THE CORRELATION-BASED LAW OF EFFECT[1]

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It is commonly understood that the interactions between an organism and its environment constitute a feedback system. This implies that instrumental behavior should be viewed as a continuous exchange between the organism and the environment. It follows that orderly relations between behavior and environment should emerge at the level of aggregate flow in time, rather than momentary events. These notions require a simple, but fundamental, change in the law of effect: from a law based on contiguity of events to a law based on correlation between events. Much recent research and argument favors such a change. If the correlation-based law of effect is accepted, it favors measures and units of analysis that transcend momentary events, extending through time. One can measure all consequences on a common scale, called *value*. One can define a unit of analysis called the *behavioral situation,* which circumscribes a set of values. These concepts allow redefinition of reinforcement and punishment, and clarification of their relation to discriminative stimuli.

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I. INTRODUCTION

The traditional view of the law of effect makes contiguity between a response and a reinforcer central. It holds that reinforcement strengthens whatever response is contiguous with it, and that a response must be contiguous with reinforcement to be strengthened. Accordingly, a contingency would operate by ensuring contiguity of certain responses with reinforcement.

Recently, a number of authors have criticized this reliance on sheer response-reinforcer contiguity, and have tried to restate the law of effect in more global terms (Herrnstein, 1969, 1970; Seligman, Maier, and Solomon, 1971; Staddon and Simmelhag, 1971; Bloomfield, 1972). The present paper attempts to show that such a reinterpretation of the law of effect follows directly from the understanding that the organism and its environment constitute a feedback system. It attempts also to elucidate a notion of *correlation* that can replace mere contiguity. Finally, it attempts to show some of the implications of the new view.

II. INSTRUMENTAL BEHAVIOR AND FEEDBACK

The opening sentence of *Schedules of Reinforcement* (Ferster and Skinner, 1957) reads: "When an organism acts upon the environment in which it lives, it changes that environment in ways which often affect the organism itself." This statement implies that an organism's relations with its environment can be treated as a closed chain of events: the environment affects the organism's behavior, the organism's behavior changes the environment, the environmental changes again change the organism's behavior, and so on. Although it has long been recognized that behavior, through its consequences, feeds back to the organism—even before Thorndike (Morgan, 1894)—an obvious, but fundamental, implication of the relation has been overlooked until recently.

A. THE ORGANISM-ENVIRONMENT SYSTEM

Consider how the organism and its environment can be likened to a feedback system. Figure 1 diagrams the interactions in the organism-environment system. The experimenter manipulates the E-rules by which the organism's behavior (output) affects the environment, and attempts to discover the O-rules (functional relations) by which the environmental consequences (feedback) affect the organism's behavior. Some of the organism's output is also fed back directly by somesthesis. This loop within the organism is a logical necessity in characterizing the system, because variables such as effort expenditure produce important consequences internal to the organism. These variables are measurable, however, because they can produce effects (*e.g.,* force or work) in the environment as well as within the organism. When a procedure differentially reinforces effort expenditure, the external consequences (reinforcement) will tend to increase effort expenditure, while the internal consequences will tend to keep it from increasing. An internal loop is no different in principle from an external loop. It can be studied from its external effects.

A complete description of the system will include quantitative specification of both 0-rules and E-rules. The 0-rules are familiar as Skinner's (1938) "functional relations". They describe the control of feedback over output. A possible example might be a dependence of re-
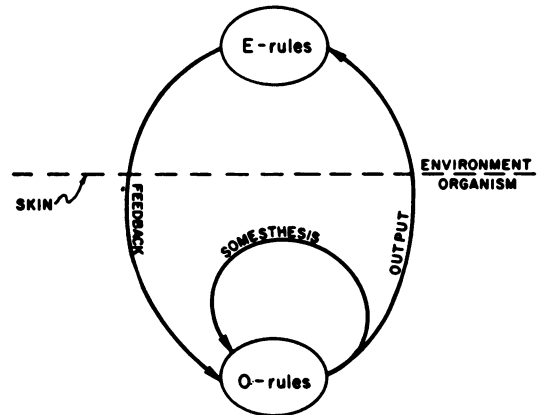

Fig. 1. Schematic view of the organism-environment system, showing the E-rules that determine feedback to the organism and the 0-rules that determine output from the organism.

sponse rate on rate of reinforcement. The E-rules are feedback loops or feedback functions. By governing feedback, which in turn governs the output (behavior), they cause the output to control itself.

B. FEEDBACK FUNCTIONS

A feedback function does not correspond exactly to the usual meaning of a contingency of reinforcement. A contingency is often thought of as a verbal statement of the conditions necessary for reinforcement to occur. A feedback function expresses the quantitative relation a contingency imposes between output and feedback. The contingency "fixed-ratio 5", for example, specifies that every fifth response will be reinforced. A possible feedback function imposed by FR 5 would be: $r = 0.2B$, where B is response rate and r is rate of reinforcement. Since there will be five responses for every reinforcement, the rate of reinforcement will always be one fifth of the response rate.

Another example would be the function imposed by a variable-interval schedule. A simple version might be:

$$r = \frac{1}{t + .5\left(\frac{1}{B}\right)} \tag{1}$$

where r is rate of reinforcement, t is the average scheduled interval, and B is the response rate. The equation states that the rate of reinforcement equals the reciprocal of the average interreinforcement time, which equals the scheduled interval plus half the average inter-

response time (1/B). This estimate depends on the assumption that the scheduling of the intervals is unrelated to the distribution of responses in time—that the scheduling of a reinforcement is equally probable at any point within the interresponse time (1/B). This holds as long as the scheduled intervals are not too short or the response rate is not too low. If the scheduled intervals are frequently shorter than the interresponse time, the interreinforcement intervals can exceed the scheduled intervals by more than half the interresponse time. As the scheduled intervals become shorter and shorter, or the interresponse times become longer and longer, the schedule must become functionally more and more similar to continuous reinforcement (CRF or FR 1). When the shortest interresponse time equals or exceeds the longest scheduled interval, Equation 1 no longer holds. The feedback function changes to r = B, the relation specified by FR 1.

The broken curves in Figure 2 represent some functions from the family produced by varying t in Equation 1. Each curve rises rapidly to its asymptote, the scheduled rate of re-

Fig. 2. Variable-interval feedback functions (broken curves) and performance (circles and solid curve). The broken line represents the reinforcement function of FR 1. The data are from Catania and Reynolds (1968, Figure 1, Bird 279). The solid curve was fitted to the points by Herrnstein (1970).

inforcement. Above some low response rate—lower for lower rate of reinforcement—increases in response rate produce no discernible increase in rate of reinforcement. The function for FR 1, the line r = B, appears also. Where each curve intersects this line, the curve ceases to hold, and the line takes over. The circles show the performances of a typical pigeon [Catania and Reynolds (1968), Pigeon 279]. The solid curve was fitted to these data by Herrnstein (1970).

Although any feedback function is derived from properties of the schedule employed, it is more than a description of the apparatus. Whereas the conditions of reinforcement imposed by the apparatus usually can be expressed exactly, specifying feedback functions is partly an empirical problem, because the variables that will produce orderly description of performance cannot always be determined in advance. Since it must meet a criterion of conformity to data, a proposed feedback function constitutes part of a theory of performance. In general, it summarizes a number of assumptions about the system. In particular, it states the parameters of feedback and output, and specifies how they are to be scaled. For example, if food intake through time is important to the organism, then both rate of food presentation and amount of food at presentation must be important. How can these two parameters be combined into one scale? When a pigeon's pecking produces grain, one may need only to multiply rate and duration of reinforcement (Neuringer, 1967; Ten Eyck, 1970; Rachlin and Baum, 1969, 1972). A feedback function would summarize the rule for such combination.

C. THE PRIMACY OF TIME

An implicit assumption underlies the foregoing discussion: that time is a fundamental dimension of all interactions between behavior and environment. The control depicted in Figure 1 occupies time. Performance of the system can be assessed only as it extends through time. This means that no particular momentary event should be seen in isolation, but rather, as part of an aggregate, a flow through time. The relations suggested in Figure 1, then, are not relations among momentary events, but a continuous exchange.

Continuous flow is measured as a rate. That emphasis on time inevitably leads to measure-
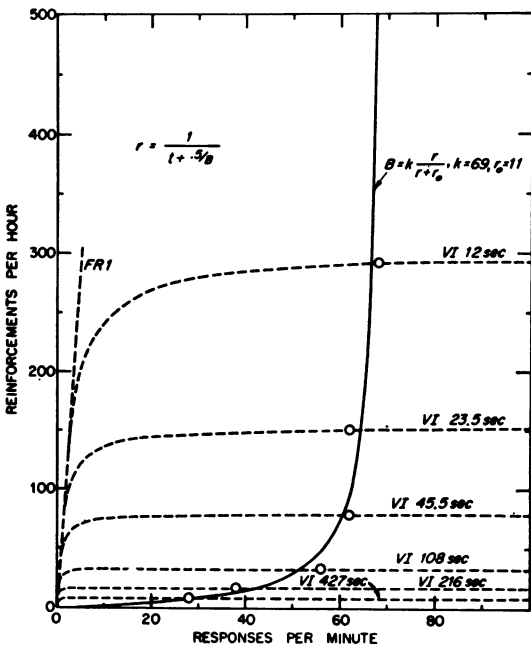
ment of rates may be understood from the dependence of behavior on physiological needs. Under normal circumstances, the maintenance of the body requires energy expenditure. As time passes, energy resources are depleted. The rate at which the energy reserve is restored must be crucial, because continual failure to offset output will result in death. Rate of energy utilization must, therefore, govern required rate of food and water intake. These basic physiological needs only exemplify, however, the importance of rate in all reinforcement. In normal exchanges, no reinforcer fails to increase in efficacy as deprivation increases or to decrease in efficacy as satiation proceeds.

Emphasis on rate of feedback leads inevitably to emphasis on rate of output, as well. If feedback is characterized as a flow through time, then the output governing and sustaining this flow must be similarly continuous. This is not to say that feedback and output undergo no temporary interruptions. It is to say that order in the interactions between behavior and environment appears at the level of aggregate flow in time, rather than momentary events.

A substantial body of research points to more orderly description on such a molar level, rather than on a momentary, molecular level. Herrnstein (1970) summarized evidence that many phenomena of positive reinforcement can be understood as dependencies between rate of responding and rate of reinforcement. It appears that aversive control also can be understood best on this molar level, as a relation between rate of responding and rate of punishment (Schuster and Rachlin, 1968; Herrnstein and Hineline, 1966; de Villiers, 1972). In general, then, this analysis takes rate as a basic dimension of all feedback.

D. MAINTENANCE AND ACQUISITION

An engineer studying a physical equilibrium system—an amplifier, for example—varies the input or feedback, and measures the output. He asks two kinds of question. First, when the system changes, what new equilibrium becomes established? Second, what is the course of change in the output as it approaches equilibrium? The first asks about stable performance; the second asks about transient performance going from one stable performance to another.

When the feedback to the organism changes,

its output, like that of the amplifier, goes through a transient phase, moving, quickly or slowly, directly or with oscillation, toward a new equilibrium. Sometimes a researcher calls the observed change in performance learning; sometimes he accepts it simply as a change from one condition to another. Usually, the nature of the change in situation determines whether or not the transient is called learning. If a new response is made available, it is called learning; if the level of deprivation is changed, it is not. When amount of reinforcement or a schedule parameter is changed, sometimes the transient is called learning, and sometimes not. In all cases, however, the transient results from a change in parameters of either the E-rules or the O-rules (Figure 1)—of either the contingencies (reinforcement or punishment) or the physiological state of the organism. One may question whether the understanding of these performance transients is in any way aided by labelling some of them "learning".

Since more is understood of the organism-environment system at equilibrium than in transition, we are concentrating on stable performance—that is, the maintenance of behavior. It is important to remember, however, that the approach to behavior described in this paper is no way limited to stable performance. The full understanding of the organism-environment system depends on the study of both equilibrium and transition.

III. CORRELATION versus CONTIGUITY

A. CORRELATION AND CONTIGUITY

Although the flow of feedback may be virtually endless, some finite sample of feedback must control output. Events remote in the past have little influence, but present behavior never depends solely on present circumstances. Since the samples controlling behavior must be finite, they must be subject to error.

A feedback function specifies a regression curve around which the samples of feedback and output vary. A contingency, therefore, establishes a correlation between output and feedback. This correlation determines performance.

Staddon and Simmelhag (1971) proposed the following statement of the law of effect:

If, in a given situation, a positive correlation be imposed between some aspect of

an animal's behavior and the delivery of reinforcement, that behavior will generally come to predominate in that situation. (p. 17)

Their use of "correlation" suggests a conception of the effects of contingency similar to the one in this paper. They distinguish two types of principles governing performance: principles of variation, which include all the effects of reinforcers and punishers not contingent on behavior—mainly the result of phylogeny—and principles of reinforcement, which govern the selection of behavior by reinforcement and punishment. Procedures such as autoshaping and classical conditioning operate only through the principles of variation, because they impose no contingency between behavior and consequence: "for all practical purposes, classical conditioning may be defined operationally as a class of reinforcement schedules that involve presentation of reinforcement independently of the subject's behavior (p. 27)." The effects are "due in part to a reinforcement schedule that happens to prescribe no correlation between the delivery of reinforcement and the subject's behavior (p. 27)." In the present context, such non-correlation procedures omit feedback. They are open-loop systems. Since this paper concerns the law of effect, or feedback, it is limited to consideration of the effects of procedures that impose a correlation between behavior and reinforcement or punishment.

Figure 3 illustrates, with hypothetical data, the relationships in a correlation. Part A shows the kind of temporal relation that characterizes a typical schedule of reinforcement. Suppose that it shows performance on a VR schedule. Time proceeds from left to right. The upper line shows the distribution of responses, the lower the distribution of reinforcements. Note that although only some responses produce reinforcement, each reinforcement follows immediately upon a response. The broken vertical lines delineate two equal time samples. The response rate in the first sample is higher than in the second. Appropriately, the rate of reinforcement also is higher in the first sample than in the second, because ratio schedules make rate of reinforcement always directly proportional to the response rate. A VR feedback function appears in Part C. Since the time samples are limited in size, they conform

only approximately to the function imposed by the schedule. When one plots the rates of reinforcement and responding from various time samples like those in Part A, they produce points like those in Part C that cluster around the ideal feedback relation, which is really the regression line of the correlation between rate of reinforcement and rate of responding.
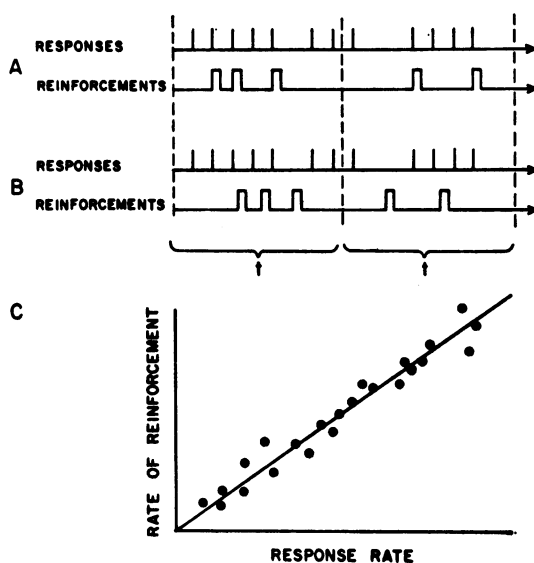

Fig. 3. Contingency as correlation. A: Close contiguity between responses and reinforcement, as in a usual schedule of reinforcement. Time progresses from left to right. The broken vertical lines delimit two equal time samples. B: Correlation without close contiguity. The rates of responding and reinforcement in the two time samples are the same as in A. C: An example of a correlation—the relation between rate of reinforcement and response rate imposed by a variable-ratio schedule. See text for explanation.

According to the traditional view of reinforcement, responding on such a schedule depends on the close contiguity between some responses and reinforcement. The correlation-based law of effect suggests that simple response-reinforcer contiguity cannot account for instrumental behavior—that the molar relation between responding and reinforcement is crucial. It does imply a definite role for contiguity, however. We will discuss the relationship between contiguity and correlation a little later. First, since most writing on the law of effect has emphasized response-reinforcer contiguity, whereas the correlation-based view calls for its de-emphasis, we must assess the adequacy of the contiguity-based law of effect.

B. The Contiguity-Based Law of Effect

Thorndike's (1911) original statement of the law of effect reads:

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

Two underlying notions about behavior are apparent: first, that strengthening depends on close contiguity between response and reinforcement ("satisfaction"), and second, that response and reinforcement should be conceived as discrete events, occurring at certain moments in time. The two ideas are logically connected. Temporal contiguity between events presupposes a point in time at which they coincide. These notions have long historical momentum, because contiguity and momentary events are basic to description of behavior as composed of reflexes. It is not surprising, therefore, that psychologists after Thorndike (*e.g.,* Hull, Skinner, Spence, and Mowrer) conceived of instrumental behavior as the outcome of pairing of momentary events.

This approach has been criticized recently along three lines. One line would focus on the phrase "of several responses" in Thorndike's statement. It suggests that all responses are equally susceptible to strengthening by a given reinforcer. Recent work has shown, however, that a reinforcer usually is more effective in strengthening some responses than others (Breland and Breland, 1961; Seligman, 1970; Staddon and Simmelhag, 1971). Although phylogenetic biases may constrain the law of effect in important ways, they bear little on the theme of this paper, because our concern is not to delimit, but better to describe.

A second line of criticism attacks the concepts of discrete response and reinforcement. We will consider this in the next section, when we discuss the molar view of behavior and consequences.

The third line of criticism, perhaps the most fundamental, questions the adequacy of contiguity itself. The arguments have arisen from the study of two separate phenomena: avoidance and conditioned reinforcement.

1. Avoidance

The observation that organisms avoid unfavorable events poses a serious problem for the requirement of reinforcement contiguity in the law of effect. A man will not only flee a fire in his house; he will take precautions against fire. A rat will not only jump out of a chamber in which it is being shocked; it will jump out of a chamber in which it has been shocked in the past, if by doing so it avoids the shock. In both examples, no obvious reinforcement follows the behavior to maintain it. How then is the law of effect to account for avoidance?

2. Two-Factor Theory

Although the contiguity-based law of effect cannot explain avoidance, it does provide a simple explanation for escape. The way to account for avoidance was to recast it as escape: to suppose some unobservable reinforcer contiguous with the response. If an animal were exposed to electric shock, the stimuli associated with the shocks might, through Pavlovian conditioning, come to evoke much the same autonomic reaction (*e.g.,* "fear") as electric shock. The responses that terminated the conditioned aversive stimuli and the reaction they produced would be maintained by negative reinforcement. Thus, avoidance could be thought of as escape maintained by conditioned negative reinforcement ("fear" reduction).

This theory of avoidance, known as two-factor theory, because it appealed to both classical and instrumental conditioning, has been thoroughly reviewed and criticized by Herrnstein (1969). It quickly encountered difficulty in the observation that avoidance could be maintained in the absence of termination of any obvious exteroceptive conditioned aversive stimuli (Sidman, 1963). To account for such performances, two-factor theorists had to postulate unobserved conditioned aversive stimuli in addition to unobserved reinforcement (*e.g.,* Anger, 1963). This modification, Herrnstein said, made the theory irrefutable, because it could no longer be subjected to empirical test.

As an alternative explanation of avoidance, Herrnstein offers the simple proposition that the behavior can be acquired and maintained by reduction in frequency of aversive stimulation. An experiment by Herrnstein and Hineline (1966), in which rats were trained to press a lever solely in order to reduce the frequency

of unavoidable shocks, supports his thesis. Herrnstein views avoidance, therefore, as acquired and maintained through negative reinforcement, which he defines as reduction in frequency of aversive stimulation. It follows that the conditioned stimulus in discriminated avoidance and the passage of time in free-operant avoidance (Anger, 1963) need not be thought of as conditioned aversive stimuli. Instead, Herrnstein suggests, these stimuli serve simply as cues or signals to the organism. They are discriminative stimuli correlated with the contingency between responding and reduction in frequency of aversive stimulation.

3. Conditioned Reinforcers

Not every response in a sequence need be reinforced for the behavior to be acquired or maintained. This commonplace observation poses difficulty for the requirement of response-reinforcement contiguity. The carpenter building a house does not demand food after every nail he drives. He does not require reinforcement at each new stage of construction. And when he is done, he will accept inedible money in place of food.

Although the problems posed by behavioral chains and avoidance may appear to differ, at least superficially, the solutions accepted have been highly similar. If stimuli paired with aversive stimulation can become conditioned aversive stimuli, then stimuli paired with reinforcement can become conditioned reinforcers. An associative process like Pavlovian conditioning played a crucial role in both explanations.

A neutral stimulus, according to this view, after numerous pairings with a primary reinforcer, acquires reinforcing capability of its own, through a purely associative process similar to Pavlovian conditioning. Indeed, the basic notion was originally Pavlov's (1927), since secondary reinforcement was implicit in secondary conditioned reflexes.

The explanation for the maintenance of behavior chains proposes that the stimuli correlated with each link in the chain serve as a reinforcer for the behavior in the previous link that produces them. Since the stimuli produced are discriminative stimuli for the next link in the chain, conditioned reinforcers are generally, if not always, discriminative stimuli.

This conception of chaining has been so widely accepted that some authors have used it to explain complex behavioral sequences in which no exteroceptive discriminative stimuli appear. Ferster and Skinner (1957), for example, explained performances on both fixed-interval (FI) and fixed-ratio (FR) schedules as chains. They suggested that FI performance, in which responding is absent for a period after reinforcement and then accelerates to a moderate response rate, was mediated by a chain of behavior, only some of which was recorded by the apparatus. After reinforcement, a pigeon might, for example, walk around in a circle several times before pecking the response key, then circle a few more times, peck again, circle again, peck again, and gradually circle less and peck more, until it is only pecking.

The unrecorded behavior (circling here), Ferster and Skinner suggested, could function as a crude "clock" to mediate the apparent temporal discrimination in FI performance. In a similar vein, they proposed that FR performance, in which the ratio requirement is met by a rapid run of responses up to reinforcement, depends on the animal's "counting" its responses, each response producing a change in an interoceptive discriminative stimulus analogous to the reading of a counter. The progress of the stimulus along a continuum from its state at zero pecks to its state at reinforcement, they asserted, maintains the run of responses through conditioned reinforcement: ". . . at any point during a fixed ratio, a response may be reinforced because it increases the number and advances this stimulus toward the reinforced end of the continuum." (1957, p. 40).

In contrast, they explained performance on variable-interval (VI) or variable-ratio (VR) schedules, in which reinforcement occurs irregularly in relation to time and behavior, without appeal to conditioned reinforcement. They suggested instead that the rate of reinforcement produced by a VI schedule serves as a discriminative stimulus for responding (1957, p. 362), and that VR performance results simply from differential reinforcement of high response rates (1957, p. 391). The notions that a rate of reinforcement is a dimension of the environment that can acquire stimulus control and that rate of responding is a dimension of performance that can be differentiated accord well with the viewpoint of this paper. We will discuss such non-momentary (molar) dimensions a little later.

More recent work on FI and FR perform-
ance has sought explanations beyond the level
of momentary response and reinforcements.
The explanation of FI performance as a chain
has been discredited. Dews (1962, 1965) has
shown that the characteristic pattern of re-
sponding persists when periods of timeout
break up the interval and interrupt respond-
ing. B. A. Schneider (1969) showed that, after
extensive training, a fixed-interval becomes
functionally equivalent to a period of extinc-
tion followed by variable-interval reinforce-
ment. Both Dews and Schneider suggest that
FI performance depends on more molar as-
pects of the experimental situation than mo-
mentary response-generated stimuli.

The move from momentary control of be-
havioral sequences parallels the move from
momentary control of avoidance. Just as one
may question the necessity of attributing he-
donic value to the stimuli for avoidance, one
may question the necessity of attributing he-
donic value to the stimuli in a chain (positive
two-factor theory). If the stimuli in avoidance
serve only a discriminative function, and the
behavior is maintained by the correlation be-
tween responding and shock-rate reduction,
then the stimuli in a chain also may serve only
a discriminative function, and the behavior be
maintained by the correlation between re-
sponding and rate of reinforcement.

An experiment by Schuster (1969) directly
attacked the notion of conditioned reinforcers.
He gave pigeons a choice between two equal
VI schedules of food reinforcement, one of
which provided extra presentations of the
stimuli paired with food delivery, on a super-
imposed FR schedule. The birds developed an
aversion for the schedule with the extra pre-
sentations of the stimuli paired with food. If
these stimuli acted as a conditioned reinforcer
—if they had hedonic value—the birds should
have perferred the schedule with the extra
presentations. Instead, they chose the schedule
in which the stimuli were more reliably paired
with food. Schuster concluded that stimuli cor-
related with reinforcement exert control over
behavior that produces them, not because they
acquire reinforcing properties of their own,
but only because they signal the availability of
reinforcement[2].

J. W. Schneider (1972) cast still more doubt
on the notion of conditioned reinforcers. He
gave pigeons a choice between two alternatives,
each consisting of two chained VI schedules.
He maintained one chain constant, and varied
the lengths of the components in the other.
The birds' responding on the varied chain
changed appropriately as the components
changed: longer and earlier components sus-
tained lower rates of responding. Although the
behavior was clearly under control of the
chain stimuli, the birds were indifferent in
their choice between the two chains as long as
the chains provided the same overall rate of
primary reinforcement. Regardless of the
lengths of the components, the chains were
equivalent when the sums of their components
were equal. If the response-produced stimuli
in the chains possessed reinforcing value of
their own, one would expect their value to
vary with the lengths of the components, even
if the overall time to primary reinforcement
were constant. Since the pigeons remained in-
different, one cannot suppose the stimuli had
reinforcing value that simply added to the
value of the food. A theory of conditioned rein-
forcers could explain the simple summing of
times that Schneider found only with great
complexity.

It seems, therefore, that the stimuli in a
chain serve a discriminative function, but not
a reinforcing function. As with conditioned
aversive stimuli, conditioned reinforcers can
be treated simply as discriminative stimuli
without hedonic value.

If we are to do without the concept of condi-
tioned reinforcer, how can we account for the
observation that originally inspired the con-
cept? Long sequences of behavior remain in-
tact, even though only the terminal response is
actually reinforced. Schuster (1969) pointed
out that the nature of the stimuli controlling
behavior in the sequential links of a chain can

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[2]A recent review by Gollub (1970) overlooked the sig-
nificance of this experiment. Since the extra stimulus

presentation produced a higher response rate, Gollub
concluded: "This experiment does not . . . invalidate
any particular theory of reinforcement, but rather cor-
roborates Fantino (1968) that higher response rates in a
terminal link produce lower preferences in the initial
links" (p. 367). Herrnstein (1964) and Autor (1969)
showed, however, that when high response rates are
not *required,* there is no relationship between response
rate and choice. Schuster's experiment does, therefore,
invalidate theories of conditioned reinforcers, because
the added stimulus presentations failed to enhance
preference.

be understood in terms of the functions that these stimuli serve in the maintenance of the organism. That is, the stimuli in a chain exert control by virtue of their relation to reinforcement. They signal that reinforcement is either closer in time or imminently available. The entire chain is organized around its ultimate outcome; the stimuli act as the cement of this organization. We will return to this question when we consider redefinition of reinforcement and punishment.

The attacks on positive and negative two-factor theory have a similar thrust. They suggest that the strict requirement of contiguity between responses and reinforcement espoused by Thorndike, Skinner, and others unnecessarily complicates the accounts of such basic phenomena as avoidance and chaining. Greater flexibility and simplicity prevails when the law of effect is stated in terms of correlation: behavior increases in frequency if the increase is correlated with an increase in rate of reinforcement or a decrease in rate of aversive stimulation.

C. CONTIGUITY AND CORRELATION

The notion that close contiguity is necessary to the law of effect has been supported by the recognition that delay substantially reduces the effectiveness of a reinforcer. It must be understood, however, that greater delays of reinforcement usually ensure lower rates of reinforcement, as well. Chung and Herrnstein (1967), for example, studied pigeons' choices between two delayed reinforcers. Responses at each alternative produced a blackout followed by food. The experimenters varied the durations of the blackout. They found that the relative responding at the alternatives matched their relative immediacies of reinforcement, when immediacy was defined as the reciprocal of the delay. It can be seen, however, that the reciprocal of the delay of reinforcement is a rate of reinforcement: the rate of reinforcement during the delay stimulus conditions. The alternatives could be viewed as two chains, each having a terminal link consisting of response-independent reinforcement at a rate specified by the duration of the blackout. Autor (1969) showed that response-independent reinforcement is functionally equivalent to the usual response-contingent reinforcement in such a choice situation. One can say, therefore, that the pigeons' choices were governed

not by the delays of reinforcement but by the rates of reinforcement in the terminal links of the alternative chains. Many studies of delay of reinforcement lend themselves to a similar analysis (*e.g.*, Logan, 1960).

Some few studies of delay, however, do require interpretation in terms of response-reinforcement contiguity. Such procedures omit exteroceptive stimuli signalling the delay. Dews (1960), for example, trained pigeons to peck a key for reinforcements that occurred at a delay, unsignalled and independent of intervening responses. With such a procedure, the interval between a response and a reinforcement can vary from zero, if a response occurs just at the same moment as a delayed reinforcement, up to the scheduled delay, if no responses intervene between the reinforced response and reinforcement. Although reinforcement depends on responding, the contiguity between responses and reinforcements is poor—the longer the delay, the poorer the contiguity. Since Dews found, in general, that the longer was the delay the lower was the response rate, it seems clear that response-reinforcement contiguity can affect performance.

At first glance, this observation might appear incompatible with the correlation-based view. It only illustrates, however, that contiguity plays an important role within a correlation. Figure 3 makes it clear that some temporal grouping of responding and reinforcement is necessary for a correlation to exist. The smaller the duration of a sample, the closer the temporal grouping must be to maintain a correlation. The poorer the grouping, the poorer the correlation. The usual method of scheduling reinforcement, which makes each instance of reinforcement contiguous with a response (Figure 3A), makes for close temporal grouping of responding and reinforcement. Response-reinforcement contiguity, therefore, ensures a good correlation between output and feedback. It minimizes the variability around the regression function (Figure 3C).

Figure 3 suggests that contiguity may act through its effect on correlation, because poorer contiguity means more variability around the feedback (regression) function. It is possible that all effects of varying contiguity are due solely to the resulting variation in goodness of correlation (as measured by the variance around the regression function). In this way, although correlation determines per-

formance, contiguity still retains a role as a parameter.

How important is close response-reinforcement contiguity? Temporal grouping is still possible without it. Part B of Figure 3 illustrates performance produced by a schedule in all respects like a variable-ratio, except that reinforcements do not necessarily follow immediately upon a response. The situation can be likened to pressing a slightly faulty elevator button. The button has to be pressed several times to summon the elevator reliably. The elevator comes only when one presses the button, but only after a variable delay. It is also true, within limits, that the more often one summons the elevator the more often it comes. Note that, just as in Part A, the higher response rate of the first time sample in Part B is associated with a higher rate of reinforcement. The points on the graph of Part C would be

exactly the same from the schedule in Part B as from the schedule in Part A.

Is performance on the schedule of Figure 3B comparable to usual VR performance? Such schedules do indeed maintain responding, but poorer response-reinforcement contiguity produces lower and more erratic rates of responding. A computer samples response rates in equal successive intervals, and adjusts the rate of reinforcement in each interval to be directly proportional to the response rate in the one before. When the duration of the sampling interval is changed, the proportionality, and therefore the regression line, is held fixed. As a result, increasing the sampling interval loosens the correlation, whereas decreasing the sampling interval tightens it.

Figure 4 shows some sample performances of two pigeons, drawn from the last days of exposure to the conditions, during which day-to-
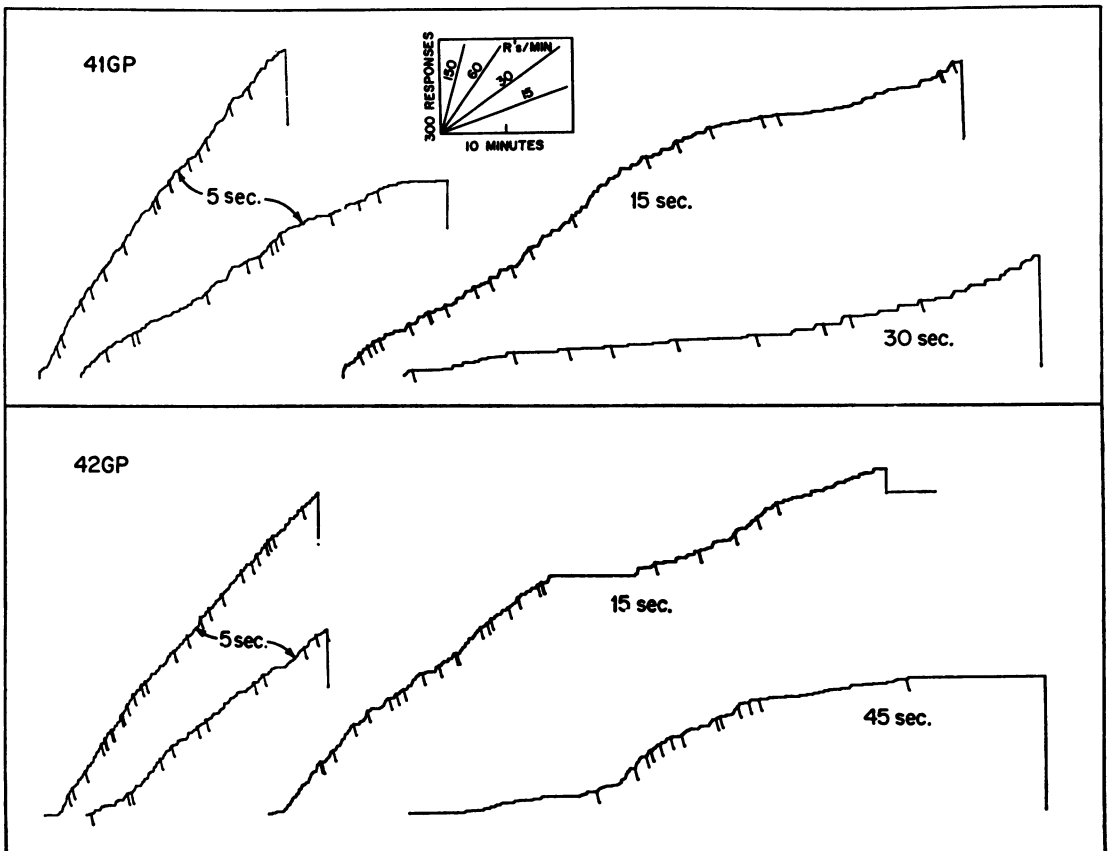

Fig. 4. Cumulative records of performances of two pigeons, 41GP and 42GP, with three different sampling intervals (durations given in seconds) for adjusting rate of reinforcement to be proportional to response rate. The proportionality maintained is that of a VR 40. Each record shows an entire day's session. Sessions ended either after 40 reinforcements or 48 min. Downward deflections of the pen indicate reinforcements (4 sec access to grain). For further explanation, see text.

day variation in response rate appeared stable. Three basic features of the procedure can be seen in the records. First, comparison of the slopes with the densities of reinforcement marks in various segments reveals the positive relation between responding and reinforcement. Second, as the sampling interval increased, reinforcement during a period of pausing became more frequent, and the pauses preceding such reinforcements grew longer. Loosening the correlation, therefore, had the side-effect of decreasing response-reinforcer contiguity. Third, as the duration of the sampling interval increased, and goodness of correlation decreased, response rate decreased. The less precise the correlation, the less it controls responding.

Herrnstein (personal communication) has done an experiment that further illustrates the lack of need for close response-reinforcer contiguity. In the absence of responding, reinforcements occurred at a low rate. Responding switched the animals to a higher rate of reinforcement, but still reinforcements occurred with irregular temporal relation to responses. The schedule produced acquisition and stable rates of responding.

The performances shown in Figure 4, Herrnstein's results, and Dew's (1960) results all support the conclusion that poor response-reinforcer contiguity reduces responding, but cannot eliminate it. As long as it produces food, responding persists. The correlation between responding and reinforcement stands out as the essential ingredient in instrumental behavior.

Can one do an experiment to separate the effects of contiguity and correlation? Since contiguity cannot vary without affecting goodness of correlation, it would be necessary to hold contiguity constant while varying correlation. One might, for example, study different correlations within a family (*e.g.*, Figures 2 and 4), or correlations from different families, trying to find or create situations in which delay of reinforcement, though greater than zero, remained invariant.

Although it may prove difficult to distinguish correlation and contiguity empirically, there are non-empirical reasons for favoring a law of effect based on correlation. The concept of correlation as embodied in feedback functions can be useful for describing contingencies, particularly in complex and natural situations,

and as a means of developing a comprehensive theory of instrumental behavior. It applies readily to procedures such as avoidance, in which the absence of discrete consequences contiguous with responses requires awkward theorizing about unobservable events for the assumption of contiguity to hold. The concept of correlation has the additional advantage that it draws together apparently diverse procedures into a single conceptual framework. Positive reinforcement, punishment, avoidance, negative reinforcement, and DRO (punishment of responding by imposing a negative correlation between response rate and rate of reinforcement) can all be described in terms of feedback functions. Discrete-trial procedures and free-operant procedures, classical conditioning and instrumental conditioning, continuous reinforcement and intermittent reinforcement, all can be described and related within this framework. Even if it should prove impossible to distinguish experimentally between contiguity and correlation, the weight of conceptual power and simplicity seems to lie with correlation.

IV. THE MOLAR VIEW

A. MOLAR BEHAVIOR

According to the contiguity-based law of effect, an organism's behavior consists of a sequence of the various responses that the organism can make. Since the responses are discrete and distinguishable from one another, the most direct method for assessing the composition of this sequence over any particular period of time (*e.g.*, an experimental session) is to count the number of instances of each response under study.

For the requirement of response-reinforcement contiguity, it is sensible, even necessary, to assume discrete momentary responses. When we recognize that responding enters into a more molar relation with reinforcement, that contiguity is not essential, the need for assuming discrete responses disappears. The notion of correlation and the description of instrumental behavior as part of a feedback system require instead that we characterize both behavior (output) and consequences (reinforcement, punishment, and response cost: feedback) on a more molar level, transcending the momentary. As noted earlier, the concept of continuous exchange between

organism and environment implies measurement that extends over time.

Procedures have begun to appear in which the conditions of reinforcement preclude the assumption of discrete responses. Brownstein and Pliskoff (1968) presented reinforcers to pigeons at variable intervals simply for being in the presence of either of two different colored lights. Each light was correlated with a particular rate of reinforcement. As long as a bird remained in the presence of a light, it continued to receive reinforcers at the light's rate of reinforcement. It could change from one color to the other by pecking a response key. Brownstein and Pliskoff found that the times spent in the presence of the lights depended in a simple and orderly way on the rate of reinforcement: the ratio of the times equalled the ratio of the rates of reinforcement. Baum and Rachlin (1969) found a similar relation between the times spent in two locations and the rates of reinforcement for being in those two locations. In both experiments, the pigeons apportioned their time between two alternatives according to the same matching law that applies to concurrent reinforcement for pecking; the proportion of time allocated to each alternative matched the relative rate of reinforcement for that alternative.

Baum and Rachlin (1969) argued that such laws of time allocation are more generally applicable than laws of response allocation, because the collective response times of discrete responses, such as key pecks or lever presses, which are highly constant in duration, are directly proportional to the number of responses. Laws of response allocation, therefore, are directly convertible to laws of time allocation. The reverse does not hold, however, because in experiments like those of Brownstein and Pliskoff (1968) and Baum and Rachlin (1969), no empirical basis exists for defining a discrete response to make the conversion from time to responses. Extending the argument, one would state the law of effect as a relation between the time spent in an activity (*e.g.*, key pecking, being in a certain location, lever holding) and the rate of reinforcement produced by that activity.

Regardless of how we measure response frequency, whether as response rate or as proportion of time spent responding, it is a variable that must be sampled and averaged over time. Since it transcends particular instances of discrete responses, it can be called a molar variable that enters into a molar relation (correlation) with another molar variable, the consequence (*e.g.*, rate of reinforcement, rate of aversive stimulation, *etc.*).

B. Molar Consequences

Much of the recent interest in rate of reinforcement as an independent variable stems from Herrnstein's (1961) finding that, in a choice between two concurrent variable-interval schedules, pigeons matched the proportion of their responses to each alternative to the relative rate of reinforcement produced by the alternative. This matching law, now well substantiated, has been obtained in a wide variety of situations (*e.g.*, Herrnstein, 1964; Catania, 1963 *a* and *b;* Shull and Pliskoff, 1967; Brownstein and Pliskoff, 1968; Baum and Rachlin, 1969; see Herrnstein, 1970, for overview).

Rate of reinforcement, like response frequency, is a variable that, by definition, must be sampled over a substantial period of time. Any variable that fails to reduce to a discrete event in time implies an averaging or integrating capability on the part of the organism. Such integrating must be commonplace in an organism's reactions to its environment, because responding rarely, if ever, depends solely on a present situation. Past experience almost always plays a large role. Averaged variables like rate of reinforcement or rate of punishment (Schuster and Rachlin, 1968), therefore, suggest an analogy to a complex system, in which input data are collected over intervals of time into aggregates, and then processed as aggregates, rather than individually. Computer systems, for example, typically treat data in this manner. Such integration occurs commonly in mechanical systems as well. The continuous movement of an automobile, for instance, depends on a succession of discrete explosions in its engine. In a like manner, an organism can be viewed as collecting time samples of the significant events in its environment (*e.g.*, reinforcers and punishers), which it integrates and utilizes to control its behavioral output. The exact nature of this integrating or averaging process has been the subject of some recent research (Killeen, 1968; Davison, 1969; Duncan and Fantino, 1970; Schneider, J. W., 1970).

Feedback to a behaving organism is more than just reinforcers and punishers. Other

stimuli, perhaps "neutral" in themselves, but correlated with reinforcement or punishment —discriminative stimuli—also control behavior. We usually characterize discriminative stimuli solely in terms of their presence or absence. They can be viewed, however, as integrated feedback in just the same manner as reinforcers or punishers. Schuster (1969), for example, showed that rate of presentation of a discriminative stimulus can have a strong effect on pigeons' preferences in a choice situation.

The suggestion of Ferster and Skinner (1957, p. 326) mentioned earlier, that responding on a variable-interval schedule depends on the rate of reinforcement acting as a discriminative stimulus, implies that the rate of occurrence, not only of a discriminative stimulus, but of a reinforcer (or punisher), can control a discrimination. One type of evidence that supports this conception is the observation that discrimination of extinction from reinforcement, measured by the number of responses made in extinction, improves with repeated extinction and reinstatement of reinforcement (e.g., Bullock and Smith, 1953). A similar improvement occurs with repeated removal and reinstatement of aversive stimulation in avoidance (Boren and Sidman, 1957).

Whatever other dimensions might characterize an event, it always will possess a rate of occurrence. Rate is the universal dimension. The rate of occurrence of a reinforcer, punisher, or discriminative stimulus can control behavior, just as the other attributes of the event can control behavior. The organism, in other words, integrates all feedback over time.

To understand the implications of this idea for our conceptions of reinforcement, punishment, and behavioral chains, we must develop two preliminary notions: value and the behavioral situation.

1. Consequences as Value

The notion of molar consequences suggests that all the various parameters of reinforcement and punishment can be drawn together into a single scale called *value*. At least two approaches to construction of such a scale have been suggested (Baum and Rachlin, 1969; Premack, 1965, 1971). Baum and Rachlin (1969) suggested that the proportion of time spent in an activity equals the relative value of the activity, that is, its value relative to the sum of

the values of all the sources (*e.g.,* all possible activities) in the situation:

$$\frac{t_1}{T} = \frac{v_1}{\sum_{i=1}^{n} v_i} \qquad (2)$$

where v_i is the value of Activity i (there are n such), t_1 is the time spent in Activity 1, and T is the total time (implicitly assumed to be exhausted by the n activities). The absolute value (v_i) of an activity is a function of the feedback it produces. It is directly proportional to rate of reinforcement (Herrnstein, 1961) and duration of reinforcement (Catania, 1963*b;* Neuringer, 1967). It may be inversely proportional to delay of reinforcement (Chung and Herrnstein, 1967). The value of an activity that decreases the frequency of electric shock appears to be directly proportional to the resultant reduction in rate of shock (de Villiers, 1972). Punishing responses with electric shock, on the other hand, reduces absolute value (Holz, 1968; Schuster and Rachlin, 1969).

For a situation in which a single activity is studied alone, Equation 2 may be simplified as follows (*cf.* Herrnstein, 1970):

$$\frac{t_1}{T} = \frac{v_1}{v_1 + v_o} \qquad (3)$$

where v_o is the sum of the values of all the activities other than v_1. In a choice situation in which two responses are studied, Equation 2 can be written:

$$\frac{t_1}{T} = \frac{v_1}{v_1 + v_2 + v_o} \qquad (4)$$

$$\frac{t_2}{T} = \frac{v_2}{v_1 + v_2 + v_o} \qquad (5)$$

Note that whereas v_o must be the same in Equations 4 and 5, v_o in Equation 3 can vary from one activity to another and is not necessarily the same as in Equations 4 and 5, because different situations will produce different values in the alternative activities (grooming, walking about, *etc.*) that are not directly controlled by the contingencies of reinforcement and punishment of the experiment. The ratio of Equations 4 and 5 produces the matching equation (Herrnstein, 1970):

$$\frac{t_1}{t_2} = \frac{v_1}{v_2} \qquad (6)$$

This states that the relative time spent in two activities equals the relative value of the two activities.

2. Value as Molar

Since the value of an activity depends on variables like rate of reinforcement and rate of punishment, which cannot be assessed at any particular point in time, but must be averaged over a period of time, the value of an activity must likewise be conceived to extend through time. In other words, since value depends on integrated feedback, an activity has value and changes value only over extended periods of time, and behavior varies with changes in value only over extended periods of time. A concept like *momentary* value could be meaningful only as the temporal derivative of value expressed as a function of time (just as momentary velocity is the derivative of distance with respect to time).

From moment to moment, however, the organism engages in one activity or another and switches from one activity to another. These moment-to-moment relationships among activities have little to do with value, because at any moment the organism may be engaging in an activity of any value; it simply engages more often in high-valued activities. The momentary fluctuations in an organism's activities result from momentary fluctuations in variables that have a constant average effect over extended periods of time (*e.g.*, deprivation).

Premack (1971) pointed out that averaged behavioral measures fail to capture momentary fluctuations that are often of interest to psychologists. During the course of a session, for example, satiation may reduce an originally high level of drinking below a low, but constant, level of wheel-running. Two activities can also differ in their temporal distribution, one producing frequent small satisfactions (*e.g.*, eating), one producing less frequent large satisfactions (*e.g.*, copulation), and yet still be of equal value and take up equal average times. In general, the study of momentary relations is compatible with the study of average relations, however; the two complement each other.

3. Behavioral Situations

A set of activities will have a corresponding set of values only under certain specified conditions. Let us call these conditions the *behavioral situation*.

A behavioral situation consists of a set of possible activities, a set of possible events or stimuli, and a set of feedback functions determining the effects of the activities on the events. Figure 1 attempted to diagram the salient features of a behavioral situation. A variable-interval schedule, for example, provides a feedback function governing reinforcement for key pecking (Figure 2). We can imagine another feedback function indicating response cost, in terms of energy expenditure and loss of opportunity for alternate reinforcement (v_0 in Equation 3). As response rate increases, response cost increases. The interaction of these two feedback functions would determine performance. This description implicitly specifies the important activities and events: key pecking, the activities that reduce response cost, and reinforcement. To complete the description, other events and stimuli, such as response feedback, keylight, and chamber size, although perhaps of lesser important, must be specified also.

Up to now we have assigned values only to *activities*. We can assign values also to *situations*. The value of a situation usually equals the sum of the values of all its possible activities. In a chain schedule, for example, an activity in one situation (link) leads to the next situation, which contains a higher-valued activity in addition to or in place of the activity in the first situation, and therefore has higher total value. The maintenance of a behavioral chain depends on this succession of situations from lower to higher value.

When a situation contains response-independent reinforcement or response-independent punishment, then the value of the situation exceeds or falls short of the sum of the activity values. Studies of chained schedules illustrate these effects of response-independent events. Autor (1969), for example, showed that the same performance holds in the initial link of a chain if the value (rate of reinforcement) of the terminal link is the same, regardless of whether the reinforcement in the terminal link is response-contingent or response-independent. Schuster and Rachlin (1968) found a similar equivalence for punishment. They studied a concurrent-chain schedule in which the two terminal links were identical, except that in one, every response produced an electric shock,

whereas in the other, electric shocks occurred at a regular rate, independent of the animal's responding. They found that preference in the initial choice link for the terminal link with response-independent shock was an inverse function of the rate of these shocks. Furthermore, the animals were indifferent between the two terminal links when the rates of shock were equal, regardless of whether the shock was response-dependent or response-independent. Assuming that the responding in the initial link reflects the values of the terminal links, these results suggest that the value of a *situation* depends simply on rate of punishment and rate of reinforcement, regardless of whether the punishment and reinforcement arise from behavior. The value of an *activity*, on the other hand, depends entirely on its producing reinforcement and punishment. In the terminal link with response-produced shocks, for example, the rate of responding was low, whereas in the terminal link with response-independent shocks, the rate of responding was high and largely independent of the rate of shock. The denominator of Equation 2 should represent the value of the situation, rather than the sum of the values of the activities (Rachlin and Baum, 1972).

4. Definition of Reinforcement and Punishment

Now that we have developed the notions of value and situation, we can redefine reinforcement and punishment in terms consistent with the correlation-based law of effect. Reinforcement can be viewed as a transition from a lower-valued situation to a higher-valued situation. A simple schedule of reinforcement, for example, periodically produces a situation in which eating is possible—a maximal-valued situation for a hungry organism. Rate of reinforcement, therefore, could be thought of as rate of situation transition—that is, rate at which, in a lower-valued situation, transitions into a higher-valued situation occur.

Punishment can be viewed as the converse of reinforcement—that is, transition from a higher-valued situation to a lower-valued situation. Punishment by timeout from reinforcement arranges such a situation transition. Electric shock or another noxious event can be thought of as a low-valued situation, even if briefly presented.

A behavioral situation can be likened to a room with several exit doors. The value of the situation depends on what other situations lie behind the doors. The feedback functions control parameters such as frequency and duration of exits. The organism might, for example, find itself thrust briefly through the door to a situation including electric shock, and then returned. Or it might be moved into another situation, remain there for a time, and then exit from that one into a third situation.

This conception of reinforcement and punishment depends on a generalized notion of chaining. It suggests that instrumental behavior can be viewed as moving the organism through *chains of situations*. Where we conceive a chain to stop may be a matter of convenience. We generally stop at the last measurable event outside the organism's skin. Food presentation to a hungry animal, for example, we usually consider a terminal situation, even though it makes eating possible. Electric shock is seen as a brief presentation of a highly unfavorable situation, even though it stimulates pain receptors and produces autonomic responses. These stopping places are probably arbitrary, at least in principle.

Describing instrumental behavior in terms of chains of situations accords well with the view that conditioned reinforcers have no hedonic quality of their own, but serve rather as signals providing information about availability of reinforcement and punishment. In fact, we can define a *discriminative stimulus* as a signal of a situation transition—that is, a stimulus correlated with a situation transition. Examples would be the CS in discriminated avoidance, as well as the change of stimulus in chained schedules.

On this view, behavioral chains are maintained by reinforcement, because transition from a situation further from the terminal situation to one nearer the terminus, and thus higher-valued, constitutes reinforcement. This would be *conditioned* reinforcement insofar as the development of the chain depends on experience. Note, however, that to call a situation transition conditioned reinforcement is not to call the stimulus signalling it a conditioned reinforcer. The new situation might be a conditioned reinforcer, but the discriminative stimulus would not (Schuster, 1969; Schneider, J. W., 1972). The situation transitions, not the discriminative stimuli, maintain a behavioral chain.

Schuster's (1969) experiment, in which pigeons preferred the situation with the more reliable signal, suggest that discriminative stimuli play a purely informative role. Other experiments also have shown that, in the absence of any difference in primary reinforcement, animals prefer a situation with informative stimuli (*e.g.*, Bower, McLean, and Meacham, 1967; Wilton and Clements, 1971). Such stimuli may be of use to the organism in permitting it to perform most efficiently; that is, with no surplus of energy expenditure or sacrifice of reinforcement.

V. CONCLUSION

If, as recent research (*e.g.*, Herrnstein, 1969, 1970; Staddon and Simmelhag, 1971) suggests, we drop the contiguity-based law of effect in favor of a law based on molar correlation, many benefits ensue. We can arrive at an integrated understanding of various procedures, such as avoidance, chained schedules, superstition, and classical conditioning. And we can define the concepts of reinforcement, punishment, and discriminative stimulus in a manner that clarifies the relationships among them. This view has been, and promises still to be, highly productive.

REFERENCES

Anger, D. The role of temporal discriminations in the reinforcement of Sidman avoidance behavior. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 477-506.

Autor, S. M. The strength of conditioned reinforcers as a function of frequency and probability of reinforcement. Doctoral dissertation, Harvard University, 1960. Reprinted in D. P. Hendry (Ed.), *Conditioned reinforcement*. Homewood, Illinois: Dorsey Press, 1969. Pp. 127-162.

Baum, W. M. and Rachlin, H. C. Choice as time allocation. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 861-874.

Bloomfield, T. M. Reinforcement schedules: contingency or contiguity? In R. M. Gilbert and J. R. Millenson (Eds.), *Reinforcement*. New York: Academic Press, 1972. Pp. 165-208.

Boren, J. J. and Sidman, M. A discrimination based upon repeated conditioning and extinction of avoidance behavior. *Journal of Comparative and Physiological Psychology*, 1957, 50, 18-22.

Bower, G., McLean, J., and Meacham, J. Value of knowing when reinforcement is due. *Journal of Comparative and Physiological Psychology*, 1967, 62, 184-192.

Breland, K. and Breland, M. The misbehavior of organisms. *American Psychologist*, 1961, 16, 681-684.

Brownstein, A. J. and Pliskoff, S. S. Some effects of relative reinforcement rate and changeover delay in response-independent concurrent schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 683-688.

Bullock, D. H. and Smith, W. C. An effect of repeated conditioning-extinction upon operant strength. *Journal of Experimental Psychology*, 1953, 46, 349-352.

Catania, A. C. Concurrent performances: reinforcement interaction and response independence. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 253-263. (*a*)

Catania, A. C. Concurrent performances: a baseline for the study of reinforcement magnitude. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 299-300. (*b*)

Catania, A. C. and Reynolds, G. S. A quantitative analysis of the responding maintained by interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 327-383.

Chung, S. and Herrnstein, R. J. Choice and delay of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1967, 10, 67-74.

Davison, M. C. Preference for mixed-interval *versus* fixed-interval schedules. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 247-252.

de Villiers, P. A. Reinforcement and response rate interaction in multiple random-interval avoidance schedules. *Journal of the Experimental Analysis of Behavior*, 1972, 18, 499-507.

Dews, P. B. Free-operant behavior under conditions of delayed reinforcement. I. CRF-type schedules. *Journal of the Experimental Analysis of Behavior*. 1960, 3, 221-234.

Dews, P. B. The effect of multiple SΔ periods on responding on a fixed-interval schedule. *Journal of the Experimental Analysis of Behavior*, 1962, 5, 369-374.

Dews, P. B. The effect of multiple SΔ periods on responding on a fixed-interval schedule: III. Effect of changes in pattern of interruptions, parameters, and stimuli. *Journal of the Experimental Analysis of Behavior*, 1965, 8, 427-435.

Duncan, B. and Fantino, E. Choice for periodic schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1970, 14, 73-86.

Fantino, E. Effects of required rates of responding upon choice. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 15-22.

Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.

Gollub, L. R. Information on conditioned reinforcement. *Journal of the Experimental Analysis of Behavior*, 1970, 14, 361-372.

Herrnstein, R. J. Relative and absolute strength of response as a function of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1961, 4, 267-272.

Herrnstein, R. J. Secondary reinforcement and rate of primary reinforcement. *Journal of the Experimental Analysis of Behavior*, 1964, 7, 27-36.

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

Herrnstein, R. J. On the law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 243-266.

Herrnstein, R. J. and Hineline, P. N. Negative reinforcement as shock-frequency reduction. *Journal of the Experimental Analysis of Behavior,* 1966, 9, 421-430.

Holz, W. C. Punishment and rate of positive reinforcement. *Journal of the Experimental Analysis of Behavior,* 1968, 11, 285-292.

Killeen, P. On the measurement of reinforcement frequency in the study of preference. *Journal of the Experimental Analysis of Behavior,* 1968, 11, 263-269.

Logan, F. A. *Incentive.* New Haven: Yale University Press, 1960.

Morgan, C. L. *An introduction to comparative psychology.* London: W. Scott Ltd., 1894.

Neuringer, A. J. Effects of reinforcement magnitude on choice and rate of responding. *Journal of the Experimental Analysis of Behavior,* 1967, 10, 417-424.

Pavlov, I. P. *Conditioned reflexes.* New York: Dover, 1927.

Premack, D. Reinforcement theory. In D. Levine (Ed.), *Nebraska Symposium on Motivation.* Lincoln: University of Nebraska Press, 1965. Pp. 123-180.

Premack, D. Catching up with common sense, or two sides of a generalization: reinforcement and punishment. In R. Glaser (Ed.), *The nature of reinforcement.* New York: Academic Press, 1971. Pp. 121-150.

Rachlin, H. and Baum, W. M. Response rate as a function of amount of reinforcement for a signalled concurrent response. *Journal of the Experimental Analysis of Behavior,* 1969, 12, 11-16.

Rachlin, H. and Baum, W. M. Effects of alternative reinforcement: does the source matter? *Journal of the Experimental Analysis of Behavior,* 1972, 18, 231-241.

Schneider, B. A. A two-state analysis of fixed-interval responding in the pigeon. *Journal of the Experimental Analysis of Behavior,* 1969, 12, 677-687.

Schneider, J. W. *Conditioned reinforcement and delay of reinforcement in concurrent-chain schedules.* Doctoral dissertation, Harvard University, 1970.

Schneider, J. W. Choice between two-component chained and tandem schedules. *Journal of the Experimental Analysis of Behavior,* 1972, 18, 45-60.

Schuster, R. H. A functional analysis of conditioned reinforcement. In D. P. Hendry (Ed.), *Conditioned reinforcement.* Homewood, Illinois: Dorsey Press, 1969. Pp. 192-234.

Schuster, R. and Rachlin, H. Indifference between punishment and free shock: evidence for the negative law of effect. *Journal of the Experimental Analysis of Behavior,* 1968, 11, 777-786.

Seligman, M. E. P. On the generality of the laws of learning. *Psychological Review,* 1970, 77, 406-418.

Seligman, M. E. P., Maier, S. F., and Solomon, R. L. Unpredictable and uncontrollable aversive events. In F. R. Brush (Ed.), *Aversive conditioning and learning.* New York: Academic Press, 1971. Pp. 347-400.

Shull, R. L. and Pliskoff, S. S. Changeover delay and concurrent schedules: some effects on relative performance measures. *Journal of the Experimental Analysis of Behavior,* 1967, 10, 517-527.

Sidman, M. Two temporal parameters of the maintenance of avoidance behavior by the white rat. *Journal of Comparative and Physiological Psychology,* 1953, 46, 253-261.

Skinner, B. F. *The behavior of organisms.* New York: Appleton-Century-Crofts, 1938.

Staddon, J. E. R. and Simmelhag, V. L. The "superstition" experiment: a reexamination of its implications for the principles of adaptive behavior. *Psychological Review,* 1971, 78, 3-43.

Ten Eyck, R. L. Effects of rate of reinforcement-time upon concurrent operant performance. *Journal of the Experimental Analysis of Behavior,* 1970, 14, 269-274.

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

Wilton, R. N. and Clements, R. O. Observing responses and informative stimuli. *Journal of the Experimental Analysis of Behavior,* 1971, 15, 199-204.