Relative Frequency and Temporal Contiguity as Factors in Animal Learning: A Critical Evaluation ¹

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Abstract

Recent theorists have suggested that organisms are sensitive to and are controlled by the relative frequency of events occurring in the presence and absence of other events. The present paper focuses on this proposition as applied to Pavlovian conditioning where it is known as the contingency view. The paper attempts to distinguish this view from an older approach, the contiguity view, which emphasizes the importance of the temporal contiguity between events. The relative merits and limitations of these views are evaluated. It is concluded that the older, contiguity view is more parsimonious and has greater predictive and explanatory power.

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In the last few years these pages have contained major theoretical statements of writers proposing that animals are sensitive to or are controlled by the relative frequencies of events in the presence and absence of other events. In the Pavlovian conditioning literature, for example, it has been suggested that exposure to a positive CS:US contingency is a necessary and sufficient condition for Pavlovian excitatory conditioning. Such a contingency exists when, in a sequence of CS and US events, the relative frequency of USs is greater in CS presence than CS absence. The converse of this state of affairs-called a negative CS:US contingency-is held to be necessary and sufficient for inhibitory conditioning. When no CS:US contingency exists, that is, when the overall likelihood of a US is the same in the presence and absence of the CS, little or no conditioning is expected (Rescorla, 1967). In this view, either excitatory or inhibitory conditioning occurs when an organism detects a difference in the relative frequency with which USs occur in the presence and absence of CSs.

A similar view has also been recently advanced in the field of avoidance conditioning. In this view (e.g., Herrnstein, 1969; Sidman, 1962) the criterion (avoidance) behavior is learned and maintained to the extent that the relative frequency of aversive stimulation is lower in the presence of the behavior than in its absence. If the overall likelihood of aversive stimulation is the same in the presence and absence of the behavior, then no systematic change in the behavior is expected over time. In this view, then, avoidance conditioning occurs when the organism detects a difference in the relative frequency with which aversive stimuli occur in the presence and absence of his behavior.

The great beauty of relative frequency approaches to animal learning lies in their descriptive simplicity from the experimenter's point of view. The experimenter schedules stimuli to occur with different frequencies in the presence and absence of other stimuli (or responses), and this schedule is easy for him to describe. However, while the demands of relative frequency views on the experimenter are small, the demands on his subjects are not. They must have a long memory for the events of their past in order to compare the relative frequency of events now with what they were some time ago. In a Pavlovian experiment, for example, an animal receiving USs distributed throughout some CS must remember how frequently USs occurred before the CS came on and compare this frequency with the frequency of USs occurring now. In an avoidance experiment, an animal emitting some criterion avoidance behavior must remember how frequently aversive events occurred before he began responding and compare this frequency with the frequency of those events during or shortly after responding.

An alternative to the view that behavior is determined by the relative frequency of events in the presence and absence of other events is the view that behavior is determined by the temporal contiguity between events. A major proponent of this view in the classical conditioning literature was Pavlov. He asserted that, "The fundamental requisite ... [for classical conditioning] is that [the conditioned stimulus] must overlap in point of time with the action of an unconditioned stimulus. [And] ... it is also equally necessary that the conditioned stimulus should begin to operate before the unconditioned stimulus comes into action (Pavlov, 1960, pp. 26-27)." In this view increments in the conditioned strength of stimuli occur each time these stimuli are temporally contiguous with USs, and decrements occur each time those stimuli occur alone. Organisms are seen not as comparing relative frequencies of events but rather as conditioning or extinguishing one step at a time with each successive "trial."

Thus far, we have distinguished between relative frequency and temporal contiguity views primarily in terms of their philosophical biases about what transpires within the organism during a conditioning experiment. Now let us turn to the more tangible question of whether these positions can be differentiated on operational, experimental, or predictive grounds.

In the usual Pavlovian conditioning experiment in which every CS is paired with a US, and no US occurs alone, the relative frequency of USs is greater in the presence of CSs than in the absence of CSs. CSs and USs are also temporally contiguous. Thus, CS:US contingency and CS:US temporal contiguity are completely confounded, and it is not clear which of these CS:US relationships is responsible for conditioning. One means of finding out might be to eliminate CS:US contiguity for a control group by presenting CSs and USs explicitly unpaired in the same session. However, not only does this procedure reduce the CS:US contiguity, it also <u>reverses</u> the CS:US contingency—it makes USs now more probable in CS absence than in CS presence (Rescorla, 1967). Since the explicitly unpaired procedure differs from the original procedure in two respects, one cannot determine which of these respects is responsible for whatever behavioral differences between groups might be found.

A second means of isolating the critical CS:US relationship might be to attempt to eliminate the CS:US contingency for a control group by presenting CSs and USs in the same session but randomly and independently of each other. This procedure is, of course, the now well-known "truly random control" (Rescorla, 1967); and, unfortunately, just like the explicitly unpaired procedure, it too differs from the original experimental treatment in two respects. Not only has the CS:US contingency been removed, but also the CS:US contiguity has been reduced. CSs and USs are not as frequently contiguous when they are distributed randomly and independently in a session as they are when they are explicitly paired.) Thus behavioral differences between an experimental group and a truly random control cannot be safely attributed to differences in the CS:US contingency.³

The reader may be persuaded by these examples that CS:US contiguity and contingency are inextricable and that they cannot be manipulated independently, yet their independent manipulation is actually fairly simple. For example, if a fixed number of CSs and USs are distributed randomly and independently throughout a session, there will be no contingency between them regardless of the duration of the session. The shorter the session is, though, the greater will be the CS:US temporal contiguity.

In the avoidance literature, a similar confounding ordinarily exists. If we consider some point in time, t, each avoidance response reduces the temporal contiguity between t and the next scheduled shock. (Or, if we consider a range of possible responses, independently distributed in time, more time elapses between shock and the avoidance response than any other.) In addition to this short-term "temporal contiguity" effect, there is also a long-term reduction in the overall frequency of shocks in the presence of responding relative to the overall frequency of shocks in the absence of responding. Some attempts to tease apart relative frequency and temporal contiguity factors in avoidance learning have begun (Bolles & Popp, 1965; Hineline, 1970), but the more extensive analysis of these factors appears to have been conducted in the Pavlovian literature. Consequently, the remainder of this paper will focus on the relative frequency-temporal contiguity issue as it exists there.

First, the evidence that Pavlovian conditioning is controlled by CS:US contingencies will be examined. We will find that this evidence is equally consistent with the view that conditioning is a product of short-term temporal contiguities. Then experiments designed specifically to pit the importance of CS:US temporal contiguity against CS:US contingency will be discussed. The evidence will be found to be favorable to the contiguity view and generally unfavorable to the contingency view. Finally, we will examine a new theory (Rescorla & Wagner, in press) that seems to combine aspects of contiguity and contingency notions. We will see that the bulk of the predictive and explanatory burden rests on the contiguity principles in the model and that the model suggests some general advantages of a view that emphasizes short-term temporal contiguities relative to long-term relative frequencies.

Inhibitory Conditioning, the Explicitly Unpaired Control and the Problem of Trace Conditioning

One of the first lines of evidence that CS:US contingencies might be the critical variable in

³ This discussion has obvious implications for the selection of the proper control procedure for use in Pavlovian conditioning. Since both the explicitly unpaired and the truly random procedures differ from the experimental procedure in terms of two CS:US relationships, they are logically of equal merit. Therefore, unless an investigator has some a priori reason to believe that one of these relationships is crucial and the other irrelevant, his selection of one of these controls must be based on some empirical consideration.

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Pavlovian conditioning was presented by Rescorla and LoLordo (1965). They found that CSs in an explicitly unpaired control procedure acquired Pavlovian inhibitory stimulus control. Rescorla (1967) pointed out that this result seemed surprising given the widely held view that CS:US temporal contiguity (i.e., pairings) should lead to excitatory conditioning and that the explicitly unpaired CS should remain neutral. In contrast, he noted, this finding was easily understood given the notion that organisms are sensitive to the relative frequencies with which USs occur in the presence and absence of CSs. Since the relative frequency of USs was higher in the absence of CSs than in the presence of CSs, the CS would signal US absence. In the fear conditioning preparation used by Rescorla and LoLordo (1965) such CSs should inhibit fear rather than excite it.

In spite of the apparent difficulties the finding of inhibitory conditioning in the explicitly unpaired control seemed to present to contiguity theorists, there are a number of contiguity theories that can account for it. Among these are the theories of Denny (1971), McAllister and McAllister (1971), and of Rescorla and Wagner (in press). Rescorla and Wagner, in particular, have discussed in detail how their model accounts for inhibitory conditioning; however, there may be some controversy as to whether their theory is a contiguity theory or whether it is more appropriately considered an extension of the contingency view. For this reason we will treat it separately at the end of the paper. For the moment, we will attempt to show only that some contiguity theory can, in principle, account for inhibitory phenomena usually explained in terms of the contingency view. We will choose as an example the contiguity view of Denny (1971). And since most of the discussion of, and research on, inhibitory conditioning has dealt with inhibitory fear conditioning, our analysis, too, will focus on this case.

According to Denny's view, a stimulus, X, gains control over a response if that response is repeatedly elicited in the presence of X to the relative exclusion of other responses. In addition, through a process of "backchaining," the response may also become conditioned to stimuli that precede X. Denny further assumes that 25-40 sec after the termination of aversive stimuli like

shock, the animal begins to relax and that relaxation becomes conditioned to the stimuli contiguous with it. Finally, relaxation is held to be incompatible with fear.

Evidence for these notions derives from experiments in one-way avoidance. In one experiment (Weisman, Denny, Platt, & Zerbolio, 1966) experimental rats were trained to escape/avoid by jumping from a shock chamber into a safe chamber where they would presumably relax during long intertrial intervals (ITIs). An attempt was then made to condition the relaxation response to a flashing light by presenting the light in the safe chamber during most of the ITI. Finally the conditioned effects of the light were assessed in a "summation test" (see Rescorla, 1969b). The light was compounded with the fear-eliciting cues in the shock chamber during the extinction of avoidance. It was found that avoidance extinguished faster for the experimental subjects than for generalization decrement controls. Presumably, extinction was facilitated because of conditioned relaxation elicited in the shock chamber by the flashing light. In another experiment (Zerbolio, 1968) rats were placed in chamber A for a 150-sec period following a shock in a distinctively different chamber, B. It was presumed that relaxation would be conditioned to A. Consistent with this hypothesis, it was later found that acquisition of avoidance from A was retarded in a "retardation test" (see Rescorla, 1969b). Since the critical stimuli had the ability both to retard avoidance in a retardation test and to weaken avoidance in a summation test, they would appear to meet the criteria of conditioned inhibitors outlined by Rescorla (1969b). However, since the task used in these experiments involved one-way avoidance, one may question whether the critical stimuli inhibited the Pavlovian fear response or the instrumental response of leaving the start box. Although it may be uncertain that it is the fear response that is inhibited in these experiments, it is clear that Denny's contiguity theory can, in principle, account for inhibition of the fear response, and the evidence is at least consistent with a fearinhibition interpretation.

To extend Denny's analysis to the explicitly unpaired control, one need only assume that the inter-shock intervals are long enough to allow the subject time to relax between them. If CSs are present during the inter-shock intervals (as is the case in the explicitly unpaired control), it is reasonable to believe that relaxation could get conditioned to them, thus making them conditioned inhibitors of fear.

It appears, then, that both contingency theory and at least one contiguity theory can account for inhibitory conditioning in the explicitly unpaired control. However, there is a difficulty with the contiguity analysis that, at first glance, does not appear to exist with the contingency view. Specifically, how does one determine theoretically before running the experiment that the inter-shock intervals are long enough to permit relaxation to occur in them? Or, how does one determine whether CSs in the inter-shock interval are "contiguous enough" with succeeding shock onsets that, through backchaining, the fear response and not the relaxation response will become conditioned to them? Obviously these questions cannot be answered until data have been collected, and so the contiguity analysis tends to have an ad hoc flavor to it. In contrast, the contingency theorist appears to be able to decide in advance of experimentation that he is going to program either positive, negative or zero contingencies and thus predict in advance of data that he will obtain either excitatory, inhibitory, or no conditioning. In point of fact, however, this is not true. The contingency theorist's decision as to whether a programmed sequence involves a positive, negative, or zero contingency may also be influenced by post hoc considerations. It has been suggested that the contingency is " . . . clearly a function of the relative proportion of US events which occur during or at some specified time following the CS" (Rescorla, 1967, p. 76, italics ours). To illustrate the importance of this "specified time" in the actual computation of positive or negative contingencies, it may be helpful to refer to some concrete instances.

Rescorla (1968) distributed a number of 2min CSs and .5 sec USs randomly throughout 5 2hr sessions for a group of rats. He described the group as a .4-.4 group, meaning that P(US | CS) = .4 and $P(US | \sim CS) = .4$ (where $\sim CS$ means "in the absence of the CS"). He stated that the probability of a US occurring <u>per 2-min interval</u> was .4. Thus, in determining the relative frequency of USs per unit time in the presence and absence of CSs, the CS duration was selected as the appropriate temporal unit. Figure 1 shows how this unit is used in computing actual relative frequencies or conditional probabilities.



Figure 1. *CSs* and *USs* have been randomly assigned to intervals in a session equal in duration to the CS. The $P(US \mid CS)$ is equal to the number of times CSs and USs overlap divided by the total number of CSs. The $P(US \mid \sim CS)$ is equal to the number of times USs occur in non-CS intervals divided by the total number of non-CS intervals. The relative frequency of USs in the presence and absence of CSs is the same; hence, there is no contingency between CS and US.

The session in Figure 1 contains 12 temporal units each equal to the CS duration. Three of these are CS intervals and nine are non-CS intervals. Of the three CS intervals one contains a US, so the P(US | CS) = 1/3 = .33. Of the nine non-CS intervals three contain USs, so the $P(US | \sim CS)$ 3/9 or .33. Since the relative frequency of USs in the presence and absence of CSs is the same (i.e., .33), there is no CS:US contingency depicted in the figure.

Note that in Rescorla's experiment and in Figure 1 the proportion of US events occurring during the CS was determined-not the proportion of US events occurring during or at some specified time after the CS. The phrase "at some specified time after the CS" was ignored in computing the contingency. Unfortunately, this cannot always be done. For example, suppose that excitatory conditioning occurred in the trace conditioning experiment shown in Figure 2A. If we computed the CS:US contingency in Figure 2A as we did in Figure 1, we would have to predict that the CS would acquire inhibitory control since the CS:US contingency would be perfectly negative. To avoid this dilemma, we could simply set the "specified time" at some value greater than zero. We could ask: What proportion of the US events occur during or at some specified time following the CS? If the specified time is 30 sec, then all of the USs occur within this time. The P(US | CS) =1.0; the P(US \sim CS) = 0. The contingency is perfect. Excitatory conditioning is predicted, because for computational purposes the CSs and USs are assumed to have overlapped even though the USs did not occur until 30 sec after each CS terminat-One computes the contingency as if the ed. CS:US events were as shown in Figure 2B. If \underline{E} chooses to specify a shorter period of time, say 20 sec, then he would have to compute the contingency on the basis of the situation depicted in Figure 2C. Here again the P(US | CS) = 0 and $P(US | \sim CS) > 0.$ Since P(US | CS) $P(US \mid \sim CS)$, the contingency is negative and we would now again predict that the CS would gain inhibitory stimulus control. So whether a positive or negative contingency is computed (and hence whether excitatory or inhibitory control is predicted) is dependent on the "specified time" \underline{E} elects to use. Prior to running his experiment, E cannot know what time to specify. He can only specify a time after he has determined whether excitatory or inhibitory conditioning occurs in his particular trace conditioning situation. Thus, in the sense used here, the contingency theorist's phrase "at some specified time" is synonymous with the contiguity theorist's phrase "contiguous enough."



Figure 2. In situation A, \underline{E} wishes to determine the proportion of USs that occur during or at some specified time after CSs. If the specified time is 30 sec as in Panel B the CS:US contingency is perfectly positive, and the CS will gain excitatory control. If the specified time is 20 sec as in Panel C, the contingency will be negative. According to the contingency view the CS will now gain inhibitory control.

There is another way, however, in which we could interpret the phrase "at some specified time." Suppose E programmed a US to appear exactly 15 min after each CS and never at any other time. It is possible to argue that 15 min is, by definition, the specified time. Since USs are more likely to occur 15 min after a CS than at any other time, then by definition, a perfectly positive contingency would exist, and the CS should gain excitatory stimulus control. In fact, the CS:US contingency would be the same if the US occurred exactly 15 min or exactly 15 sec after every CS! If only the CS:US contingency is important, and the CS:US contiguity is irrelevant, then the same conditioning would be predicted in both instances. This prediction is clearly incorrect. In fact, even an interval as short as .5 sec between CS termination and US onset profoundly weakens conditioning (Kamin, 1965).

So there appear to be two ways to interpret the phrase "at some specified time." If we interpret it one way, it becomes essentially synonymous with the phrase "contiguous enough." It makes the computation of contingencies an ad hoc or arbitrary matter, and it blurs the distinction between contiguity theory and contingency theory. If we interpret it the second way, then the contingency view leads to predictions which are not empirically supported.

Evidence Favoring Contingency Theory

All of the experiments to be described in the remaining sections of this paper have certain procedures in common. First <u>E</u> establishes some type of repetitive response in his <u>S</u>s. This response is called the baseline response. It may consist of bar pressing for food, bar pressing to avoid shock, hurdle jumping to avoid shock or licking a dipper for liquid reinforcement.

Then <u>E</u> institutes some Pavlovian training procedure: CSs may be paired with USs; CSs and USs may be presented in a truly random fashion (TR procedure), or they may be explicitly unpaired, etc. Sometimes this training takes place "off the baseline," i.e., while the <u>S</u> is prevented from performing the baseline response. If so, then after the Pavlovian training sessions, <u>S</u> is given the opportunity to recover and stabilize his response. Finally, CSs are presented while <u>S</u> performs the baseline response, and CS-elicited changes in rate are taken as indices of Pavlovian stimulus control.

Some of the studies inspired by the contingency view, and whose results are consistent with it, include the work of Rescorla (1969a) and Hammond & Daniel (1970). These studies were similar to the work of Rescorla and LoLordo (1965) discussed earlier in that they showed that negative contingencies resulted in inhibitory stimulus control by the CS. Rescorla's experiment, in addition, showed that the more negative the contingency, the more inhibitory stimulus control the CS acquired. While the description of the experimental operations (and the prediction of the data) in terms of contingencies is elegantly simple, the results of these studies do not demand the contingency view for they are also consistent with contiguity accounts of inhibitory conditioning, including the theory of Denny that we examined earlier.

In the context of Denny's theory, for example, one might note that in the parametric study of inhibitory conditioning (Rescorla, 1969a) the negativity of the CS:US contingency was manipulated by increasing the density of shocks in the ITI (absence of CS). Denny (1971, p. 244.) discusses the notion of US omission as an eliciting state of affairs and notes that its ability to elicit (relaxation, in this case) depends on the extent to which the US is normally "anticipated." Presumably, the more dense the US occurrence, the stronger would be the eliciting ability of US omission. Thus the degree to which relaxation becomes conditioned to a CS should be directly proportional to the density of USs in the ITI (in contingency terms—the negativity of the contingency).

In addition, Denny's notions imply predictions which differ from those of the contingency view and which could be easily tested. For example, according to the contingency view inhibitory conditioning should be obtainable as long as the density of USs per unit time is lower in the presence of CSs than in their absence. In Denny's view, however, occasional USs during CSs should condition fear to those CSs and compete with the conditioning of relaxation. This possibility would be particularly important if fear is more easily conditioned than relaxation or if inhibitory effects are more fragile than excitatory ones (Pavlov, 1960). In this connection it is striking that in their of demonstrations inhibitory conditioning Rescorla (1969a) and Hammond and Daniel (1970) not only disallowed USs in all CS periods but also disallowed USs in the period 2 min and 6 min (respectively) after each CS! Whether a negative contingency is sufficient to produce inhibitory conditioning even in the face of occasional chance pairings is an unanswered empirical question.

Stronger support for the contingency view (stronger because it seems inconsistent with the contiguity view) was presented by Rescorla (1966, 1968). In the first study one group of dogs received a TR procedure: tone CSs and shock USs occurred randomly and independently. A second group (the Gated group) received the same CSs but got only those USs occurring within 30 sec after CSs for the TR group. Thus both groups got the same number of CSs and the same number of pairings (defined as a US within 30 sec after a CS). The TR subjects, however, got more USs in the absence of CSs. They therefore experienced a lower CS:US contingency than did the Gated group, for whom the contingency was perfect. So the TR group should have shown less conditioning. These predictions were tested by superimposing the CS on a preestablished baseline of Sidman avoidance. The CS for the TR group had no effect (as predicted by the contingency view), and the CS for the Gated group increased the avoidance rate (also as predicted).

The evidence presented by Rescorla (1968) was similar to the above but more extensive. In this study (Exp. 2) the degree of CS:US contingency was systematically manipulated across groups of rats. To simplify the exposition, we will consider only four of his groups. For all four groups the P(US CS) was .4, but the P(US ~CS) was .4, .2, .1, and 0 for different groups. Pavlovian stimulus control was assessed this time by a conditioned suppression procedure: The CS was presented without USs to animals bar pressing for food. The group for which $P(US \mid \sim CS)$ had been .4 did not suppress. But suppression increased monotonically with lowering $P(US \mid \sim CS)$. Since the contingency increased as the $P(US \mid \sim CS)$ was reduced, the strength of conditioning covaried nicely with the degree of contingency. Moreover, the theoretical number of CS:US pairings and CSs given alone was the same for all four groups. Thus contiguity theory apparently predicts incorrectly that all four groups would condition equally.

There is another way of describing Rescorla's procedure, however, that may relate his study to another literature and offer an alternative to the contingency interpretation of his results (cf. Dweck and Wagner, 1970). Rescorla's four groups all received the same number of CS:US pairings. They differed, however, in terms of the number of times shock stimuli were interpolated in the intertrial interval (ITI). Groups that got the most shocks in the ITI showed the weakest conditioning. This procedure is formally similar to that used by Hupka, Kwaterski, and Moore (1970). These authors found that shock USs interpolated between tone-shock pairings weakened conditioning of the rabbit nictitating membrane response. They interpreted their results in terms of a consolidation theory: The events placed in the ITI disrupted the consolidation of learning resulting from CS:US pairings. This interpretation is similar to that offered by Kettlewell and Papsdorf (1967), Papsdorf and Kettlewell (1963) and Snyder and Papsdorf (1968) for their findings that nictitating membrane conditioning was weakened by presentations of novel stimuli (e.g., white noise) in the ITI. These latter results are particularly important in the present discussion because the stimuli Papsdorf and his associates distributed in the ITI did nothing to the CS:US contingency. Since the events placed in the ITI were not the same USs used in CS:US pairings, they could affect neither P(US | CS) nor $P(US | \sim CS)$. In Rescorla's study, however, these events were the same USs that were paired with CSs. Therefore, each time they occurred alone, they raised P(US | ~CS) and thus reduced the CS:US contingency. There is no compelling reason to believe, however, that these changes in the contingency had anything to do with changes in the strength of conditioning. The same changes in conditioning might have been obtained if stimuli other than shocks had been interpolated in the ITI. These stimuli would have done nothing to the contingency but might have weakened consolidation as described by Papsdorf and his associates.

Other contiguity accounts, which do not rely on the consolidation principle, could also be offered. For example, it may be that USs in the ITI lead to US-habituation between CS:US pairings and thus reduce the effect of such pairings. Or, it may be that CRs conditioned to apparatus cues on US-alone trials block conditioning of CRs to the CS as Rescorla and Wagner (in press) have suggested.

From the theorist's point of view all of these contiguity accounts—by appealing to some principle in addition to CS:US contiguity—are more labored than the contingency account, which simply postulates that organisms condition to the extent that they detect a difference in the relative frequency of USs in the presence and absence of CSs. On the other hand, the contiguity view does have the merit of postulating an organism that simply reacts to each trial as an entity in itself rather than an organism with the ability to sense, remember, and compare relative frequencies.

We conclude that there is considerable evidence consistent with contingency theory, but that the evidence is equally consistent with contiguity views of conditioning. The evidence certainly does not rule out contiguity interpretations.

Evidence Against Contingency Theory

The evidence against the contingency view bears on two questions: (a) Is an overall CS:US contingency a <u>necessary</u> condition for establishing Pavlovian stimulus control? and (b) Is the abolition of a CS:US contingency a <u>sufficient</u> condition for abolishing Pavlovian stimulus control?

The first question was addressed originally by Kremer and Kamin (1971). They gave one group of white rats white noise CSs and shock USs explicitly unpaired and a second group noise CSs and shock USs in a TR procedure. Later, they tested for Pavlovian stimulus control by measuring the extent to which the CS suppressed bar pressing. CS-elicited suppression occurred in both groups but was stronger in the TR group. In a second experiment they manipulated the time between TR training and testing for stimulus control. Half their animals were tested on the third day after training and half on the twentieth day. Both groups suppressed significantly in their tests and no retention loss occurred over the 20-day interval. Thus, this second experiment showed that the "conditioning" obtained under the TR procedure resembled that obtained with more conventional conditioning procedures by persisting over a long retention interval (Gleitman & Holmes, 1967; Hoffman, Fleshler & Jensen, 1963). The effect was not due to a temporarily heightened excitability or hyperreactivity because of the shocks which had been received.

In a third experiment Kremer and Kamin again presented noise CSs and shock USs with no contingency between them to two groups of rats. This time they manipulated the interval between CS-onset and US-onset, a variable whose importance is well documented (Kamin, 1965). The CS:US interval was manipulated by alternating 2 min of white noise with 2 min of silence for one group and 15 min of noise with 15 min of silence for the other group. For both groups USs were equally probable in noise and silent periods. Both groups got the same number of shocks and the same total exposure to CSs. Thus, no CS:US contingency existed for either group, but CS onsets were much more likely to occur near to US onsets for the 2-min CS group than for the 15-min CS group. In later tests more CS-elicited suppression was found for the 2-min CS group. Kremer and Kamin concluded that their data were consistent with the view that accidental pairings of CS and US onsets result in conditioning to the CS in the absence of an intra-session contingency. (Additional support for this conclusion has more recently been described by Kremer, 1971).

Quinsey (1971) also varied across two groups of rats the number of accidental pairings in a TR procedure. The two groups received the same number of tone CSs and shock USs programmed randomly and independently. But one group received its events in a shorter period of time, thus ensuring greater CS:US contiguity (or more accidental pairings). Associated with these two groups were two "yoked" control groups that got only the USs their partners got. Quinsey later measured suppression of dipper licking produced by the tone CS in all four groups and found that only the group that had received CSs and USs in close temporal contiguity suppressed reliably.

In a second experiment Quinsey compared a traditional delayed conditioning procedure to the TR procedure at two levels of shock intensity. High shock intensity was hypothesized to be important in producing conditioning in a TR procedure because it should enhance the value of chance pairings. The results were consistent with this hypothesis. From strongest to weakest suppression the groups were ordered as follows: delayed with high shock, TR with high shock, delayed with low shock, and TR with low shock.

The studies of Kremer and Kamin and of Quinsey show, then, that excitatory conditioning <u>can</u> occur in the absence of a CS:US contingency and that CS:US contiguity and US intensity are important variables in such conditioning.

What evidence is there that the abolition of a CS:US contingency is sufficient for the extinction of a Pavlovian CR?

The usual method of extinguishing a Pavlovian CR is to present CSs alone after conditioning. If USs have previously been contingent on CSs, then CS-alone presentations will reduce the CS:US contingency. The P(US | CS) will be reduced relative to the P(US | \sim CS) until the two probabilities approach equality. The contingency view holds that it is the reduction of the contingency that is responsible for extinction (Rescorla, 1967, p. 75). Note that if the contingency view is to quantitatively predict normal Pavlovian extinction, it must assume that the organism averages contingencies across sessions. Finally, if contingency theory is to make any quantitative predictions about the course of extinction, it must provide some rule for combining P(US | CS) and P(US | ~CS) into a single predictive statistic specifying the degree of contingency before and after various types of extinction treatment as well as treatments of different durations. Although Rescorla (1967) did not explicitly suggest such a combination law, the simplest one consistent with the contingency view might be that the degree of contingency is equal to the difference between P(US | CS) and $P(US | \sim CS)$. When P(US | CS) -P(US | ~CS) is positive, a positive contingency exists; when negative, a negative contingency exists; and, when the two probabilities are equal, no contingency exists.

Figure 3 shows how the degree of contingency computed as described above is affected by three different types of treatments. Panel A shows the degree of contingency at the end of acquisition. Panel B shows how that contingency is degraded by a CS-alone treatment. Panel C shows how that contingency is degraded by a truly random treatment, and Panel D shows how the contingency is degraded by a US-alone treatment. The CS-alone and truly random procedures have been acknowledged by Rescorla (1967, p. 75) as valid methods of reducing a contingency and producing extinction, but the US-alone procedure has not. Granting the assumptions outlined in the preceding paragraph, we can see that the US-alone treatment, counterintuitive though it seems, should also produce extinction by degrading the contingency. It should not, however, produce extinction according to the contiguity view. The contiguity view holds that extinction occurs when CSs are presented without contiguous USs. Clearly, the US-alone procedure does not meet this requirement.

	(a) Plusics)	(b) Р(цы(3))	Degree of Contingency (a - b)
A	1.0	0	1.0
B	.4	0	.4
с	.5	.3	.2
D	1-0	.5	-5

Figure 3. Schematic showing how a series of CSs, a series of CSs and USs presented randomly, and a series of USs presented alone can reduce a CS:US contingency if presented after pairings. The contingency is perfect in Panel A and to the left of the dotted line in Panels B, C, and D. See Figure 1 for rules for computing the contingency.

In one test of these predictions, Ayres and Benedict (1970) attempted to weaken conditioning by interpolating US-alone (USa) trials off the baseline between CS:US pairings and the test for Pavlovian stimulus control. The USa procedure was compared with a CS-alone (CSa) procedure and a No-extinction control. The CSa and USa procedures were explicitly designed to degrade the CS:US contingency to the same extent (from 1.0 to .54.). Nevertheless, in a conditioned suppression test given 48 hr after the interpolated extinction trials, it appeared that only the CSa procedure had weakened conditioning. The CSa group suppressed less than either the USa or Noextinction groups, and these latter groups were themselves indistinguishable. It is possible that the USa trials created a permanent motivational change that counteracted the degrading of the contingency. However, the fact that the groups' pre-CS rates during the tests did not differ argues against this possibility, and the data therefore appear more consistent with the contiguity view than at least the version of the contingency view outlined above.

The use of the TR control as an extinction procedure provides a valid test of contingency vs.

contiguity views only when the TR trials are massed. According to the contingency view, extinction occurs when a contingency is degraded. According to the contiguity view, extinction occurs to the extent that CSs are presented in the absence of contiguous USs. Distribution of TR trials over a long period degrades the contingency and presents CSs in the absence or contiguous USs. Thus it should produce extinction according to both views. Massed TR trials, however, should degrade the contingency but insure close temporal contiguity of CSs and USs. Therefore, extinction should occur only according to the contingency view.

Ayres and Benedict (1970), Ayres and De-Costa (1971), and Davis and McIntire (1969) have attempted to use the TR procedure to weaken a previously established CR. The TR trials were most massed in the work of Ayres and Benedict, less massed in the work of Ayres and DeCosta, and were widely distributed in Davis and McIntire's study. Ayres and Benedict found no tendency for the TR procedure to produce extinction. Avres and DeCosta found a slight but unreliable tendency, and Davis and McIntire found that their TR procedure weakened the previously established CR for two of their four subjects but appeared to strengthen the CR for the remaining two. Thus, the available evidence is consistent with the contiguity view. We know of no study in which massed TR trials given after pairings have produced reliable extinction of a Pavlovian CR.

Very recent data (Benedict and Ayres, 1972) bear on both questions (a) and (b) raised above. These authors tested the hypothesis that conditioning in the TR control depends on the probability of chance pairings per unit time (Kremer, 1971). They varied this probability between values of .07 and .44 for six groups of rats by systematically manipulating the number of CSs and/or USs distributed randomly in a constant period of time. They later measured stimulus control by determining the extent to which the CS suppressed previously established bar pressing. Two of the six groups showed very clear conditioned suppression; four showed none. Surprisingly, however, suppression did not covary with the probability or number of chance pairings. Instead it covaried almost perfectly with an "initial contingency statistic"—a statistic that described the CS:US contingency during only the first tenth of truly random training. Such a statistic measures the likelihood of accidental pairings early in the organism's experience with CSs and USs in the conditioning apparatus.

In a second experiment the predictive power of the "initial contingency statistic" was tested, using four groups of naive rats. One group received an initially high contingency procedure that had previously produced conditioning. A control group received the same procedure but with several "accidental" pairings postponed until later in training. A second experimental group received an initially low contingency procedure that previously had not produced conditioning. Its corresponding control group received the same procedure but set up so that the "accidental" pairings of the experimental group occurred early in sequence of CSs and USs. The results of this experiment were very clear. If "accidental" pairings occurred early in the experience of the organism with CSs and USs, strong suppression was found later. But if the same pairings were postponed until later in training, animals did not suppress to the CS in the critical suppression tests.

In summary, conditioning was found in several groups for which there was no overall CS:US contingency (as it is usually computed in TR procedures, cf. Figure 1). Also, conditioning occurred in groups that had received as few as 7 chance pairings and did not appear in groups that had received as many as 44 chance pairings. Conditioning was determined by the location (not the overall density or number) of pairings. Finally, groups having an initially high contingency reduced completely to zero still showed strong conditioning. While it is possible that this conditioning might have been eliminated by prolonged exposure to the zero contingency, the results of this experiment show clearly that simply reducing an initially high contingency to zero is not a sufficient condition for the extinction of a Pavlovian CR.

The Rescorla and Wagner Model

A recent development in Pavlovian conditioning theory is a model of conditioning described by Rescorla and Wagner (in press). In various publications (Rescorla & Wagner, in press; Rescorla, in press; Wagner & Rescorla, in press), Rescorla and Wagner have shown that their model can account, in principle, for nearly all of the results discussed in previous sections of this paper as well as many other findings not mentioned. Although the model is seemingly very powerful and general, we have said little about it in our previous discussion because the status of the model as a contingency theory, a contiguity theory, or some combination of the two seems somewhat unclear and has not been explicitly discussed by Rescorla and Wagner.

Our own view of the model is that it is a contiguity theory which holds out a role for contingency but in which the contingency notion may actually be superfluous. Moreover, we see the model as possibly illustrating an advantage that contiguity theories in general may have over contingency or relative frequency theories. For these reasons it seems appropriate to conclude this discussion of contingency and contiguity theories by examining in some detail this recent theoretical development.

In the Rescorla and Wagner model, increments in the conditioned strength of a stimulus element, X, occur each time X overlaps the US according to the following formulation.

$$\Delta V_{x} = \alpha_{x} \beta_{1} (\lambda - V_{AX})$$
(1)

In Equation 1 ΔV_x represents the increment in associative strength accrued to X as a result of CS:US overlap (contiguity principle); α_x is a parameter denoting the salience of X; β_1 is a parameter related to the quality of the US; λ represents the asymptotic level of conditioning obtainable with the US in question; and V_{AX} represents the associative strength controlled by both X and other stimuli like the apparatus cues that overlap the US simultaneously with X.

When USs appear in the absence of X, conditioning strength accrues to the apparatus cues according to the following formulation.

$$\Delta V_{\rm A} = \alpha_{\rm A} \beta_1 (\lambda - V_{\rm A}) \tag{2}$$

In Equation 2 ΔV_A represents the increment in associative strength accrued to the apparatus cues as a result of their overlapping the US (contiguity principle); α_A is a parameter denoting the salience of the apparatus cues.

When X appears without a US, it loses asso-

ciative strength according to the following formulation.

$$\Delta V_{x} = \alpha_{x} \beta_{2} (\lambda - V_{AX})$$
 (3)

In Equation 3 λ is assumed to be zero since no US is present; β_2 is an extinction parameter and is usually assumed to be less than β_1 (Wagner & Rescorla, in press).

Finally, when the apparatus cues appear without a US, they lose associative strength according to the following formulation.

$$\Delta V_{\rm A} = \alpha_{\rm A} \,\beta_2 \,(\lambda - V_{\rm A}) \tag{4}$$

In Equation 4 as in Equation 3, λ is assumed to be zero. Inspection of Equations 1-4 reveals a set of assumptions very similar to those of Pavlov. Stimuli acquire conditioned strength by overlapping USs and lose conditioned strength by appearing alone. The organism is seen as changing one step at a time rather than as detecting and comparing relative frequencies and behaving accordingly. The chief difference between the model and the older, Pavlovian view is the new proviso that the effects of each pairing and each CS-alone trial on the conditioned strength of a CS element are modulated by the conditioned strength already accrued to the compound CS of which the element is a member. Specifically, the degree to which the element gains excitatory strength on pairing trials is inversely proportional to the total strength already accrued to the compound; and the degree to which the element loses strength on element-alone trials (element plus apparatus cues) is directly proportional to the total strength already accrued to the compound.

The addition of this new proviso to the contiguity principles above does not transform the model into a contingency theory. On the contrary, it stands in striking contrast to the contingency notions. For example, in the contingency view we recall that when the relative frequency of shocks in CS and non-CS periods was equal (e.g., Rescorla, 1968), subjects failed to condition because there was no difference in the relative frequencies to be detected, or because CS presence and absence did not differentially "predict" shocks. Now we see that conditioning to the CS was not obtained because USs occurring in CS absence conditioned the fear CR to the apparatus cues. When the CS subsequently chanced to overlap shock, the chance pairing was relatively ineffective because the CR conditioned to the CSapparatus-cues compound was already asymptotic. It is clear that in the model relative frequencies do not exert direct behavioral control; they merely describe the scheduling of pairings and non-pairings which do exert direct control.

Besides differing from the contingency view in terms of postulated conditioning mechanisms, the model also makes a number of predictions that are inconsistent with the earlier view. For example, in the new model, as mentioned above, USs given alone only attenuate the effects of <u>future</u> pairings. They are not seen as degrading an otherwise high CS:US contingency. Thus, US-alone trials should not produce extinction according to the new model, while for the contingency view, this was a distinct possibility (cf. Figure 3).

The new model also predicts substantial conditioning in the <u>absence</u> of a CS:US contingency. In fact, Rescorla (in press) has discussed in detail how the model accounts for the conditioning found in several TR controls (Benedict & Ayres, 1972; Kremer & Kamin, 1971; Quinsey, 1971). But the model holds that the conditioning found in these studies was <u>preasymptotic</u>, and it predicts, in agreement with the contingency view, that if these TR procedures had been run long enough, little or no conditioning would have been found asymptotically. So the model suggests that the role of contingency is as a predictor of asymptotic but not preasymptotic behavior.

It seems reasonable to ask what is the difference between preasymptotic and asymptotic behavior? Presumably, the only difference is the number of times the contiguity principles have been applied. In making predictions from the model, one applies Equations 1 through 4 more often for an animal given a long exposure to a treatment than for an animal given a brief exposure to the same treatment. Thus although knowledge of the overall CS:US contingency may, in principle, enable an investigator to predict asymptotic behavior, successive calculations using the contiguity equations enable the investigator to predict both the asymptotic behavior and the preasymptotic behavior. In this sense, the contiguity notions are more parsimonious and powerful than the contingency notions and this may be the general predictive advantage of contiguity theories over contingency theories.

This point can be made more strongly by example. We have seen that a number of investigators have reported effects resembling forward conditioning produced by TR procedures. We have noted that the Rescorla and Wagner model holds that this conditioning was preasymptotic. Suppose that twenty or thirty days exposure to random sequences were required before asymptotic performance was finally reached. Armed with the contiguity principles in Equations 1 through 4, an investigator using a preplanned sequence of CSs and USs could, in principle, predict the strength of conditioning on any day including the final day in which asymptotic performance was reached. In addition, he could apply the equations to his sequence until Vx remained constant and so could predict in advance the day on which asymptote would be reached. On the other hand, armed only with the knowledge of the relative rate of USs in the presence and absence of CSs (i.e., the global CS:US contingency), this investigator could predict nothing until the final (asymptotic) day, and he would have no way to predict when this day would occur. Furthermore, if the relative rate of USs in the presence and absence of CSs were the same on all the days of training as was true in previous experiments (Benedict & Ayres, 1972; Kremer, 1971; Kremer & Kamin, 1971; Ouinsey, 1971), he would be faced with a slippage between variable behavior on the one hand and a constant contingency or relative frequency on the other—a slippage explainable only in terms of the contiguity equations. It appears, then, that in the Rescorla and Wagner model, the contiguity principles carry the bulk of the predictive and explanatory burden and that the contingency notion has become vestigial.

Conclusions

The paper has examined the proposition that behavior is controlled by the relative frequency of events in the presence and absence of other events. This view has been contrasted with an older view that holds that behavior is determined by the temporal contiguity between events. The paper has focused on the merits and limitations of these views as found in Pavlovian conditioning where they are known as the contingency and contiguity views, respectively. The following conclusions have been suggested.

1. Experiments designed to assess the relative importance of CS:US contingency and CS:US contiguity have revealed that

a. Conditioning can occur in the absence of an overall CS:US contingency.

b. Degrading a CS:US contingency by presenting USs alone after CS:US pairings does not appear to weaken conditioning.

c. Degrading an initially positive contingency to zero my presenting CSs and USs randomly after only a few CS:US pairings does not guarantee that the resultant conditioning will be extinguished.

2. Evidence once thought to demand a contingency interpretation can be interpreted in a manner congruent with one or more versions of the contiguity view. Such evidence includes the demonstrations that the strength of excitatory and inhibitory conditioning has correlated with the degree of positive or negative CS:US contingency.

3. In a recent theoretical model proposed by Rescorla and Wagner (in press et seq) relative frequencies or global CS:US contingencies can be used to predict asymptotic but not preasymptotic behavior. In the same model contiguity principles can be used to predict both. In the model, then, the contiguity notions are more parsimonious and have greater predictive power. Thus the model seems to illustrate a general advantage of views of conditioning which emphasize the role of CS:US temporal contiguity as opposed to CS:US contingency.

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