JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 2001, **75,** 311–333 NUMBER 3 (MAY)

STIMULI INEVITABLY GENERATED BY BEHAVIOR THAT AVOIDS ELECTRIC SHOCK ARE INHERENTLY REINFORCING

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A molecular analysis based on the termination of stimuli that are positively correlated with shock and the production of stimuli that are negatively correlated with shock provides a parsimonious account for both traditional discrete-trial avoidance behavior and the data derived from more recent free-operant procedures. The necessary stimuli are provided by the intrinsic feedback generated by the subject's behavior, in addition to those presented by the experimenter. Moreover, all data compatible with the molar principle of shock-frequency reduction as reinforcement are also compatible with a delay-of-shock gradient, but some data compatible with the delay gradient are not compatible with frequency reduction. The delay gradient corresponds to functions relating magnitude of behavioral effect to the time between conditional and unconditional stimuli, the time between conditioned and primary reinforcers, and the time between responses and positive reinforcers.

Key words: avoidance, feedback, safety signal, delay, molar, frequency reduction, shock

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Two current behavior-analytic approaches differ with respect to the consequences that are assumed to reinforce the behavior that precludes, postpones, or reduces the severity of forthcoming electric shock. A contemporary variant of the traditional two-factor or two-process theory relies on the reinforcing effect of terminating stimuli that have been paired with shock (Dinsmoor, 1954; Schoenfeld, 1950; Sidman, 1953b; Skinner, 1953) and producing stimuli that have been paired with the absence of shock (Dinsmoor, 1977; Dinsmoor & Sears, 1973). An alternative formulation, sometimes known as the single-process or shock-density-reduction theory, hypothesizes a direct reinforcing effect resulting from the negative correlation over extended periods of time between rate of responding and the frequency or the severity of the shocks (Herrnstein, 1969; Herrnstein & Hineline, 1966; Sidman, 1966). It is frequently assumed that these two theories are mutually exclusive and that shock-frequency or shock-density reduction is accepted behavior-analytic doctrine. To the contrary, my argument is that two-process theory provides a satisfactory integration of available data and that shock-frequency reduction is neither needed nor empirically substantiated as a source of reinforcement.

This material was first presented as the B. F. Skinner Memorial Address at the 11th annual convention of the International Society for Behaviorology, Sacramento, California, March 20, 1999. A later version was presented as a plenary address at the Quinto Congreso Internacional sobre Conductismo y las Ciencias de la Conducta, Xalapa, Mexico, October 8, 2000. Criticisms of the shock-density formulation had early roots in D. G. Anger's presentation at the 1966 meeting of the American Association for the Advancement of Science, Washington, D.C., and in his unpublished review entitled "Two-Factor Theory and the Avoidance Puzzles," March 1969.

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DISCRETE-TRIAL AVOIDANCE

In the conditioning laboratory, the procedures used to establish and maintain avoidance are customarily divided into two broad categories: In the early discrete-trial research on the topic, each presentation of the shock was preceded by a brief warning signal, sometimes described in the literature as a conditional stimulus or CS; in most of the more recent free-operant or continuous avoidance work, no signal has been provided. Simply put, performing the required response postpones the arrival of the otherwise impending shock (Sidman, 1953a, 1953b). Because the discrete-trial procedure came earlier historically and leads more directly to an appropriate theoretical analysis, I will take that up first.

In its most effective form (e.g., Bolles, Stokes, & Younger, 1966; Kamin, 1956, 1957a; Mowrer & Lamoreaux, 1942), discrete-trial avoidance proceeds as follows: First, an innocuous stimulus, such as a tone, a buzzer, or a light, is presented to the experimental subject, usually a rat. After that, one or the other of two mutually exclusive sequences may occur: (a) If the animal does not perform the response chosen by the experimenter, the warning signal is followed within a few seconds by an electric shock. (b) If the animal does perform the designated response, the signal is turned off and no shock ensues. On a given trial, these are the only two alternatives. That is, they are exhaustive, as well as mutually exclusive. Historically, the response most commonly used in studies of this sort has been crossing over a hurdle or barrier from one experimental compartment to another, but in other studies bar pressing, wheel turning, running, jumping, or other topographies have been used.

Theoretical Puzzle

The theoretical puzzle posed by animals that learn, in effect, to avoid electric shock is that it is not clear what consequence of the required response could have served as the source of its reinforcement (Mowrer & Lamoreaux, 1942). The mere absence of shock does not qualify as a possible reinforcer, because that condition is ubiquitous, following all sorts of behavior on all sorts of occasion. In these other cases, the absence of shock does not appear to increase the probability of the behavior that precedes it. Only under special circumstances is this consequence effective.

The problem has led cognitive theorists to postulate that it is the absence of a shock that is *expected* by the animal that does the trick (e.g., Bolles, 1972b, 1978; Dickinson, 1980, 1989; Hilgard & Marquis, 1940; Ritchie, 1951; Seligman & Johnston, 1973; Tolman, 1932; see also Mowrer, 1940; Mowrer & Lamoreaux, 1942), but this explanation raises the vexing problem of specifying the conditions under which an expectancy is formed, maintained, and eliminated (see MacCorquodale & Meehl, 1953, 1954; Osgood, 1950), and other theorists have used constructs bearing other labels.

Following in the footsteps of Mowrer (1939) and Miller (1948), many authors have postulated a construct known as fear or anxiety. The temporal pairing between the signal and the shock, they note, appears to be similar to that between the CS and the unconditional stimulus (US) in Pavlovian conditioning, and these authors maintain that a reaction of fear or anxiety is conditioned to the signal. From that point on, the fear or anxiety is increased whenever the signal is presented and is reduced whenever the signal is terminated (e.g., Ayres, 1998; Levis, 1989). To conform with Hullian theory, both Mowrer and Miller also assumed that the conditioned fear or anxiety was a drive and that is why its reduction was reinforcing.

Behavior-Analytic Version

The hypothetical status of these early theoretical constructions may have prejudiced behavior analysts against any form of two-factor theory, but the theory can also be stated without reference to anything hypothetical intervening between the observed events (Dinsmoor, 1954, 1977; Schoenfeld, 1950; Sidman, 1953b). Note that, after the pairing, the fear and the warning signal virtually duplicate one another in their temporal sequence: They arrive and depart at the same time, under the same circumstances, and all that is necessary to complete the picture at an observable level is to note that the ending of the signal now reinforces whatever behavior produces that consequence.

In its original form, the basic interpretation of avoidance learning that I have supported for many years (see Dinsmoor, 1954)—two-factor or two-process theory—asserts that the acquisition of the behavior that avoids the shock results from the interaction of two behavioral factors or processes, corresponding to the two sequences that are used in the discrete-trial avoidance procedure (e.g., Schoenfeld, 1950; Skinner, 1953). The first process involves a temporal correlation or pairing between the warning signal and the shock. This makes the signal aversive to the animal. Here, I am using the word *aversive* in a strictly behavioral sense, to mean simply that the subsequent removal of the signal will be a reinforcing event. The reinforcing action is the second of the two processes. Another term that is sometimes applied to this type of stimulus is *conditioned negative reinforcer.*

Control Procedure

It has been noted by such critics as Herrnstein (1969), W. Baum (1973), and Hineline (1977, 1981) that two-process explanations of some portions of the experimental literature involve extrapolations that are not subject to direct empirical test. But that criticism certainly does not apply to the basic explanation of discrete-trial avoidance. The avoidance of the shock, according to this explanation, is a joint product of the temporal pairing or correlation between the signal and the shock and of the subsequent termination of that signal by performance of the designated response. The ideal control procedure, it seems to me, is one that preserves the two processes specified by the theory but that eliminates any effect of the response on the nature or timing of any subsequent shock. Studies of conditioned aversive stimulation—usually described in the literature as studies of fear conditioning or of acquired drive—provide the appropriate test (e.g., Brown & Jacobs, 1949; Kalish, 1954). Because no shock is ever prevented, postponed, or modified in any way by the performance of the response that is acquired by the animal, these results cannot be explained by any theory that depends on the direct effect of some change in the severity of subsequent shocks or in their distribution in time, as in single-factor accounts by Herrnstein and his associates (W. Baum, 1973; de Villiers, 1972, 1974; Herrnstein, 1969; Herrnstein & Hineline, 1966; Hineline, 1977, 1981, 1984), for a reinforcing event.

The alternative sequences that can occur on any given trial of signaled avoidance are still presented, but each of these sequences is presented by itself in a continuous block of trials, so that the two procedures are kept well separated in time. There is no overlap. In the first block of trials, the signal is presented a number of times, followed on each occasion by a shock. But that is all that is done. During these trials, the animal has no opportunity to alter the sequence of events. The response eventually to be learned either is not available or is not effective.

In the second block of trials, no shock is ever presented, so again no shock can be altered in any way. The signal is repeatedly presented, and each time that the animal performs the designated response, the signal is turned off. In numerous replications (see McAllister, McAllister, Hampton, & Scoles, 1980; also see Azrin, Holz, Hake, & Ayllon, 1963, and Dinsmoor, 1962, for an alternative technique), this procedure has repeatedly produced an increase in the frequency of responding (typically measured as a decrease in the time between the onset of the stimulus and the occurrence of the response). To be sure, the increase is temporary, but that, too, is in accord with two-process theory, as during the second block of trials the signal is no longer being followed by the shock (see Kalish, 1954). Let me emphasize once again that in these studies the responses and the shocks never appear in the same set of trials, so the animal never is given an opportunity to modify or to postpone a shock by performing the designated response. Briefly put, no avoidance contingency is present, and none is required. Nevertheless, the two processes specified by two-process theory are sufficient to generate responding. If this theory can be extended to account for the acquisition and maintenance of continuous, free-operant avoidance, it is difficult to see why any additional explanatory device should be needed.

Variations in Discrete-Trial Training

Confirmation that the two factors continue to operate within the context of full-blown discrete-trial avoidance is provided by studies involving parametric variations in the standard procedure. For example, Kamin (1957b), Mowrer and Lamoreaux (1942), and Verhave (1959) have all found that delaying the occurrence of the presumed reinforcing event, termination of the signal, reduces the level of responding. The effect of delayed termination was confirmed by Bower, Starr, and Lazarovitz (1965), who also found that the magnitude of the physical change in the signal was a relevant parameter: The greater the change, the more effective it was as a reinforcer (see also Baron, DeWaard, & Lipson, 1977; M. Baum, 1965; Crawford & Masterson, 1978; Knapp, 1965; Modaresi, 1978). Although it is conceivable that the effects observed during training can be explained by some confounded relation between the signal and the shock, the same cannot be said of findings obtained when there is no shock. Delprato (1969), Katzev (1967), and Katzev and Hendersen (1971) all found that delaying the termination of the warning signal (or onset of the safety signal) during extinction—where such a delay did not affect the relation between signal and shock—produced much more rapid declines in responding (see also Katzev & Berman, 1974).

Another telling observation is that procedures that reduce the correlation between the signal and the shock have a deleterious effect on the acquisition of the avoidance response. Studies by Kamin (1956, 1957a) and by Bolles et al. (1966), which have repeatedly been cited as evidence against the two-factor theory of avoidance, actually support it. In what have been called ''no avoidance'' procedures, reducing the trial-by-trial correspondence between the signal and the shock by presenting the shock on all trials, regardless of whether the signal was still present or had been terminated by the animal's response, severely reduced the frequency of responding. Keeping the signal on during all trials (''no termination''), regardless of whether or not a response had occurred and therefore whether a shock was or was not to be administered, had a similar effect.

EXTENSION OF TWO-FACTOR THEORY TO UNSIGNALED AVOIDANCE

The question remains, of course, why procedures like this last one should work at all. If the warning signal is not turned off by the response, what is now the source of reinforcement? Even more challenging is the generation of responding under the avoidance procedure devised by Sidman (1953a, 1953b), in which no exteroceptive warning signal is ever *presented,* let alone terminated. It is this procedure that has led to an alternative formulation originally suggested by Sidman (1962b) and subsequently elaborated by Herrnstein and Hineline (1966), Herrnstein (1969), and Hineline (1977, 1981, 1984). In the unsignaled or free-operant avoidance procedure, brief shocks are presented at predetermined (shock–shock or SS) intervals during periods when the animal does not respond but are postponed for a different but also predetermined (response–shock or RS) interval following each response. In most experiments, the value of each of these predetermined intervals remains fixed throughout a series of experimental sessions, but variable intervals can also be used (e.g., de Villiers, 1972, 1974; Herrnstein & Hineline, 1966; Logue & de Villiers, 1978).

Response-Generated (Feedback) Stimuli

As Herrnstein has put it, to deal with the effectiveness of the unsignaled procedure, ''two-factor theory must here find, or invent, a stimulus change at the moment of response'' (1969, p. 59). Nothing could be simpler. Evidently Herrnstein considered the specification of a stimulus change to be difficult for two-factor theorists, but in the same article he quoted a passage from Schoenfeld (1950, p. 88) that provided a straightforward solution. The main thrust of Schoenfeld's article had been that because of their pairing with shocks the tactile and proprioceptive stimuli (more broadly specified, response-produced or response-dependent stimuli; see Dinsmoor, 1954, 1977; Dinsmoor & Sears, 1973) generated by ineffective or nonavoidance behavior, in compound with any warning signals provided by the experimenter and with the general experimental situation, became aversive to the animal. But he also mentioned the possibility that the corresponding stimuli emanating from the successful avoidance response had become positively reinforcing. In this early paper, Schoenfeld attributed the acquisition of reinforcing properties by the latter stimuli to pairings of their onset with the termination of the conditioned aversive stimuli, but since then other writers have suggested that a stimulus that typically precedes a shock-free or shock-reduced period, so that it is inversely or negatively correlated with the receipt of shock, constitutes what is commonly called a safety signal and that this safety signal is reinforcing (e.g., Azrin et al., 1963, p. 454; Bolles, 1970, 1972a; Bower et al., 1965; Denny, 1971; Dinsmoor & Sears, 1973; Mowrer & Keehn, 1958, p. 216; Mowrer & Lamoreaux, 1942, p. 27). Furthermore, in an early report on free-operant avoidance, Sidman (1954b) added an observation that came very close to completing the present analysis, noting that ''The occurrence of an avoidance response appears to initiate a 'safe period' '' (p. 401).

Scientific Legitimacy of Response-Dependent Stimuli

In his critique, Herrnstein (1969) complained repeatedly about the use of ''inferred stimuli'' by two-factor theorists, as if the stimulus required were entirely hypothetical. Similarly, W. Baum has complained about ''awkward theorizing about unobservable events'' (1973, p. 147) and has asserted that ''explanation of . . . free-operant avoidance by molecular theory requires hypothetical constructs'' (1989, p. 168), yet I can find none in the present account. The occurrence of a physically defined response is just as material, just as observable, just as specifiable a source of stimulation as the presentation of a light or a tone, and even more readily observed than a shock (in addition, see Berryman, Wagman, & Keller, 1960; Hefferline, 1950, 1958; Hefferline & Perera, 1963; Notterman & Mintz, 1965; Skinner, 1950, p. 210; Vandell & Ferraro, 1972; Winnick, 1956). The only difference worthy of note is that this stimulus is under the immediate control of the subject, rather than under the control of the experimenter.

Evidence for Safety Signals

When examining the influence of a stimulus they do not directly control, research psychologists sometimes add a stimulus that they do control, placing the controlled stimulus in the same temporal relation to the animal's behavior as the stimulus they wish to investigate (e.g., Bower et al., 1965; Ferster & Skinner, 1957; Notterman & Mintz, 1965; Starr & Mineka, 1977). They then proceed to manipulate the added stimulus in some way, observing the consequences.

A number of investigators have added external stimuli as feedback to the response in otherwise unsignaled avoidance procedures (for citations, see Dinsmoor & Sears, 1973). Studies by Rescorla (1969) and by Weisman and Litner (1969) are particularly instructive. Rescorla trained dogs to avoid electric shock by pressing either of two panels. When he added a separately trained safety signal as a consequence of pressing one of the panels, he found that the dogs pressed that panel more frequently than the other one. Weisman and Litner found that a tone that had been inversely correlated with the delivery of shocks during independent conditioning sessions could be used either to increase or to decrease the rate of a target response, depending on the contingency that was employed. When presented as a reinforcer on a differential-reinforcement-of-high-rate schedule the tone increased the rate of wheel turning, but when presented as a reinforcer on a differential-reinforcement-of-low-rate schedule it decreased the rate of responding (see also Morris, 1975).

A limitation on the procedures just described is that logically one cannot differentiate between the onset of a safety signal and the termination of a warning signal. The warning signal indicates when shocks are coming, and the safety signal indicates when shocks are not coming. Thus, the absence of one constitutes the presence of the other, and the presence of one constitutes the absence of the other. Specifically, in the standard signaled avoidance paradigm, the termination of a warning signal could be treated as the presentation of a safety signal, and in the experiments just cited the presentation of a safety signal could be interpreted as the termination of a warning signal. Therefore, it is difficult to say which relation between stimulus and shock is responsible for the effect on the subject's behavior.

Dinsmoor and Sears (1973) conducted an experiment that demonstrates that production of the safety signal does indeed have a positive reinforcing effect that is separate and distinct from any negative reinforcing effect exerted by termination of a warning signal. The subjects were pigeons with implanted electrodes. During otherwise unsignaled avoidance training, these investigators presented a tone of 1000 Hz for 5 s each time the pigeon depressed a pedal—in terms of its temporal relation to the response, a rough equivalent to the natural feedback. Whenever the pigeon produced the tone, the next shock was postponed for 20 s.

During interspersed test periods in which no more shocks were administered, continued response-dependent presentations of the tone served as positive reinforcers, maintaining higher rates of pressing than during corresponding test periods when no tones were presented. Moreover, during some of these periods tones of 250, 500, 2000, or 4000 Hz were tested in the same manner. The result was a gradient of generalization in which response-produced tones closer in frequency to the original training stimulus maintained higher rates of pressing than those more distant from that stimulus. Presumably, the stimulus dimension of auditory frequency is orthogonal, or very nearly so, to the dimension of presence versus absence. Therefore, these tones did not differ in their similarity to the absence of tone as a warning signal but only in their similarity to the presence of the 1000-Hz tone as a safety signal. In short, similarity to the training stimulus was isolated as an effective parameter, indicating that in this experiment, at least, it was the production of the safety signal, rather than or in addition to the termination of a warning signal, that was responsible for the maintenance of the pigeons' behavior.

Experiments like those above by Dinsmoor and Sears (1973), Morris (1975), Rescorla (1969), and Weisman and Litner (1969) testify to the conclusion that just as stimuli directly or positively correlated with the delivery of shock become aversive to the subject, so stimuli inversely or negatively correlated with the shock (safety signals) become positive reinforcers. Hineline (e.g., 1982) has expressed agreement with this conclusion. The natural feedback as well as the programmed consequence from the performance of any response that persistently postpones shock fits the specification above, and the natural feedback should become an automatic reinforcer (see Vaughan & Michael, 1982). Note that response-generated stimuli are not a theoretical invention but are *inherent* in both the discrete-trial and the free-operant avoidance procedures. As they are both readily observable and entirely relevant, to preclude them from a systematic analysis of the interaction between organism and environment would be to leave an inexcusable gap in that analysis. Finally, because of their temporal relations to shocks and to the subject's behavior, the *inevitable* effect of such stimuli is to condition and maintain the response that produces them.

Effects of Different Response Topographies

If the stimuli intrinsically generated by the performance of a particular form of response (feedback) play a major role in avoidance, then different behavioral topographies like bar pressing, key pecking, flying, wheel turning, jumping, or running—together with experimental arrangements like one-way or two-way shuttling—should differ to a substantial extent in their ease and rapidity of conditioning. Because of the differences that typically exist among other parameters of the experiment (e.g., quality and intensity of shock, mode of delivery, species of organism, age, gender, electrode- or grid-cleaning routines, apparatus feedback, or temporal characteristics of procedure), this conjecture is not easy to verify with any degree of confidence, but Bolles (1970) has asserted that such is indeed the case, and many observers seem to agree with him. Bolles, of course, attributed these differences in ease of conditioning to differences in the survival rate during individual encounters between prey and predator throughout the evolution of the species. Aside from the initial probability of a given category of behavior, however, it is difficult to see how a form of learning that typically requires repeated exposures to the aversive stimulus in the conditioning laboratory could be selected though a process that depends on the fatal consequences of the first error. A more plausible interpretation, to my mind, is that, with the possible exception of freezing, most of the variations that Bolles addressed can be attributed to differences in the magnitude and duration of the change in stimulation (feedback) generated by different forms of behavior. Safety signals that differ to a large degree from the general background stimulation are more effective than those that differ by only a small magnitude (Bower et al., 1965).

Response–Shock Time as a Parameter

When their physical properties are held constant, the effectiveness of warning and safety signals is a function of their temporal proximity to the shock. The relative time to each of the ensuing shocks within a fairly short window following the response, in conjunction with such additional parameters as intensity, duration, and cumulative number of shocks, should determine the rate at which the designated response is repeated in continuous, free-operant avoidance (see Dinsmoor, 1985; Lewis, Gardner, & Hutton, 1976; Sidman & Boren, 1957). Allowing for differences in the magnitude of the physical feedback from different topographies, this factor should also determine the relative frequency of different forms of response. This two-factor formulation applies to punishment as well as to active avoidance (Baron, Kaufman, & Fazzini, 1969; Dinsmoor, 1985, 1998). Sidman's (1954a) findings illustrate the seamless nature of the transition between avoidance and punishment as the delay is increased or decreased.

AN ALTERNATIVE HYPOTHESIS: SHOCK-FREQUENCY REDUCTION

The history of the alternative behavior-analytic formulation—nonmediating or single-factor theory, as it is commonly but somewhat misleadingly known—begins with another experiment by Sidman (1962b). In this experiment, Sidman provided his rats with two bars or levers, each lever serving to reset a separate and independent timing device. The setting on a given timer governed not only the time between a depression of the corresponding lever and the subsequent shock delivered by that timer (RS interval) but also—which is a key to our understanding of Sidman's results—the time between each shock and the next shock delivered by that same timer (SS interval), assuming that no instance of the relevant response intervened. When no presses occurred on a given lever, the timer it controlled recycled repeatedly, delivering a series of shocks with a temporal spacing determined by the SS interval. It is important to keep in mind that neither lever had any effect on the shocks delivered by the other timer.

When the time intervals for the two levers were set at different values, the result seemed to be counterintuitive: On the assumption that postponing shock for a long period of time should be a more effective reinforcer than postponing it for a short period, it would have been predicted that Sidman's rats would respond more often on the lever producing the longer of the two RS intervals. Instead, they responded mainly on the lever that produced the shorter of the two intervals.

Sidman's Analysis

Sidman's analysis of these data is most clearly set forth in a chapter he subsequently published in Honig's *Operant Behavior: Areas of Research and Application* (1966): "The animals . . . will select the lever associated with the . . . response-shock interval that is the more efficient method of reducing the [overall] frequency of shocks" (p. 482), that is, capable of producing the larger reduction over an extended period of time (see Figure 24, p. 481). But as Sidman went on to say, "It is not easy, however, to specify how changes in shock rate make contact with the animal" (p. 483).

RS and SS Intervals

The critical variable in Sidman's (1962b) experiment was not the respective RS intervals or the overall frequency of shock, however, as has regularly been assumed in subsequent discussion, but the respective SS intervals. For a given lever, the same timer controlled both intervals, and the two intervals were always equal in duration. Although Sidman described the interval set on a given timer as an RS interval, it was also an SS interval, and it was the time between successive shocks that controlled the greater number of shocks delivered to the animal and that therefore had the greater influence on its preference between the two levers.

To put it another way, it was the scheduled time to next shock immediately prior to the occurrence of the response (as determined by the SS interval) that was the parameter critical to Sidman's (1962b) results, not the time to shock following that response (as determined by a cumulative series of RS intervals). Pressing the shorter interval lever ended a series of shocks that were closely spaced in time and that had made the stimulation (setting and behavior) prevailing before that response highly aversive and the natural stimulation contingent upon that response highly effective as a safety signal. Pressing the longer interval lever ended a more widely spaced series of shocks. It turned off a less aversive preresponse stimulation and turned on a less potent safety signal. As frequency of shock and average time to shock ("delay") are reciprocals, the argument can also be stated in terms of the relative delay to shock from any point in the session. The chances are that such a formulation will be mathematically more accurate than one based on frequency (see Dinsmoor, 1985; Fantino, 1977; Fantino & Abarca, 1985).

To summarize the one-factor interpretation of Sidman's (1962b) results, then, the animal pressed the lever that produced the greatest increase from the average time to shock during SS intervals to at least one full RS interval or, commonly, the interval produced by the summation of a series of RS intervals. This effect was mediated by the correlations between pre- and postresponse stimuli and the length of time to the next shock.

MOLECULAR CONTINGENCIES

To evaluate the shock-frequency-reduction theory of avoidance, it is necessary to make clear the distinction between the type of contingency between individual occurrences of the response and individual deliveries of the reinforcer studied by Skinner (e.g., Ferster & Skinner, 1957; Skinner, 1938/1991) and the type of covariation over a more extended period of time between rate of response and rate of reinforcer delivery championed by Herrnstein (e.g., 1969), W. Baum (1973), de Villiers (1972, 1974), and Hineline (1977, 1981). The first has been called a molecular relation, the second a molar relation.

Response-Contingent Schedules

In molecular terms, shock-frequency-reduction theory runs into a *fatal* logical difficulty. Perhaps I can make that difficulty clearer by comparing shock-frequency reduction with traditional schedules of positive reinforcement like fixed ratio, fixed interval, variable ratio, variable interval, or differential reinforcement of low rate. Under the traditional schedules, each and every delivery of the reinforcer is brought about by some individual instance of the recorded operant that meets a specified criterion (i.e., schedule requirement) concerning such matters as the number of responses that have occurred since the previous delivery of a reinforcer, the amount of time that has elapsed, time since the previous response, and so on. Unless delay of reinforcement is itself a subject of inquiry, the reinforcer always follows immediately upon some individual occurrence of a member of the designated response class (e.g., Zeiler, 1977). This intimate correlation between response and reinforcer (commonly known as a contingency) enables the traditional schedules to exert a selective effect on one category of behavior (e.g., bar pressing or key pecking) to the detriment of others (e.g., sniffing, scratching, bobbing, flapping, rearing, or grooming). This selective effect is not found with fixed-time or variable-time schedules, however, in which the delivery of the reinforcer is automatic as soon as the interval has been timed out, rather than dependent on the subsequent occurrence of a response. The moment-by-moment correlation between response occurrence and reinforcer is no longer present, and the latter schedules are conventionally described as noncontingent, superstitious, or response-independent schedules.

Absence of Temporal Locus for Frequency Reduction

The problem that I am raising with shock-frequency reduction does not refer to the nature of the animal's computational procedure, as was inferred by Hineline in his 1981 response to my 1977 paper, but to the logical requirements for a determination by any means whatsoever of the rate of shock delivery. Logically, or mathematically, the frequency of shock for any period is defined as the number of shocks per unit of time. Increases in frequency necessarily depend upon changes in the numerator of that fraction. Each time a shock is delivered, there is a sudden increment that can be localized in time. On the other hand, there is no way in which shocks can be withdrawn or subtracted by the experimental apparatus, so decreases in their frequency depend entirely on changes in the denominator of the fraction, that is, on the passage of time. Time, of course, is not disbursed in discrete packets but flows continuously throughout the experimental session. Graphically represented, the decline in frequency is not a step function but a slope. Because frequency is *always* declining—except at the moments when that decline is interrupted by the receipt of a shock—the decrement in frequency cannot be assigned a specific locus in time like that assigned to the delivery of a pellet of food or access to a tray of grain. Therefore, it cannot closely and selectively follow individual instances of the class of behavior chosen by the experimenter to serve as the avoidance response. Unless we venture into two-factor theory, shock-frequency reduction does not provide the linkage between individual occurrences of a specified class of behavior and individual deliveries of a reinforcing event found in the standard schedules of positive reinforcement. In the usual sense of the term, then, there is no contingency, there *can* be no contingency, between the response and the putative reinforcer.

At a molecular level, the reduction in the frequency of shock is noncontingent, like a schedule of response-independent food presentation. Although, significantly, noncontingent schedules of reinforcement can transform temporally correlated stimuli into conditioned reinforcers (e.g., Autor, 1969; W. Baum & Rachlin, 1969; Brownstein & Pliskoff, 1968; Kelleher & Gollub, 1962; but especially Browne & Dinsmoor, 1974; Dinsmoor, Bowe, Green, & Hanson, 1988; Jenkins & Boakes, 1973), they are not effective procedures for selectively increasing the frequency of an arbitrarily chosen class of behavior.

Linking Response and Reinforcement

An analysis that compares the frequency of shock or the time to the next shock under the stimulus conditions just before and the stimulus conditions during and just after each occurrence of the designated response (i.e., a stimulus mediation, or two-factor theory) supplies the missing link between behavior and consequence. The sensory feedback from the avoidance response provides a stimulus that *is* localizable in time. As has already been demonstrated, by its negative correlation with the delivery of shocks, this stimulus becomes a safety signal (e.g., Dinsmoor & Sears, 1973). From the perspective of a safety-signal interpretation, Sidman's (1962b) results make perfect sense. In its emphasis on the parameter of frequency of shock or time to next shock, the safety-signal formulation is similar to Sidman's analysis of his data. As indicated above, however, it does not lump all shocks together to calculate a total frequency: It considers relatively brief periods of time before and after each occurrence of the response, and it distinguishes between those shocks that are delivered on an RS schedule and those delivered on an SS schedule.

MOLAR OR DISTAL APPROACH

When I pointed out (Dinsmoor, 1977) that shock-frequency reduction has no locus in time and cannot participate in the type of contingency between response and reinforcer studied by Skinner and most other students of conditioning, Hineline's response was to reject the necessity of what he called "contiguity-based theory" or "contiguous causation" (1981, p. 228). But two-factor theory does not depend on contiguity other than in a relative, and entirely proper, sense: that the length of the interval that elapses between a conditional, secondary, or derivative event and the primary or inherently effective event (e.g., conditional stimulus and unconditional stimulus, secondary and primary reinforcer, response and reinforcer, response and punisher, warning or safety stimulus and shock) is an extremely powerful parameter of that relation's effectiveness. A more appropriate term for this set of functions might be *relative temporal proximity*.

What Hineline was rejecting was my reliance on a conventional molecular approach to the correlation between behavior and consequence. The proposed alternative is what W. Baum (1973), Hineline (1977, 1981) and several other writers have called a molar approach to that problem. In dealing with schedules of reinforcement, the molar approach circumvents the issue of the relation between individual instances of the response class and individual deliveries of the reinforcer or punisher by averaging across some relatively long period of time, that is, by restricting its consideration to the pooled outcome or overall end result: "If a specified response class uniquely affects the density of shocks distributed over time, the shocks are consistently related to the specified responses" (Hineline, 1981, p. 227). Or as Baum has put it, the molar principle of reinforcement reads as follows: "Behavior increases in frequency if the increase is correlated with an increase in rate of reinforcement or a decrease in rate of aversive stimulation" (W. Baum, 1973, p. 145).

Molar Principle Versus Molecular Contingencies

Although the molar principle provides an economical description of certain arrays of data (e.g., de Villiers, 1972, 1974; Herrnstein, 1970; Logue & de Villiers, 1978; Williams, 1988), it falls far short of a complete account of the variations in behavior produced by different schedules of reinforcement. For example, it makes no mention of the many differences in contingency studied by Skinner (1938/1991) and by Ferster and Skinner (1957). An obvious objection to it as a fundamental explanatory principle is that it is so readily overridden by such local contingencies as the selective reinforcement of least frequent interresponse times (Blough, 1966), differential reinforcement of high rate, pacing schedules (Ferster & Skinner, 1957), or differential reinforcement of low rate (Kramer & Rilling, 1970), and even by tandem schedules in which a brief period of differential reinforcement of high or low rate is appended following a much more prolonged exposure to an interval or a ratio contingency (Ferster & Skinner, 1957). The effects of these schedules highlight the critical importance of the rate of responding at the moment the reinforcer is delivered. Particularly illuminating were the relative rates of pecking on tandem schedules in which a temporally yoked variable-interval contingency was followed by a variable-ratio contingency or the same variable-ratio contingency was followed by a temporally yoked variable-interval contingency (Peele, Casey, & Silberberg, 1984, Experiment 3). In this comparison, the correlations between rate of response and rate of reinforcement were equated, but in each case the rate of responding was typical of the second contingency.

Furthermore, such investigators as Anger (1956, 1973) and Shimp (1969b, 1973, 1979) have demonstrated that it is possible to produce excellent simulations of the subjects' performances on standard variable-interval schedules by using synthetic equivalents in which deliveries of the reinforcer are programmed separately for different ranges of interresponse time in proportion to those appearing under the original schedules. Peele et al. (1984) simulated representative variable-interval and variable-ratio performances by using a response-generating algorithm suggested by Shimp (1969a). In other words, the molar functions generated by these schedules appear to be produced by more molecular contingencies. As Donahoe, Palmer, and Burgos (1997) put it, in the course of an extended discussion of the issue, ''Reinforcers cause certain environment–behavior relations to be strengthened; this has the effect, under some circumstances, of producing molar regularities. Selection by reinforcement *for* momentary environment–behavior relations produces selection *of* molar regularities'' (p. 201).

Temporal Proximity

A more systematic objection to a principle that depends on the correlation over relatively extended periods of time between rate of responding and rate of consequence may be expressed as follows: (a) By simple logic, at least two occurrences of each type of event are required to provide even single instances of the respective interevent times from which the corresponding rates may be derived or detected by any instrument or organism, including the experimental subject. (b) When the time between reinforcers or the time between shocks varies, as is often the case in operant research, repeated instances of each type of interevent time will be required to determine or detect an average rate. (c) In laboratory studies of the scheduling of positive reinforcement, the time between two successive deliveries is often measured in minutes, rather than in seconds, and in unsignaled avoidance well-trained animals may receive only a few shocks in each experimental session (see Anger, 1963, pp. 485–486, 487–488, and Hineline, 1977, p. 406). But (d) it is copiously documented that the effectiveness of each delivery of a reinforcer is sharply reduced when even a few seconds have elapsed since the last previous occurrence of the operative response (for partial reviews of a massive literature, see Logue, 1995; Renner, 1964; Schneider, 1990; Tarpy & Sawabini, 1974). Temporal proximity between behavior and reinforcer is an extremely important determinant of the effectiveness of that reinforcer. The molar principle of reinforcement, however, rests on consequences that cannot even be specified until a substantial period of time has elapsed since the occurrence of the response. This is not to assert that temporally remote consequences have no effect whatsoever on behavior but only to assert that under normal experimental circumstances their effectiveness is severely diminished by even a few seconds delay and that the effects of any correlations that may prevail over longer periods of time must therefore be drowned out by the immediate consequences specified in more conventional contingencies of reinforcement.

W. Baum (1973) has attempted to forestall this criticism by arguing that the delay-of-reinforcement gradient should not be attributed directly to the time that elapsed between the response and the reinforcer but to the resulting addition to the total time between two successive reinforcers (i.e., a reduction in rate of reinforcer delivery). However, in most of the literature surveyed by Renner (1964) and by Tarpy and Sawabini (1974), discrete trials were employed, and the total time from one reinforcer to the next was not affected by the length of the delay. Moreover, under procedures in which the constituent values were separately varied, both Logan (1965) and Logue, Smith, and Rachlin (1985) found that where in the sequence of events the increase in time between reinforcers occurred was critical. Their subjects' performances were much more sensitive to differences in that portion of the total time that fell between the response and the next reinforcer (delay of reinforcement) than they were to differences in the portion that fell between the delivery of the reinforcer and the next occurrence of the response (postreinforcer delay). Therefore, only a very small part of the effects of increased time between response and reinforcer can be attributed to Baum's variable, an increase in the time between successive reinforcers. It is specifically the temporal proximity between response and reinforcer that is important.

Direct Tests of the Molar Principle of Reinforcement

Furthermore, direct tests of W. Baum's (1973) molar reinforcement hypothesis have yielded negative results. For example, Cole (1999) exposed rats to two versions of a variable-interval-with-linear-feedback schedule, under which rate of reinforcement was correlated with rate of response. He found ''little evidence of other than a relatively flat relationship between reinforcement rate and response rate'' (p. 328). Under a procedure used by Thomas (1981), the first response in any 20-s interval produced an immediate pellet of food but canceled a response-independent pellet and postponed the start of the next interval. The rats acquired and maintained the behavior of pressing a lever, even though this response reduced the total number of pellets received and thus produced a negative correlation over an extended period of time between rate of response and rate of reinforcement. With pigeons, Shull, Spear, and Bryson (1981) also varied delay and frequency independently and found that delay was the operative parameter. They concluded that ''each food presentation after a response adds an incremental effect to the rate of response and . . . each food presentation's contribution is a decreasing function of its delay timed from the response'' (p. 129). (See Lewis et al., 1976, for the corresponding case with shock.)

Delay-of-Shock Gradient

Although the data on the delay-of-shock gradient are fragmentary compared to those on positive reinforcement, they do not suggest that it extends substantially farther than the positive gradient, certainly not far enough in time to play a significant role in conditioning and maintaining avoidance behavior (e.g., Baron et al., 1969; Camp, Raymond, & Church, 1967; Cohen, 1968; Deluty, 1978; Dinsmoor, 1962; Kamin, 1957b; Sidman, 1953b, 1954a).

An experiment by Mellitz, Hineline, Whitehouse, and Laurence (1983) is sometimes cited as extending the temporal limits of the response–stimulus relation, but it is not clear to what degree such a conclusion is vitiated by selective sampling. At first, pressing in this experiment was maintained only by equal concurrent shock-postponing schedules on each of two levers. Later, however, a contingency was added that reduced the length of the experimental session by 1 min each time the animal pressed the nonpreferred lever; this operation increased the rate of responding. When the procedure is described in this fashion, our attention is directed to the small and temporally remote consequence of each press during the course of the session. But the cumulative effect of this contingency was to produce quite a large change in the length of the session: ''For each subject, the introduction of the conjoint session-shortening contingency occasioned an initially substantial reduction in the duration of subsequent avoidance sessions'' (p. 60). To insulate the subject's behavior from this consequence, the authors arranged that presses during the last 2 min did nothing to hasten the termination of the session. Despite this precaution, presses close to the end of the session were nonetheless followed on a noncontingent basis by the very potent combination of escape from the experimental chamber, in which many shocks had been received, and return to the home cage, in which much food and water had been consumed. If we can assume a positive correlation between the relative rate of pressing on the nonpreferred lever earlier in the session and the relative rate on this lever as the session came to a close, those sessions with high rates toward the end were also the sessions that were followed by earlier than usual termination. That is, there was a correlation between rate of responding and probability of terminating the session. For sessions with relatively high rates of responding on the nonpreferred lever, the rate of session termination (terminations per unit of time) was higher. Note also that even if the results are taken at face value, they do not differentiate between the Herrnstein-Hineline decline-in-frequency hypothesis and an extended delay-of-shock gradient.

If X-irradiation or the ingestion of a substance that causes gastrointestinal distress is substituted for the electric shock and flavored water is used as the warning stimulus, avoidance training may be effective at intervals between the two stimuli that are much longer than with electric shock (e.g., Etscorn & Stephens, 1973; Smith & Roll, 1967). But these data offer scant comfort to frequency-reduction theorists, as this type of conditioning requires only a single pairing between the two stimuli (e.g., Logue, 1979; Revusky, 1977).

Direct Tests of Shock-Frequency Reduction

What is more, I have not been able to find any direct evidence for the effectiveness of correlations over extended periods of time within the literature on avoidance. Sidman's (1962b, 1966) suggestion that it might be the reduction in overall frequency of shock that reinforced avoidance was soon endorsed by Herrnstein and Hineline (1966), by Herrnstein (1969) in a lengthy article in *Psychological Review,* and by W. Baum (1973). According to Herrnstein and Hineline, ''A response-dependent change in the amount of subsequent aversive stimulation appears to be the *sine qua non* of avoidance conditioning'' (p. 429), yet this factor does not appear to be a necessary condition for the acquisition and maintenance of behavior in situations like those they addressed. For example, Badia, Harsh, and Abbott (1979) have summarized an extensive series of experiments in which rats were allowed to switch from an unsignaled condition to a condition in which shocks were preceded by signals and shock-free periods were preceded by the absence of those signals. The compound stimulation of the signaled condition combined with the absence of a warning signal served as a safety signal, and the safety signal reinforced the choice of the signaled condition (see Abbott, 1985, for the clearest discussion). Moreover, I have already referred to the many experiments published before the shock-frequency theory was formulated in which innocuous stimuli were made aversive by a pairing with shock during one series of trials and then terminated by responding during a second, temporally segregated, series of trials (see McAllister et al., 1980, for citations). Because no shocks were ever delivered while the recorded behavior was being acquired, the increasing frequency (decreasing latency) of responding could not and cannot be attributed to a response-dependent reduction in their quality or number.

Shortly after Sidman's (1962b) article was published, Bolles and Popp (1964) demonstrated that under the free-operant procedure, shock-frequency reduction was not even a sufficient condition for the acquisition of avoidance. It was the length of the interval between the response and the proximal (or a proximal) shock—delay—that was the effective parameter, rather than the average time between shocks (frequency) over some extended period of time. Under the arrangements programmed in their Experiment 4, a press during an SS interval did not affect the scheduled arrival of the very next shock that was programmed but did postpone for the usual length of time the next shock after that. The effect of this procedure on overall shock frequency was the same as that of the standard unsignaled avoidance procedure, in which it was the very next shock that was postponed. However, the length of time between the stimuli accompanying bar pressing and the arrival of the next shock was no greater than the time between other stimuli and the shock. My interpretation of these results is that the sensory feedback from the response was not sufficiently favored by the relatively remote consequence of postponing the shock after next and did not become an effective safety signal. Therefore, even though the frequency of shock was reduced, animals in this group did not acquire the avoidance response.

Moreover, by the time Herrnstein (1969) published his review and critique of two-factor theory, data had already been collected in his own laboratory that confirmed the conclusion that it was the interval from response to shock (delay) that was the effective variable, even when this delay did not reduce the overall frequency of shock. In his review, Herrnstein cited an ingenious experiment by one of his students that appeared in print the following year (Hineline, 1970, Experiment 1). Using a novel procedure that resulted in a delay in the delivery of the shock if the rat pressed the lever within 8 s after its insertion into the chamber but produced no change in the overall frequency with which shocks were delivered, Hineline was able to establish and maintain a stable bar-pressing performance.

In a follow-up to Hineline's (1970) Experiment 1, Benedict (1975) varied the delay as a function of the latency of the response following the insertion of the lever. When short-latency responses maximized the delay, the subjects tended to make short-latency responses; when long-latency responses maximized the delay, the subjects tended to make long-latency responses. Again, there was no reduction in the overall frequency of shock. A difference in the time that passed between the response and the next subsequent shock was a sufficient condition for a selective effect on the subject's behavior.

In his Experiment 2, Hineline (1970) modified his procedure in such a way that one of the consequences of pressing the lever was an increase in the overall frequency of shock. Under this procedure, naive rats did not learn the response, and 2 rats with prior training ceased to respond. Hineline attributed the failure to the increase in frequency, but this was not necessarily the relevant variable. As I pointed out in an earlier review (Dinsmoor, 1977), under the procedure used in Experiment 2 the temporal interval between bar pressing and the shock (8 s) was shorter than the mean interval between alternative behavior and the shock (10 s). In terms of temporal proximity, this constituted a punishment contingency.

Other experimenters have also separated delay and frequency. For example, Baron et al. (1969) added a delayed punishment contingency to an unsignaled avoidance procedure. Under most of their parametric settings, the rats reduced their rate of pressing to such an extent that it increased the total number of shocks received. In other words, it was the RS interval that was the controlling factor, not the overall frequency. In subsequent studies, Gardner and Lewis (1976, 1977) found that relatively long delays between the response and the next subsequent shock were effective in maintaining responding despite a 100% increase in the overall frequency of shock. For pigeons, delays to the second and third postresponse shock were also effective (1977, Experiment 2). These data were complicated, however, by the addition of exteroceptive stimuli that accompanied the change in the scheduling of the shocks. In other words, the changes in delay to shock were confounded with changes in the accompanying stimuli.

To summarize the data from these several experiments, the relevant variable seems to be the time that elapses between the response and an ensuing shock, rather than any decrement in the total number of shocks. To the best of my knowledge, all of the evidence that is consistent with the frequency-reduction hypothesis is also consistent with the delay interpretation, but some of the evidence that is consistent with the delay interpretation is not consistent with the frequency-reduction hypothesis. To put it in other terms, there do not seem to be any empirical data that selectively favor the claim that a decline in the overall frequency of shock serves to condition and to maintain avoidance behavior. Note, however, that if we treat the sensory feedback from each form of behavior as a CS and the shock as a US, the variable that is relevant, the time between these two events, corresponds to the familiar CS-US interval in classical or Pavlovian conditioning procedures (e.g., Davis, 1968; Domjan & Burkhard, 1986;

Gormezano & Kehoe, 1981; Lyon, 1968; Pavlov, 1927/1960; Terrace, 1973).

ADDITIONAL VARIABLES

It was not long after the formulation of the shock-frequency reduction theory that the relevance of other parameters was demonstrated. Bersh and Alloy (1978) found that reductions in the subsequent intensity of the shock following short interresponse times could increase rate of pressing in the absence of any change in the temporal distribution of the shocks. They also pointed out that under their procedure the sensory feedback from the designated response (safety signal) was not consistently followed by a lower level of shock and suggested that a three-term contingency, involving a discrimination of time since the previous response, was necessary. Bersh and Alloy further suggested that such an analysis was inconsistent with a safety-signal interpretation of avoidance, but I see no reason why this source of reinforcement should differ from other sources in the manner in which it generates control by antecedent stimuli. It also seems possible that following some portion of the rats' presses with shocks of reduced intensity may be sufficient to explain their data. As rate of responding increased, time between responses decreased, producing more responses that met their criterion and were in turn reinforced. Although their procedure did not reduce the frequency of shock, Bersh and Alloy did not criticize the shock-frequency-reduction approach.

Using a similar design, Bersh and Alloy (1980) reduced the duration of shock from 1.0 s to 0.3 s whenever the time between presses dropped below a criterion value of 15 s. For 6 of 8 rats, avoidance responding reached levels at which 90% or more of the shocks were curtailed in duration.

Please note two aspects of these developments. First, they both involved reductions in the severity of the very next shock following a response meeting certain criteria. That is, in both cases the authors made use of changes in immediate (molecular) consequences of responding to produce their results. Second, it is clear that shock-frequency reduction is not necessary and that there are other parameters of shock delivery that are fully adequate to establish and to maintain avoidance behavior. The efficacy of shock-duration reduction has also been attested by Lewis, Gardner, and Lopatto (1980), who, after rejecting two-factor theory, went on to conclude that "One situation is in effect before a response; another situation is in effect following a response. . . . The value of the situation transition is a joint function of the duration of the shocks before a response versus the duration of shocks after a response" (p. 227). As the alternative situations were accompanied by differential patterns of stimulation, this interpretation is indistinguishable, except in its vocabulary (W. Baum, 1973; Hineline, 1977, 1981, 1984), from conventional two-factor theory.

INTEGRATING PRINCIPLES

According to such eminent practitioners of science as Einstein (1954; see also Vallentin, 1954) and Skinner (1947/1999), the goal of scientific theory is to discover and describe the common characteristics that link together seemingly unrelated observations. From laws of local or limited application, broader generalizations may be constructed. Applying that objective to the present discussion, I first call attention to an earlier conclusion that the principles describing the acquisition of conditioned reinforcing properties by a stimulus are similar to (basically the same as) the principles describing the acquisition of eliciting properties by a CS during Pavlovian training. As I noted some years back (Dinsmoor, 1985), Fantino's formula for calculating the reduction in delay to reinforcement in concurrent chained schedules (e.g., Fantino & Abarca, 1985), which he uses to predict the efficacy of a conditioned reinforcer, corresponds very closely to the formulae suggested by Jenkins, Barnes, and Barrera (1981) and by Gibbon and Balsam (1981) for Pavlovian conditioning. To these two sets of principles may now be added the principles describing the acquisition of negatively reinforcing or aversive properties by stimuli positively correlated with the receipt of shock and the acquisition of positively reinforcing properties by stimuli inversely correlated with the receipt of shock (safety signals). On this basis, three areas that have quite separate research traditions, historically, can be unified within a broader theoretical framework.

By contrast, a treatment such as that pursued by Hineline, which simply adds a controlling variable to the list of avoidance parameters each time one is discovered, does not unify the several consequences that have been found empirically to establish and maintain avoidance responding, let alone integrate these relations with other areas within the provenance of a theory of behavior.

HINELINE'S CRITIQUE OF TWO-FACTOR THEORY

For the last two or three decades, the most active critic of two-factor theory and the leading advocate of a formulation appealing to correlations extending over relatively long periods of time has been Hineline (e.g., 1977, 1981, 1984, 1991). His writings have been extensive, and his emphasis has been on the results of unusually complex procedures, which tend to be the most difficult to analyze in an unambiguous fashion. Most of his interpretations have been entirely compatible with two-factor theory. Except where explicitly stated, therefore, it is not easy to judge which of his passages are meant only to extend his analysis to specific procedures in the shock-postponement literature and which are intended to serve as critiques of two-factor theory. However, his main criticisms appear to lie in the contentions that two-factor theory is ''incomplete'' and that the warning stimuli in avoidance studies have been discriminative in their function rather than conditioned aversive stimuli (Hineline, 1977, 1981).

Warning Stimuli as Discriminative Stimuli

It is true that earlier writers on avoidance had concentrated on the puzzling and contentious issue of the source of its reinforcement and usually made no explicit reference to variables or processes that were not relevant to that issue. Yet there is nothing in two-factor theory that suggests, let alone requires, a suspension of other laws of behavior. Behavioral effects that depend on the positive or negative correlation of stimuli with shock, for example, obviously come under stimulus control (Dinsmoor, 1995). In particular, the discriminative role of the warning stimuli in various avoidance paradigms comes as no surprise to two-factor theorists (e.g., Dinsmoor, 1952, 1954; Mowrer & Lamoreaux, 1946, 1951; Schoenfeld, 1950; Sidman, 1955). However, this role does not preclude their serving a reinforcing function as well. In chained schedules, to cite a parallel case, both discriminative and reinforcing properties are conventionally ascribed to the same stimuli (e.g., Dinsmoor, 1994; Fantino, 1977; Gollub, 1977; Kelleher & Gollub, 1962; Williams, 1994). Stimuli early in a sequence leading to food may even be negatively reinforcing (Dinsmoor, Lee, & Brown, 1986; Palya, 1993).

Warning Stimuli Are Not Postponed

In detailed surveys of the literature on stimulus functions in avoidance, Hineline (1977, 1981) has repeatedly pointed out that the experimental subjects typically do not exhibit substantial rates of response in the absence of the warning stimulus, even when such responses postpone the onset of that stimulus. His conclusion is that warning stimuli are not aversive. In a molecular analysis, however, the reason why postponing these stimuli is not reinforcing is easy to see: Such responses do not produce a change in the exteroceptive stimuli from ones that are positively correlated (warning) to ones that are negatively correlated (safety) with the shock, as demanded by two-factor theory. Short of third-order conditioning, which is presumably very weak, there is no mechanism provided under that theory for reinforcing behavior that merely postpones, rather than terminates, a conditioned aversive stimulus.

Vocabulary

In his writings on avoidance, Hineline has repeatedly referred to ''transitions between situations'' (W. Baum, 1973; Hineline, 1977, 1981, 1984) and ''contingencies within situations.'' Apparently these phrases were intended as replacements for such traditional and more commonly used terms as conditioned reinforcement, chaining, and stimulus control. They may have been used to highlight certain empirical relations within the general area of interest. But the relations in question were already quite familiar (e.g., Dinsmoor, 1951, 1994, 1995; Dinsmoor & Clayton, 1963, 1966; Fantino, 1977; Ferster & Skinner, 1957; Gollub, 1977; Williams, 1994), and Hineline has not expressed objections to the standard vocabulary. Moreover, promoting a second set of terms for well-known empirical concepts can foster the illusion that a new and different set of categories has been constructed, and this can lead to a certain amount of theoretical confusion (e.g., Lewis et al., 1976, 1980).

Key Studies

Two studies that Hineline (1991) has noted as being especially important to a decision between our contrasting views are those of Krasnegor, Brady, and Findley (1971) and Feild and Boren (1963). The Krasnegor et al. study indicates that response requirements are a relevant variable in avoidance, as in positive reinforcement. I have no quarrel with that conclusion.

Feild and Boren used an avoidance procedure first described by Sidman (1962a) in which each lever press added one unit (in this case 10 s) to the time remaining before the delivery of the next shock, up to a maximum of 100 s. In addition, they frequently provided standardized sequences of auditory or visual stimuli, or both, that functioned like a resettable countdown timer. These stimulus sequences represented the time remaining at any moment, if no response intervened, before the next shock was to arrive. The authors numbered the successive temporal units or steps in a backward order, starting from the oncoming shock. During sessions in which the stimulus sequences were not presented, the rats pressed most often at Step 10 (100+ s), maintaining a maximum temporal distance from the shock; but during those sessions in which the stimuli were presented, the rats waited until Step 3 (20 to 30 s), much closer to the shock. Hineline has described this experiment as ''clearly revealing that the role of the warning stimuli was that of discriminative rather than of conditioned aversive events'' (1991, p. 9). However, in analyzing the data from a similar experiment in which a sequence of stimuli preceded the shock, Pisacreta (1981) pointed out that ''If [warning signals] serve only as S^Ds for avoidance responses . . . then it would have been expected that the rats would only have responded to the last WS. Responding to the last signal (S1) would have effectively enabled the rat to avoid all shocks'' (p. 586).

What is more, in their overall form these results are just what two-factor theory would predict. When the auditory and visual stimuli were present, a very small number of responses sufficed to replace the stimuli immediately preceding the shock with stimuli somewhat earlier in the sequence, stimuli that were rarely followed—and never closely followed—by the delivery of a shock. That is, only stimuli arriving relatively close to the shock functioned as warning signals, and there was no reason to continue responding when these warning signals had been replaced by stimuli at a greater distance from the shock. When no auditory or visual stimuli were provided, however, there was no exteroceptive support: The rat was completely dependent upon the stimuli generated by its own behavior, and these stimuli faded as a function of the time that had elapsed since its last response (see Dinsmoor, 1977; Dinsmoor & Sears, 1973; for data, see Anger, 1963) and therefore required relatively frequent renewal. Otherwise, the current stimulus pattern was one that might soon be followed by shock. As it had no exteroceptive stimuli to indicate when it was safe, the rat continued to press the lever even when the time accumulated by the controlling circuit had reached the maximum possible duration of 100 s.

WHEN REINFORCEMENT OCCURS

Under an avoidance procedure with a fixed RS interval, the animal's rate of responding is constrained by a temporal discrimination (Anger, 1963; Libby & Church, 1974; Sidman, 1966), but under an adjusting avoidance schedule it is free to vary in accord with the current environmental input. Data from Sidman's (1962a) adjusting avoidance experiment provide us with a closer, more intimate look at the temporal relation between shocks and responses. They offer a different and entirely independent line of evidence showing that the reinforcement of free-operant avoidance behavior depends not only on the change in stimuli produced by the effective response but also on the pairing of alternative stimuli with the shock.

Each time the rat pressed the lever, 5 s were added to the time remaining before the next shock was due, up to a maximum of 50 s. Samples of 1 animal's performance during the beginning, the middle, and the end of an experimental session are provided in Sidman's Figure 3 (p. 274), reproduced here as Figure 1, which continuously tracks the net accumulated time in seconds to the next shock as a function of the elapsed time in minutes since the beginning of the session. Shocks are indicated by dots immediately below the record of the animal's performance.

The lever presses are not as equitably distributed in time as they would be if responding were maintained by a negative correlation over an extended period between the rate of responding and the frequency of shock (molar principle of reinforcement). The rate of pressing rises and falls in a systematic fashion. As Sidman put it, ''The picture is generally one of rapid buildup of safe time and gradual backsliding'' (Sidman, 1962a, p. 274; see also caption for Figure 4, p. 542, in Feild & Boren, 1963).

When does the rapid buildup occur? In the first third of the session, repeated shocks are sometimes necessary to initiate a series of responses, but later a single shock is usually sufficient. The inflection point in the function comes immediately after the receipt of the shock. At that point, a sudden increase occurs in the rate of responding: A series of closely spaced responses drives the accumulated time to next shock up to the maximum level provided by the programming circuit. The precipitating event is not a successful avoidance response but the shock that results when the animal fails to respond. It is difficult to reconcile this relationship with any kind of single-factor account. According to a two-factor analysis, the upsurge in rate results from the increase in the automatic reinforcing effect (second factor) caused by a pairing of the shock with the experimental situation in the absence of avoidance behavior (first factor).

Note again when it is that the surge in responding begins: It is directly following the receipt of another shock, an event that increases rather than decreases the overall frequency of shock delivery. After that, although shock frequency is now decreasing, as called for by the molar principle of reinforcement, the remainder of the cycle shows irregular declines in rate (extinction) until the previously accumulated safe time is dissipated and another shock is received (see also Sheffield, 1948, Figure 3, for equivalent data with a discrete-trial procedure). These cyclic changes do not seem to be consistent with the theory that responding is maintained by a reduction in the frequency of shock that extends over a period of time. They point to the conclusion that whatever is reinforcing the behavior is most effective immediately after the receipt of a shock and thereafter declines.

The pairing of the stimuli prevailing in the experimental chamber (including the subject's behavior) in the absence of a press with the receipt of a shock increases the aversiveness of those stimuli, and the pairing of the stimuli accompanying and following the press with the concurrent and subsequent absence of shock restores the reinforcing efficacy of the feedback from each press. For some minutes after one of those pairings, each press automatically changes the pattern of stimulation from negatively to positively reinforcing, and a run of responding ensues. But as the animal continues to be exposed repeatedly to the same pre- and postresponse stimuli, without further shocks, these stimuli gradually lose their efficacy and the rate of responding declines until yet another shock is received.

The overall form taken by the behavioral record between successive shocks may be compared with that of an extinction curve, with the highest rate at the beginning, followed by a gradual decline. It corresponds to the cumulative records obtained by Skinner (1938/1991) for the conditioning or reconditioning—and subsequent extinction—of lever pressing by the introduction or restoration of a positive conditioned reinforcer (Figures 13, 25, and 26). I do not see how this pattern of events can be explained via the molar principle of reinforcement.

CONCLUSIONS

Now that the separate strands of a two-factor theory of avoidance have each been evaluated within the context of their historical development, the argument for such a theory may be summarized in a more logical sequence, as follows: (a) Response-generated (feedback) stimulation is inherent both in the original discrete-trial and in the more recent free-operant training procedures. (b) Although these response-dependent stimuli are not under the direct control of the experimenter, they are material and observable, rather than hypothetical,

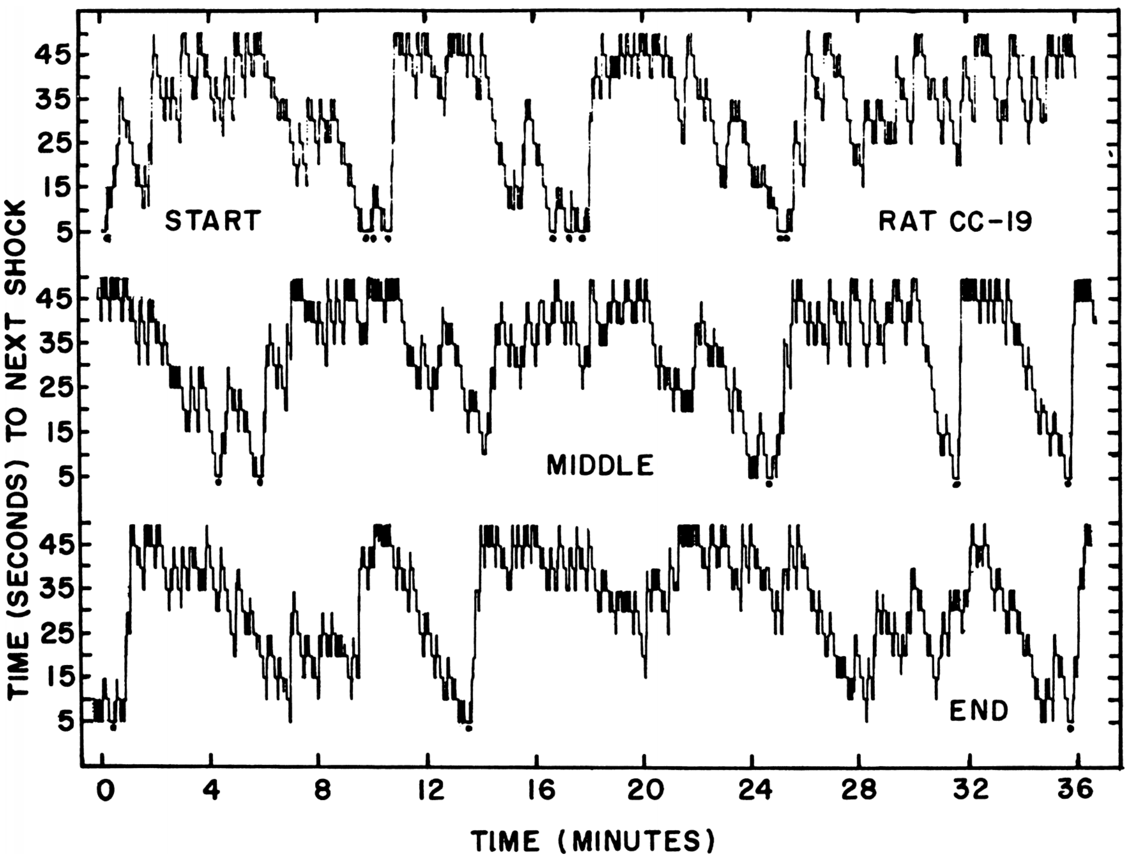

Fig. 1. Temporal distance to next scheduled shock, plotted as a function of time since the beginning of the session. The pen moved up one step each time the rat pressed the lever and down one step each time 5 s elapsed without a press. Shocks are indicated by dots below the record of the animal's performance. (Reproduced from Sidman, 1962a, by permission)

and cannot legitimately be ignored in describing the animal's interaction with its environment. (c) In the absence of avoidance behavior, the experimental environment (vs. the home cage) is positively correlated with the receipt of shock, and sometimes a more precisely correlated "warning signal" is added by the experimenter. (d) In the presence of the avoidance response and for a short time thereafter (see Dinsmoor, 1977), there is a negative correlation between response-generated stimuli and the receipt of the shock; sometimes an exteroceptive "safety signal" is also provided by the experimenter. (e) The termination of stimuli positively correlated with shock and the production of stimuli negatively correlated with shock have been shown to be reinforcing. (f) The presence of such stimuli in the training procedure is therefore sufficient to account for the selection, acquisition and continuation—in short, reinforcement—of avoidance behavior. (g) Any direct effect of correlations over extended periods of time (i.e., shock-frequency reduction) would depend on the reinforcing action of temporally distant events, which are normally far less effective than immediately subsequent events in selecting and maintaining learned behavior. (h) Finally, a detailed analysis of the temporal interaction between shocks and avoidance responses under an adjusting schedule reveals a pattern consistent with a two-factor theory of avoidance reinforcement but inconsistent with the molar principle of shock-frequency reduction.

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[1] Feild is misspelled as Field in the article referenced here.

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Received July 9, 1999
Final acceptance September 25, 2000