lever pressing previously maintained by a VI schedule of food reinforcement. Groups of rats were exposed to a DRO 30-s schedule or to a yoked VT schedule that was equated for the number and temporal distribution of reinforcers arranged by the DRO schedule. Responding decreased to lower levels and decreased more rapidly under DRO than under VT. Rescorla and Skucy (1969), however, found no significant differences in response reductions produced by a DRO 5-s or a VT schedule. The elimination conditions followed only 5 days of training of the previously naïve rats on a VI 2-min schedule. Such minimal baseline training makes it difficult to compare the results with more standard operant preparations in which stable baseline responding is obtained first (cf. Zeiler, 1971).

GENERATIVE EFFECTS OF EXTINCTION

Even though the operant response may be diminished or even reduced to zero during extinction, extinction is not a behavioral Aigues Mortes, a period in which all behavior simply is dead in the water. Rather, as the rate of the previously reinforced response decreases, other responses emerge. The generation of other responses often begins during the transition to response elimination and can continue after the former operant response has been eliminated. These generated responses are the subject of this section.

Response Bursts at the Onset of Extinction

Keller and Schoenfeld (1950) noted that the extinction curve of a response previously maintained on a CRF schedule "begins with a steeper slope (higher response rate) than that during [CRF]" (p. 71). Anecdotally, response bursting is commonplace at the onset of operant extinction, yet there are few systematic data on the effect. A problem is that a response burst is ill defined, both qualitatively and quantitatively. Nor are there many systematic data on the regularity of its occurrence. An exception is the meta-analyses of Lerman and Iwata (1995) and

Lerman, Iwata, and Wallace (1999). They examined, respectively, published data sets and their own data in which extinction was implemented either alone or in combination with some other procedure (differential reinforcement; response-independent, time-based reinforcer delivery; or antecedent manipulations). Extinction bursts were more common when extinction was implemented alone, rather than in combination with other interventions. Even when implemented alone, bursting (defined as response rates in the first three sessions of extinction exceeding rates in the last five sessions in the previous phase) was far from universal but did occur in two thirds of the cases from their own laboratory.

It is difficult to draw firm conclusions about the prevalence of extinction bursts from these meta-analyses combining results from several different preextinction procedures. With both human and nonhuman subjects, response bursts in extinction likely vary as a function of other differences in pre-extinction conditions of reinforcement, such as the operant response, the reinforcement schedule, and other parameters of reinforcement. Yet another complexity is that the period over which extinction bursts are measured, in both basic and applied research, may not be consistent. Responding averaged across an entire session may obscure an extinction burst that occurred more locally, for example, during the first few minutes of extinction.

Comparing extinction bursts across multiple experiments may be fraught with other complexities. Keller and Schoenfeld (1950), for example, suggested that one reason for extinction bursts may be that “responses are no longer separated by eating time” (p. 71). At least some of the differences in the occurrence of extinction bursts as reported earlier may be related to the type of reinforcer used. In applications, especially, different reinforcers can vary considerably in their consumption time (e.g., a simple “good” vs. 30 s of attention).

Increased Variability of Response Topography During Extinction

When an operant response is extinguished, response variability increases. Antonitis (1951; see also Eckerman & Lanson, 1969) reinforced a nose-poking response of rats on a 50-cm-long opening along one wall of an operant conditioning chamber. A nose poke at any location along the slot, defined by photobeam breaks, produced a food pellet. Even though nose poking was reinforced at any location, responding occurred primarily in a restricted location in the slot. When reinforcement was discontinued, responding at other locations along the slot increased. That is, extinction induced greater variability in responding, at least in the short term. Increased variability during extinction also occurs across other response dimensions, such as response duration (Margulies, 1961), force (Notterman & Mintz, 1965), reaction time (Stebbins & Lanson, 1962), number (Mechner, 1958), displacement (Herrick, 1965), and sequences (Mechner, Hyten, Field, & Madden, 1997).

Response variability during extinction can extend to responses that previously were unreinforced but are related topographically to the previously reinforced response. Skinner (1938), for example, recorded a continuum of response force and duration, reinforcing only responses that exceeded a predefined criterion. When the required minimum force or duration required for reinforcement was increased (thus placing the previous responses on extinction), the force of the responses varied within a few minutes. This variation included responses that reached forces not previously observed, with some sufficient to reach the new criterion for reinforcement. Skinner concluded that when a previously reinforced response is extinguished, responses that fall outside the criterion for reinforcement will increase. Such responses that fail to reach or exceed the reinforcement criterion can be described as instances of response generalization or response induction (Catania, 1998; Skinner, 1938) and thus can be conceptualized as representing a continuum of response variability during extinction. The terms *induction* and *response generalization* both describe the generation of responses that are similar to, but not isomorphic with, the previously reinforced operant when that operant is extinguished. The terms can be confusing because induction also describes responding brought about by extinction that may not be topographically similar to the previously reinforced response (see Extinction-Induced Behavior section) and, in multiple schedules in particular, to topographically similar or dissimilar responses in the presence of stimuli other than those associated with extinction.

Other studies have extended and elaborated the analysis of response variability in extinction. For example, Hefferline and Keenan (1963) measured the amplitude of small thumb-muscle movements of humans. During a baseline, most responses were of low amplitude. Reinforcement of responses only within a specified range of amplitudes led to a predominance of responses within that range. During the first 10 min of extinction for the two subjects after 85 to 90 min of CRF training, the frequency of all amplitudes increased. For the other two subjects exposed to CRF training for only 60 min, only the one or two lowest amplitudes increased; the others were unchanged from the CRF training. Increasing response strength via longer exposure to CRF thus also increased response variation during extinction.

The experiments discussed in this section have shown that the eliminative effects of extinction on the target response are accompanied by the generation of responses that previously were unreinforced but are related topographically to the reinforced response. This generative effect of extinction is important during response differentiation (e.g., shaping) because it enables adaptation to changes in the requirements for reinforcement (e.g., Keller & Schoenfeld, 1950; Segal, 1972). That is, these extinction-generated variations in the operant can become new targets for reinforcement. As with any response, of course, these extinction-generated variations must be reinforced to persist.

Research by Grow et al. (2008) illustrates this latter point. They exposed children with developmental delays to extinction after first reinforcing problem behavior. When the problem behavior subsequently was extinguished, Grow et al. observed a variety of appropriate responses that had not occurred in previous sessions. They selected one of these novel responses as the new criterion for reinforcement, replacing problem behavior with an appropriate response. These results suggest that extinction-induced variability extends to responses not previously observed within the operant class (see also Morgan & Lee, 1996).

Extinction-Induced Behavior

As noted in the preceding section, responding induced by extinction may or may not be similar topographically to the extinguished operant. Aggressive responses induced by extinction illustrate the point. T. Thompson and Bloom (1966) found that rats' biting a response lever increased when the lever-press response was extinguished. They suggested that the response bursting often seen at the onset of extinction could be extinction-induced aggressive responses directed toward the operandum. With one pigeon restrained at the rear of an operant chamber, Azrin, Hutchinson, and Hake (1966) exposed other pigeons to a multiple CRF extinction schedule during which the two components alternated every 2 minutes throughout each session. During the CRF component, pigeons pecked the response key and consumed the reinforcers thereby produced. The restrained pigeon was ignored. When, however, the component changed to extinction, each pigeon ceased pecking the response key and initiated a bout of aggressive pecking at the restrained pigeon. This attack continued intermittently until the stimulus correlated with the CRF schedule was re-presented. At that point, aggressive responding ceased, and the pigeon returned to key pecking. Kelly and Hake (1970) obtained a similar result with adolescent boys earning monetary rewards by pulling a plunger. When plunger pulling was extinguished, seven of nine subjects vigorously hit an electronic padded punching cushion. Of the six subjects returned to the reinforcement schedule after extinction, three reverted to baseline rates of plunger pulling. Extinction-induced aggression has been replicated and extended many times in both laboratory animals (e.g., Pitts & Malagodi, 1996) and human subjects (e.g., Goh & Iwata, 1994; Lerman, Iwata, & Wallace,1999). In some cases, the topography of the aggressive response is similar to the extinguished operant response, but in others it is not, for example, in the Kelly and Hake experiment or in cases in which extinguishing inappropriate behavior (such as self-injury) leads to increased aggressive responses toward others (e.g., Goh & Iwata, 1994).

Schedule-induced drinking or polydipsia (Falk, 1961) provides another example of the induced response not being topographically similar to the extinguished operant response. During the nonreinforcement period (postreinforcement pause) on FR or FI schedules, for example, rats given access to a water source drink large amounts. The amount exceeds what the rat would consume if an equivalent amount of food to that earned in a session were given to the animal en masse (e.g., Roper, 1981). In general, schedule-induced behavior, also labeled *adjunctive behavior,* occurs during periods of chronic or local nonreinforcement as a function of having an appropriate stimulus object present. Licking a stream of compressed air, pica, wheel running, and even stereotyped motor patterns such as neck stretching and presenting or grooming have all been shown to occur during periods of nonreinforcement (e.g., Staddon, 1977).

Extinction-induced behavior also has been reported with human participants. For example, polydipsia has been found when the responding of young children is reinforced according to an FI schedule (Porter, Brown, & Goldsmith, 1982). Adults with and without developmental disabilities engaged in increased durations of stereotyped behavior during interval and time-based schedules as the schedule values increased (e.g., Hollis, 1973; Wieseler, Hanson, Chamberlain, & Thompson, 1988). Such induced responding has been suggested to be a mechanism through which increases in drug taking might occur. Human participants, for example, drank more beer while playing a gambling game when game play is reinforced according to a FI 90-s schedule than during an FI 30-s schedule (Doyle & Samson, 1985), and smokers took puffs as a bitonic function of the schedule value (Cherek, 1982). There is generally a bitonic relation between reinforcement rate and the rate of induced responding: As reinforcement decreases, schedule-induced responding increases to a point and thereafter decreases.

Stimulus Generalization and Extinction

Stimuli similar to those in effect during extinction may control lower rates of responding than stimuli less similar to the extinction-correlated stimuli. Tests of stimulus generalization gradients around the S− typically use an S− that is on a different dimension than the S+. Thus, for example, with pigeons one might use a red key light as the S+ and a black vertical line on a white background as the S−. If, after training a discrimination, variations in the angle of the line are superimposed on the red background (e.g., 75°, 60°, 45°, 30°, 15°, and 0° of line tilt), responding typically increases the more dissimilar the line is to the original S− (the vertical line). That is, stimuli less like the S− are more likely to generate responding (e.g., Farthing & Hearst, 1968). This stimulus generalization gradient also has been interpreted by some to suggest that extinction also induces a tendency to not respond to stimuli that are more like the S− (i.e., inhibition; Hearst, Besley, & Farthing, 1970). Thus, children whose responding is extinguished in one classroom may tend to be, other things being equal, similarly unresponsive in similar settings.

Positive Behavioral Contrast

When two or more schedules of reinforcement are in effect either successively (a multiple schedule) or concurrently, extinguishing responding on one of them increases responding in the unchanged component relative to the preceding baseline (Reynolds, 1961; see Williams, 1983, for a review). This effect is labeled *positive behavioral contrast* (hereinafter, *contrast*). Although such behavioral contrast often is described as an increase in responding in the unchanged component in the context of response decreases in the other component, this description is something of a misnomer because its controlling variable is not response rate but (largely) reinforcement rate (e.g., Halliday & Boakes, 1971; Terrace, 1966).

The time course of contrast has been the subject of several experiments. When Terrace (1966) removed reinforcement from one component of a multiple VI–VI schedule, response rates in the unchanged component increased substantially relative to the preceding condition, but this effect dissipated over the following 60 sessions. An absence of contrast was observed when extinction was faded in Terrace (1963), leading Terrace to conclude that introducing extinction through a fading procedure (see the Sudden Versus Gradual Introduction of Extinction section) was functionally different than allowing responding to occur in the presence of the S−. Williams (1983) noted that experiments showing contrast to be a sustained effect and not a transient one (Hearst, 1971; Selekman, 1973) undermine Terrace's conclusion "that contrast is a byproduct of discrimination learning in which the negative stimulus (S−) acquires aversive properties because of its association with nonreinforced responding" (p. 358).

Contrast obtained with pigeons as subjects is an exceptionally reliable and robust finding, particularly when extinction is used in the alternate condition. It occurs across a variety of reinforcement conditions, including both positive (e.g., Reynolds, 1961) and negative reinforcement (Wertheim, 1965). It also has been observed in rats and humans, but, as Williams (1983) has cautioned, because so much of the research on behavioral contrast involved pigeons, the question remains open as to whether contrast effects reported in other species yield the same functional relations as do those with pigeons.

Only a few studies have examined contrast in the context of application, and they typically have yielded weak, transient, or no contrast. For example, Koegel, Egel, and Williams (1980) found only transient contrast. Kistner, Hammer, Wolfe, Rothblum, and Drabman (1982) found no evidence of contrast in the context of classroom token economies. This general absence of contrast in applied settings could be related to the nature of the responses under study and the inclusion of multiple treatment components in these investigations. Even human behavioral contrast in laboratory studies with nonclinical participants, which precludes both of these elements, is generally weak in comparison to the findings with pigeons (e.g., Edwards, 1979; Hantula & Crowell, 1994; Tarbox & Hayes, 2005; but see Waite & Osborne, 1972). Contrast, of course, is not the only phenomenon in which there are differences between humans and nonhumans, and the question remains as to whether these effects are functional or procedural (e.g., Perone, Galizio, & Baron, 1988).

Despite the paucity of demonstrations of behavioral contrast in humans, laboratory demonstrations of the effect have implications for using extinction in applied settings because the conditions that produce contrast in the laboratory also occur in extralaboratory settings. For example, during a child's school day, one teacher might reinforce appropriate behavior, but another teacher might stop doing so (appropriate behavior would be placed on extinction). During this arrangement, contrast might be expected to occur as an increase in appropriate behavior in the former classroom. Similarly, a teacher might reinforce problem behavior while the parents judiciously implement extinction for that behavior. The teacher may see an increase in problem behavior at school after the parents start extinction at home, even though the reinforcement contingencies at school remain unchanged. Such findings were reported by Wahler, Vigilante, and Strand (2004).

Spontaneous Recovery

Spontaneous recovery, the recurrence of the previously reinforced response at the onset of successive periods of extinction, has been reported widely (e.g., Rescorla, 2004). Skinner (1933a) initially labeled the effect as a loss of extinction, but subsequently he too labeled it spontaneous recovery (Skinner, 1938).

Skinner (1950) accounted for spontaneous recovery in terms of stimulus control, specifically, in terms of the discriminative stimuli present at the beginning of each experimental session. During conditioning, responses are reinforced after handling the organism and placing it in the experimental situation. When present during extinction, he reasoned, these same stimuli result in increased responding. Skinner proposed that extinction without spontaneous recovery could be achieved only if the organism is exposed to these presession stimuli in conjunction with extinction over several occasions.

Support for Skinner's (1950) analysis has been mixed. Consistent with this analysis, D. R. Thomas and Sherman (1986, Experiment 1) found spontaneous recovery only when the handling stimuli during extinction were the same as those during conditioning (see also Welker & McAuley, 1978). In another experiment (D. R. Thomas & Sherman, 1986, Experiment 2), however, pigeons tested after normal handling before an extinction session showed no more spontaneous recovery than pigeons that remained in the experimental chamber before the extinction session. Furthermore, in a third experiment, spontaneous recovery increased if the pigeon was transported to the chamber before the extinction session in a different cage than the one used to transport it during conditioning. These latter two experiments suggest that the stimuli associated with handling during conditioning might play a minimal role in spontaneous recovery.

Kendall (1965), by contrast, provided support for Skinner's (1950) interpretation by showing that spontaneous recovery can be found at any time during a session if the discriminative stimuli resemble those in the training condition. Kendall first maintained key pecking of pigeons on a VI schedule with the chamber and key lights on. Next, he alternated periods of time out, during which all the lights in the chamber were off, and time in, during which the chamber lights were identical to those used during the VI training. Extinction was in effect in both time out and time in. Kendall reasoned that responding was extinguished in the time-in periods only after the presentation of the time out. So, after responding was eliminated, he tested for spontaneous recovery by alternating periods of time out and time in during the first 45 min of the session, followed by removal of the time-out periods. Removing the time-outs increased time-in responding, as would be expected with spontaneous recovery. When the time-out periods were removed, the discriminative stimuli uniquely correlated with extinction were eliminated and responding recurred (cf. Reynolds, 1964).

This mixed evidence has precluded general acceptance of Skinner's (1950) account of spontaneous recovery. Rescorla (2004), for example, observed that the finding that spontaneous recovery is larger with longer times between exposure to extinction and the spontaneous recovery test (e.g., Quirk, 2002) cannot be explained by appealing to stimuli present at the onset of extinction. As Rescorla noted, additional research is necessary to identify the variables responsible for spontaneous recovery.

Lerman, Kelley, et al. (1999) reported spontaneous recovery of problem behavior (screaming) when a relatively small-magnitude reinforcer (10-s access to toys) was discontinued in extinction. Little spontaneous recovery occurred, however, when a large reinforcer (60-s access to toys) was used. In a related experiment, Homme (1956) exposed groups of rats to one conditioning session in which 15, 50, 100, or 250 water reinforcers were delivered according to a CRF schedule. Spontaneous recovery during five sessions of extinction increased between groups as the number of reinforcers increased. There also was more spontaneous recovery when 250 reinforcers were delivered across five sessions of conditioning than when the same 250 reinforcers were delivered in a single session. Waller and Mays (2007) suggested that when extinction-induced aggression occurs, it is actually the spontaneous recovery of previously reinforced aggression. Without additional data, however, it is difficult to say whether such aggression is most usefully categorized as an instance of spontaneous recovery, reinstatement, or resurgence (the latter two topics are discussed next).

Resistance to Reinforcement

Even though a response is reduced to zero or near-zero probability as a function of nonreinforcement, the response typically recurs under appropriate conditions (see also the Stability and Variability Functions of Extinction section). It is thus of interest to assess whether different conditions of extinction result in differential recurrence or regeneration of the eliminated response. Just as resistance to extinction after some condition of reinforcement indexes the effectiveness or strength of a reinforced response (e.g., Hull, 1943; Nevin, 1974, 1979; Chapter 5, this volume), resistance to reinforcement after extinction has been proposed to index the strength of a nonreinforced response. For example, after establishing stimulus control around a vertical line S−, Hearst et al. (1970) reinforced responding in the presence of all stimulus configurations. During the first four sessions, the gradient had the classic inhibitory stimulus control V form, but thereafter the gradient flipped such that it formed an inverted V, ending with peak responding at S−. The results during the first four sessions attest to the persistence of the suppressive effects of the S− in the face of reinforcement. Hearst et al. concluded that "the resistance to reinforcement technique is both a feasible and sensitive procedure for studying generalization along a dimension of S−" (p. 396).

As a part of their comparison of the relative resistance to reinforcement of extinction and DRO, Uhl and Garcia (1969) reintroduced a VI schedule after first reducing responding of two groups of rats to near zero with one of the two procedures. When the VI schedule was reintroduced, there was no attempt to induce or otherwise evoke the formerly reinforced lever-press response. When a lever press occurred, however, it was and continued to be reinforced according to the VI schedule. Although responding was more resistant to reinforcement for the group previously exposed to DRO than to extinction, the differences between the conditions were not statistically significant. The analysis was confounded, however, because response rate increased across the 5-minute periods. The analysis of variance used to compare response rates after extinction and after the DRO was based on means for the entire time period, with a variance that included changes in responding from the beginning to the end of the 20-min period. In another experiment, however, using a similar design, responding on a VI schedule increased more slowly after exposure to DRO than to conventional extinction. A statistically significant interaction between the effects of the previous schedule, either DRO or extinction and the number of sessions of exposure to extinction, substantiated this result.

Rieg et al. (1993) found that responding eliminated by using longer (18- or 36-s) DRO values to eliminate lever pressing by rats was more resistant to reinforcement than responding eliminated by using shorter (2- or 4-s) DRO values. A potential obstacle in using resistance to reinforcement as a test of the efficacy of extinction in eliminating behavior is that of understanding the variables that might cause a previously eliminated response to recur. Perhaps some of the research on variables controlling response acquisition with delayed reinforcement (e.g., Lattal & Gleeson, 1990) in the absence of any form of response training might be useful in isolating some of the controlling variables of renewed responding of extinguished responses.

Reinstatement

Reinstatement is similar to the resistance-to-reinforcement test, the difference being that reinstatement involves the response-independent delivery of what previously functioned as a reinforcer for the response; in resistance-to-reinforcement tests, the delivery is response dependent. Franks and Lattal (1976) maintained lever-press responding of rats on a VR schedule before reinforcement was eliminated and the response extinguished. Then an FT 30-s schedule was introduced. After the first food pellet, responding increased rapidly and remained high for some time before eventually slowing to a low rate. The entire sequence then was repeated, but instead of using a VR schedule during the reinforcement condition, a DRL schedule was used. When the food pellets were delivered independently of responding after extinction of the lever-press response, responding was reinstated, but at a much lower rate than occurred when the VR schedule was used in training. Franks and Lattal interpreted the different reinstated response rates as evidence that the food pellets functioned as discriminative stimuli controlling the previously reinforced response rates (cf. R. H. Thompson et al., 2003). That is, during the reinforcement phase, the food pellets functioned as discriminative stimuli for continued high- or low-rate responding, depending on whether the schedule was VR or DRL. Reinstating the pellets after extinction therefore reinstated the discriminative stimulus for different rates of response, with the results just described. Similar effects were reported earlier when children with developmental delays were exposed to similar conditions by Spradlin, Girardeau, and Hom (1966) and Spradlin, Fixen, and Girardeau (1969).

A variation of reinstatement is renewal (Bouton & Bolles, 1979), in which responding in one environment is reinforced, followed by extinction of the operant response in a second environment. When returned to the original environment, the response recurs (e.g., Nakajima, Tanaka, Urshihara, & Imada, 2000). Thus, in both renewal and reinstatement, discriminative or contextual stimuli previously associated with reinforcement are re-presented. In renewal, it is replacement in an old environment, and in reinstatement, it is reinstating the previous reinforcer, albeit independently of responding.

Exposure therapies used to treat phobic behavior (e.g., Dirikx, Hermans, Vansteenwegen, Baeyens, &

Eelen, 2007) or drug-seeking behavior (e.g., See, 2002; Shaham & Miczek, 2003; Shalev, Erb, & Shaham, 2010) also exemplify reinstatement. In these contexts, reinstatement typically refers to the reemergence of undesired behavior when reintroduced to stimuli in the presence of which the response previously occurred. (The term *reinstatement* is used in a different way to describe some treatment procedures promoting positive behavior. Under these circumstances, however, the reinstatement refers not to a response but to a response-dependent reinforcer after a hiatus during which reinforcement was omitted; e.g., Hoyer, Kafer, Simpson, & Hoyer, 1974).

Resurgence

Resurgence is the recurrence of previously reinforced responding when a more recently reinforced response is extinguished. The procedure involves three phases. In the first, reinforcement, phase, a response is reinforced. Reinforcement of the first response then is discontinued concurrently with the reinforcement of a second response in the second, alternative reinforcement, phase. When the second response is extinguished in the third, resurgence, phase, resurgence is manifest as a transient reoccurrence of the first response, even though it is not reinforced. Another procedure involves continuously recording patterns of responding (e.g., keystrokes on a keyboard in humans) during conditioning and then comparing them with the patterns observed during extinction. In this case, resurgence is manifest as the reappearance of patterns reinforced during the earlier exposure to conditioning, but not of patterns occurring during more recent exposure (Carey, 1951; Mechner et al., 1997). Resurgence may be considered a generative effect of extinction in that the extinction of a response is likely to bring about, at least transiently, the recurrence of previously reinforced responses. The provenance of these resurged responses is presumably the organism's past experiences.

The responding that occurs during the resurgence phase depends on events in each of the aforementioned phases (see Lattal & St. Peter Pipkin, 2009, for a review). Responding established in the first, reinforcement phase is the basis for the resurgence. The importance of the parameters of the reinforcement phase was demonstrated by da Silva, Maxwell, and Lattal (2008), who used a concurrent VI 1-min–VI 6-min schedule in the reinforcement phase. After eliminating responding to both by using a DRO contingency in the alternative reinforcement phase, the two responses resurged differentially in terms of absolute response rates, as a function of the schedule in effect during the reinforcement phase. The effects of the duration of the reinforcement phase are less clear. Bruzek, Thompson, and Peters (2009, Experiment 2) examined resurgence of caregiving responses of human subjects who were instructed to provide care to a simulated infant. Two responses were reinforced by successfully terminating crying. The first-established response was reinforced until the participant engaged in the response for 5 consecutive min across three sessions. The second-established response had a relatively shorter reinforcement history (until the participant engaged in the response for 5 consecutive min in one session). During the resurgence phase, five of eight participants showed more resurgence of the first and longer trained response in the reinforcement phase. None of the participants showed greater resurgence of the second, more briefly trained response (see also Leitenberg, Rawson, & Mulick, 1975). Lieving and Lattal (2003), however, did not find systematic differences in resurgence as a function of five or 30 sessions of training the response in the reinforcement phase with pigeons.

An important question in assessing the resurgence effect is whether resurgence is simply an artifact of a failure to extinguish (to zero) the response trained in the reinforcement phase during the alternative reinforcement phase. Cleland, Foster, and Temple (2000) replicated an earlier finding of Leitenberg, Rawson, and Bath (1970), suggesting that extinguishing the response trained in the reinforcement phase attenuates resurgence. Epstein (1983), however, extinguished key pecking of pigeons established in the reinforcement phase before reinforcing an alternative response in the second phase, as did Lieving and Lattal (2003) and Bruzek et al. (2009). Despite the extinction of the first-established response, resurgence was still manifest when the second response was extinguished in the resurgence phase of the experiment. Related to this, after establishing key pecking in the reinforcement phase, da Silva et al. (2008) used a DRO schedule in the second phase such that the key-peck response was functionally extinguished until it reached the point that a pause occurred that was sufficiently long to meet the DRO contingency. Responding resurged in the third phase, even though the key-peck response was eliminated in the second phase. These experiments together present a mixed picture of the role of extinguishing or failing to extinguish the first response on subsequent resurgence. It does appear, however, that under some conditions resurgence is not simply a result of the first-established response failing to extinguish in the second phase.

Resurgence occurs most reliably when the second response is extinguished, as opposed to having its rate of reinforcement reduced. Lieving and Lattal (2003) found that only small, temporary increases in response rates occurred when the reinforcement schedule for the alternative response was changed from a VI 30-s to VI 360-s schedule. Resurgence occurred to a much greater extent, however, when both responses were extinguished. Volkert, Lerman, Call, and Trosclair-Lasserre (2009) used a procedure similar to that of Lieving and Lattal, but with children with developmental disabilities who engaged in problem behavior. In addition, Volkert et al. reinforced behavior on FR 1 schedules during the reinforcement and alternative reinforcement phases. The resurgence test consisted of abruptly thinning the reinforcement schedule for appropriate behavior from FR 1 to FR 12. Rates of problem behavior increased for all three participants, but an extinction condition that immediately followed was not conducted, so relative magnitudes of resurgence could not be assessed.

Lattal and St. Peter Pipkin (2009) observed that in application, the behavior that resurges can be either beneficial or detrimental. On one hand, resurgence has been described as the crucible of creativity and problem solving (Epstein, 1985a, 1985b) in that the extinction of well-established behavior patterns generates responses that can serve as the basis for a creative or novel solution to a problem that was intransigent to previously successful solutions. On the other hand, extinguishing a response can lead to the resurgence of problem behavior that has in the past been reinforced.

Extinction as an Establishing Operation for Other Behavior

Depending on the circumstances, extinction can serve as an establishing operation for responding that eliminates, postpones, or produces periods of nonreinforcement. Both J. R. Thomas (1965) and DeFulio and Hackenberg (2007) provided evidence that escape or avoidance responding by a pigeon can be maintained if the response allows escape from or postponement of a period of nonreinforcement that otherwise would be imposed during a schedule of positive reinforcement maintaining a second response. Because the necessary condition for the escape or avoidance response is the period of nonreinforcement of the other response, the extinction period may be described as an establishing operation for maintaining such escape or avoidance.

By contrast, Perone and Galizio (1987) maintained responding using a shock-avoidance schedule. They then arranged a contingency such that responding on a second operandum produced a discriminated period in which the negative reinforcement schedule was suspended (a time-out or extinction period). Thus, the extinction period made available in this way established and then maintained an operant response that produced it.

CONCLUSION

The experimental analysis of operant extinction has methodological, theoretical, and applied implications extending beyond the findings of any particular experiment reviewed in this chapter. Methodologically, many extinction processes related to both elimination and generation of responding epitomize what Sidman (1960) called a *transition state.* Transition states characterize not only extinction and acquisition of simple operant responses but also describe many significant behavioral processes in everyday life, such as acquiring new skills, kicking bad habits, making new friends, and ending bad relationships. The methods of analysis of transitional processes of extinction hold the promise of offering new methods for studying other important, but often neglected, transition states.

Three theoretical comments are suggested by the experimental investigations of operant extinction that have been discussed. First, extinction has been defined in different ways with, unsurprisingly, varied behavioral effects. Second, extinction effects generally are contextual and situational and not permanent, although research in applied behavior analysis, in particular, has suggested ways of achieving more permanent behavior change through variations on extinction and extinction in combination with other behavioral techniques. The third theoretical point concerns the attribution of response elimination and generation to the extinction operation per se. Extinction operations may strengthen or weaken responses directly, but they also may have, or fail to have, their effects indirectly as a result of or in concert with other processes such as discriminative stimulus control or adventitious reinforcement (as with removal of the response–reinforcer dependency) or satiation (in the case of FT schedules in some applications).

The implications of extinction research for application are both broad and myriad, making extinction ripe for still further translational research. In undertaking such research, the devil remains in the details. As was noted throughout the chapter, extinction incorporates a number of procedures and behavioral effects in both basic and applied research in behavior analysis that preclude a singular characterization of it. This makes it essential that the processes being translated correspond to the "original text," that is, to specific extinction operations in the basic science and not to extinction as a generic construct.

The roots of extinction extend both to the beginning of behavior analysis (recall, e.g., that extinction was at the serendipitous birth of the FI schedule) and well beyond the bounds of contemporary behavior analysis into other psychological and neurophysiological scientific worldviews. The research reviewed in this chapter attests to its impact on both the elimination and the generation of behavior, both historically and contemporaneously. Despite its longevity and the wealth of data on its effects, operant extinction continues to be a wellspring of new research problems and new promises for understanding the reinforcement process and its translation into useful applications.

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