

Blocking of Subsequent and Antecedent Events

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Stimulus competition (e.g., blocking) has been observed between antecedent events (i.e., conditioned stimuli or potential causes), but recent evidence within the human causal learning literature suggests that it could also be obtained between subsequent events (i.e., unconditioned stimuli or potential effects). The present research tested this hypothesis with rat subjects. To avoid confounding the antecedent versus subsequent variable with the affective value of the events involved (i.e., unconditioned stimuli are ordinarily of greater affective value than conditioned stimuli), a preparation was used in which antecedent and subsequent events all lacked affective value during the blocking phases of the study. This was achieved through the use of sensory preconditioning. Blocking of subsequent events as well as antecedent events was observed. The challenge to most associative theories that is provided by blocking of subsequent events is discussed.

Suppose one stimulus event occurs prior to another stimulus event. We can define the earlier event as an antecedent event and the later event as a subsequent event. Under appropriate conditions, animals exposed to this sequence of events learn a relationship between the two events. In a Pavlovian framework, the representation of this relationship can be referred to as an association between the antecedent event, called a conditioned stimulus (CS), and the subsequent event, called an unconditioned stimulus (US). In a cause-and-effect framework, such a representation is referred to as a causal link between the antecedent event (called a cause) and the subsequent event (called an effect). The conditions that encourage the formation of Pavlovian associations appear similar (but not necessarily identical) to the conditions that encourage the formation of causal links (e.g., Allan, 1993; Shanks & Dickinson, 1987). Thus, a better understanding of each type of learning (causal and

Pavlovian) might result from a dialogue between these two areas of research. We view the present article as an example of the benefits of such a dialogue.

In both Pavlovian and causal frameworks, the presence during training of two simultaneously occurring antecedent events allows the possibility that one of these antecedent events will influence the relationship that is learned between the other antecedent event and the subsequent event. If the influence is adverse, the effect is commonly known as cue (or stimulus) competition. Similarly, the presence of two simultaneously occurring subsequent events during training allows the possibility that one of the subsequent events will adversely influence the relationship between the other subsequent event and the antecedent event. This report is centrally concerned with the possibility of competition between subsequent events in rats. Such a phenomenon is of interest because it is explicitly not predicted by many contemporary theories of learning.

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Stimulus Competition Between CSs and Between Causes

Blocking (Kamin, 1968) is a well-known example of stimulus competition. In blocking, responding to a conditioned stimulus (CS2) as a result of pairing it with a US is attenuated by the presence of another stimulus (CS1) during the CS2-US pairings of training, provided that CS1 has been paired previously with the US. Conventionally, we say that the previously established CS1-US association has blocked learning about (or at least responding to) CS2. More generally, stimulus competition in Pavlovian conditioning refers to attenuated responding to a CS as a result of that CS being trained in the presence of another stimulus that was a better predictor of the US than was the target CS. Most demonstrations of competition between Pavlovian CSs have been with animals (e.g., Kamin, 1968, 1969), but there are demonstrations of the phenomenon with human

participants (e.g., Hinchy, Lovibond, & Ter-Horst, 1995; Jones, Gray, & Hemsley, 1990; Martin & Levey, 1991). Additionally, numerous investigators have also reported the occurrence of stimulus competition between multiple potential causes of an effect in human causal learning experiments (e.g., Dickinson, Shanks, & Evenden, 1984; Shanks & Dickinson, 1987; Van Hamme, Kao, & Wasserman, 1993; Waldmann & Holyoak, 1992). These researchers found that an event is degraded as a judged cause of a particular effect if, during causal training, it is paired with the effect in the presence of a previously established cause or more consistent cause of that effect.

Stimulus Competition Between USs and Between Effects

In contrast to the numerous reports of stimulus competition between antecedent events in Pavlovian preparations, prior to this report there has been little examination in Pavlovian preparations of stimulus competition between subsequent events (but see Kamin, 1969; Rescorla, 1980, pp. 90–97). In causal judgment situations, however, competition between potential effects has been investigated extensively in recent years. Although there have been a few failures to obtain stimulus competition between potential effects of a cause (Van Hamme et al., 1993; Waldmann & Holyoak, 1992, Experiments 1 and 3), the majority view has been that competition readily occurs between effects (Chapman, 1991; Matute, Arcediano, & Miller, 1996; Price & Yates, 1993, 1995; Shanks, 1991; Shanks & Lopez, 1996). However, despite the many reports in the literature of competition between effects, the reality of the effect is still not firmly established because most of the studies used conditions in which the potential effects were presented to the participants prior to the potential causes (e.g., participants played the role of physicians who observed fictitious medical records, and the experimenter presented the symptoms [i.e., effects] that the fictitious patient showed before telling the participant what the potential cause was [e.g., Waldmann & Holyoak, 1992]). Thus, in most of those studies, effects were presented as antecedent events rather than as subsequent events, which allows for two alternative interpretations. Shanks and Lopez (1996) have argued that, when an effect is presented before a cause, as is the situation in the typical medical diagnostic task, the effect will be treated as an antecedent event (i.e., like a CS) rather than as a subsequent event (i.e., like a US). In this case, the result of competition between effects could be accommodated by associative theories that predict competition between antecedent events. On the other hand, Van Hamme et al. (1993) have interpreted prevailing associative theories to predict an absence of competition between effects even when effects are presented in the antecedent position. One study by Matute et al. (1996) observed competition between effects in a situation in which effects could not be interpreted as antecedent events because they were presented simultaneously with the potential causes (in a list format). This can

be interpreted as competition between effects that were presumably perceived as subsequent events, a result that would be contrary to most current theories of learning. However, because Matute et al. presented their causes and effects simultaneously in a list format, there is still a need for a clear demonstration of competition between effects when the competing effects are actually presented after the cause in both training and testing. The present research provides such a demonstration.

Observation of competition between subsequently presented events would be contrary to most contemporary associative theories in that it would imply comparable processing of antecedent and subsequent events. For example, the Rescorla–Wagner (1972) model is centrally concerned with the discrepancy between the expectation of the subsequent event evoked by the antecedent event and the subsequent event that actually occurs. Among contemporary associative theories, only the temporal coding hypothesis of Miller and Barnet (1993; also see Barnet, Arnold, & Miller, 1991; Matzel, Held, & Miller, 1988), the rate estimation theory of Gallistel (1990), and Wagner's (1981) SOP model, all of which treat CSs and USs symmetrically, could accommodate competition between subsequent events.

The study of competition between subsequent events using rats as subjects provides some additional benefits over the previous human causal learning studies. These include the avoidance of (a) the use of cover stories (i.e., the fictitious situations in which the human experimental tasks were embedded, such as the medical situation that we previously described), (b) the prior knowledge and biases evoked in the participants by the cover story, (c) the questions asked to assess stimulus competition, and (d) the temporal order in which the information is presented to the participants relative to the temporal order in which the events presumably actually occurred (e.g., in some studies, effects were presented to the participants before causes). As an example of the prior knowledge and biases evoked by the cover story, from previous experience, participants surely had some preexperimental expectation that certain causes (such as diseases) tend to occur independently of one another, whereas certain effects (such as the multiple symptoms of a disease) tend to occur in consistent clusters; this likely resulted in a predisposition for competition to more readily occur between causes than effects in situations that used the medical cover story. Additionally, from the Pavlovian literature there is reason to suspect that biologically significant stimuli (i.e., stimuli that elicit vigorous responding, typically USs or cues previously associated with USs) are less vulnerable to stimulus competition than are stimuli of low biological significance (Denniston, Miller, & Matute, 1996; Hall, Mackintosh, Goodall, & Dal Martello, 1977; Miller & Matute, 1996). The present research is intended as an analogue to a human causal judgment task. More specifically, we used a sensory preconditioning procedure to minimize the influence of factors a–d as well as to minimize the influence of differential biological significance between antecedent and subsequent events.

Experiment 1

The purpose of Experiment 1, which is the focal study in this report, was to examine competition between subsequent events and between antecedent events in a situation in which subsequent events could not plausibly be interpreted as causes rather than effects. Experiments 2 and 3 are ancillary studies that examine alternative explanations of the outcome of Experiment 1. Notably, we minimized factors that possibly confounded prior comparisons of competition between antecedent events with that between subsequent events, including differences in cover stories, prior knowledge evoked, wording of assessment questions, other demand characteristics of the tasks, inversion of temporal order of event presentation relative to the presumed actual order of occurrence, and biological significance of the antecedent and subsequent events.

A conventional measure of Pavlovian responding by rats was used to assess the acquired relationship between events. The experiment used a blocking design in which the potentially blocked stimulus was either an antecedent event or a subsequent event. Hereinafter, we refer to the potentially blocked stimulus as the target stimulus. To equate antecedent and subsequent events in terms of biological significance, all stimuli presented during the blocking phase of the experiment were of low biological significance. Specifically, they were auditory stimuli lacking signal value that induced only a moderate orienting response. Only after the blocking phases of the experiment were completed was the noncompeting stimulus (i.e., the event not presented simultaneously with the target event) made biologically significant by pairing it with a footshock US. This procedure constitutes a sensory preconditioning procedure (e.g., Rizley & Rescorla, 1972). By use of a sensory preconditioning procedure, we avoided confounding our focal independent variable (redundant antecedent event vs. redundant subsequent event) with differences in biological significance between antecedent and subsequent events.

Table 1 illustrates the central aspects of our three-phase procedure. For all groups, the first two phases involved presentations of three innocuous auditory stimuli: A, the antecedent stimulus; S, the subsequent stimulus; and X, the target stimulus. In Phase 1, two experimental groups (EXPA and EXPS) received stimulus A paired with stimulus S, with

A (the antecedent event) preceding S (the subsequent event); whereas two control groups (CONA and CONS) received comparable unpaired exposures to A and S. In Phase 2, stimulus X was introduced. For groups EXPA and CONA, X was presented in compound with A and followed by S (AX→S); whereas for groups EXPS and CONS, X was presented in compound with S and preceded by A (A→SX). Thus, Phases 1 and 2 constituted the two phases of a blocking procedure with X serving as the target stimulus. Stimulus X was an antecedent event in condition A (i.e., groups EXPA and CONA) and a subsequent event for condition S (i.e., groups EXPS and CONS). Condition A was designed to assess competition between antecedent events (i.e., competition between causes), and condition S was designed to assess competition between subsequent events (i.e., competition between effects).

Phase 2 not only served as the second phase of a blocking procedure but was also the first phase of a sensory preconditioning procedure for stimulus X. Phase 3 constituted the second phase of the sensory preconditioning procedure. In Phase 3, the stimulus from Phase 2 that had not been presented in compound with X (i.e., stimulus S for groups EXPA and CONA and stimulus A for groups EXPS and CONS) was paired with a US. This provided a motivational basis for responding so that stimulus competition between the two compounded stimuli could be assessed in a subsequent test phase.

Blocking was assessed by using conditioned suppression of drinking as an index of associative status. The animals were water-deprived rats that were acclimated to drinking water in the experimental apparatus. The US was a footshock. Testing consisted of presenting stimulus X while the rats were drinking. The duration of interrupted drinking served as our measure of association between X and the US. Presumably, presentation of X activated a representation of the footshock US and the activated representation of the US in turn induced fear that disrupted ongoing drinking. After testing with X, we then tested with the blocking stimulus (A or S).

Presentation of stimulus X to groups EXPA and CONA during the test phase was expected to activate a fear-inducing representation of the US in the predictive (forward) direction (i.e., from X to S and from S to the US; see Table 1; also see Matzel et al., 1988, for evidence that with these parameters a first-order association between X and the US is not formed). By contrast, presentation of stimulus X to groups EXPS and CONS was expected to activate a fear-inducing representation of the US in the diagnostic (backward) direction (i.e., X diagnosing that A had occurred, and the implied occurrence of A leading to a fear-inducing expectation of the US). Notably, this design potentially confounds competition between causes and between effects with type of reasoning required at the time of testing. However, if similar blocking or its absence were detected in the antecedent and subsequent conditions using this procedure, no further research to factor out these two variables would be necessary. Neither variable would likely be a factor in producing stimulus competition. Moreover, Matute et al. (1996) have reported that testing for compe-

Table 1
Design Summary of Experiment 1

Group	Treatment			Test
	Phase 1	Phase 2	Phase 3	
EXPA	A→S	AX→S	S→US	X? A?
CONA	A/S	AX→S	S→US	X? A?
EXPS	A→S	A→SX	A→US	X? S?
CONS	A/S	A→SX	A→US	X? S?

Note. EXPA and EXPS = experimental groups; CONA and CONS = control groups; A and S = antecedent and subsequent stimuli (tone and buzzer, counterbalanced); X = target stimulus (click train); US = unconditioned stimulus (footshock); → = followed immediately by; / = unpaired with.

tition between effects in the predictive direction (from cause to effect) may be a reason for the lack of competition between effects observed in some studies. At least for human participants, competition between effects is more readily obtained with diagnostic testing (from effect to cause) than with predictive testing; and competition between causes is readily obtained with predictive testing (from cause to effect). Consequently, the present design appears to maximize the likelihood of our observing competition both between antecedent events and between subsequent events.

Many studies of Pavlovian sensory preconditioning led us to expect responding to X by CONA animals when tested in the predictive (forward) situation (e.g., Rizley & Rescorla, 1972). Moreover, the results of a study by Matzel et al. (1988, Experiment 2) led us to expect responding to X by CONS animals when tested in the diagnostic situation. Matzel et al. investigated backward conditioning by using neutral stimuli X and Y and a US. They found that associations acquired as a result of backward pairings, although often latent, can be revealed through a sensory preconditioning procedure. Specifically, they observed that although US→Y pairings did not result in the elicitation of conditioned responding by stimulus Y, X→Y pairings (prior to the US→Y pairings) resulted in elicitation of conditioned responding by X. Thus, the sensory preconditioning procedure (i.e., X→Y) established X as a cue that revealed acquisition of the otherwise latent US→Y association. Presumably, response elicitation by a CS normally requires a predictive relationship of the CS to the US. In Matzel et al.'s study, X had a predictive relationship to the US, but one that was mediated by Y, which itself indicated the presence of the US in the diagnostic direction.

In summary, the use of a sensory preconditioning paradigm in the current experiment served two purposes. First, because the US was not introduced until the blocking phase (Phase 2) was completed, differences in the biological significance of stimuli A, S, and X during the blocking phase of the study were eliminated. Second, sensory preconditioning increased the likelihood that, at test, conditioned responding to X would be evidenced in at least the control animals trained in the subsequent condition despite the dependency of such responding on activation of a backward (i.e., diagnostic) association.

Method

Animals

The animals were 18 male and 18 female naive Sprague-Dawley rats (*Rattus norvegicus*), 80–110 days old, from our own breeding colony. Body weights were 250–310 g for males and 200–285 g for females. The animals were housed in standard hanging stainless steel wire mesh cages in a vivarium maintained on a 16:8-hr light–dark cycle. Experimental manipulations occurred approximately halfway through the light portion of the cycle. In the home cage, animals had free access to food (Purina Chow, Ralston-Purina, St. Louis, MO); water availability was limited to 10 min/day, following a progressive water deprivation schedule initiated 6

days prior to the start of the study. From the time of weaning until the start of the study, all animals were handled for 30 s three times a week. The rats were assigned to four groups ($n = 9$), counterbalanced for sex to the extent possible.

Apparatus

Twelve experimental chambers, 30.5 cm × 26.0 cm × 26.7 cm (length × width × height), were used. Each chamber was housed in an environmentally controlled chest. A houselight consisting of a #1820 bulb on the ceiling of each chamber provided constant dim illumination. Chamber ceilings and side walls were clear Plexiglas, and the front and back walls were sheet metal. Chamber floors were constructed of parallel, stainless steel rods that could be used to deliver the 0.5-mA, 5-s footshock, which served as the US.

All chambers were equipped with speakers that could deliver a complex tone (3000 Hz and 3200 Hz presented simultaneously), a click train (6 clicks/s), or a buzzing sound (hereinafter called a buzzer), all of which served as CSs. Each CS was approximately 8 dB(C) above the background noise level of 74 dB(C) re. SPL produced by a ventilation fan. All CS presentations were 5 s in duration. The tone and buzzer (counterbalanced to the extent possible within groups) served as stimuli A and S. The clicks always served as stimulus X.

In one corner of each chamber, there was a rectangular column with sheet metal walls, 13.0 cm × 7.8 cm, extending from the floor to the ceiling. There was a 5.4 cm × 3.5 cm × 4.0 cm (height × width × depth) niche present at the bottom of this column. A water-filled lick tube was left–right centered in the niche, 3.5 cm from the bottom and protruding 1.7 cm from the back of the niche. This lick tube was present except during training sessions. An infrared photobeam, 0.5 cm in front of the lick tube, monitored the animals' licking.

Experimental Design

The 2 × 2 factorial design of the experiment is depicted in Table 1. One independent variable was treatment in Phase 1: Stimuli A and S were either paired (EXP) or unpaired (CON). The second independent variable was treatment in Phase 2: Stimulus X (the target event) was presented simultaneous with either stimulus A (the antecedent event) or stimulus S (the subsequent event). In Phase 3, all animals received pairings of the footshock US with the stimulus that had not been compounded with the target stimulus (i.e., S→US or A→US). The dependent variable of primary interest was duration of suppression of licking in the presence of the target CS (i.e., X) during testing.

Procedure

Acclimation (Day 1). Each animal was acclimated to its chamber for 60 min during which the lick tube was available. All lick tubes were removed following acclimation.

Phase 1: Training with the blocking CS (Days 2–6). During each 60-min session, groups EXPA and EXPS were exposed to four A→S pairings. This treatment was designed to establish stimulus A as an antecedent event for stimulus S and S as a subsequent event for A. Onset of S coincided with the offset of A. The pairings were scheduled to occur pseudorandomly within the sessions; they were initiated 10, 20, 37, and 50 min into each session. Groups CONA and CONS were exposed daily to an equivalent number of A and S presentations in an unpaired manner with buzzer presentations being initiated 6, 22, 39, and 51 min into

the session and tone presentations being initiated 11, 16, 34, and 56 min into the session.

Phase 2: Training with the compounded blocking and target CS (Day 7). During a single 60-min session, a novel stimulus X (click train) was introduced. For groups EXPA and CONA, X was presented simultaneously with A; the offset of the AX compound coincided with the onset of S (i.e., AX→S). For groups EXPS and CONS, X was presented simultaneously with S; the offset of A coincided with the onset of the SX compound (i.e., A→SX). There were four of these pairings. They were initiated 10, 20, 37, and 50 min into the session.

Phase 3: First-order conditioning (Day 8). The intent of this training phase was to facilitate later testing by endowing with biological significance the Phase 2 event that had not been presented simultaneously with X. During a single 60-min session, all animals were exposed to a total of four CS-US pairings. Onset of the footshock US coincided with offset of the CS. Groups EXPA and CONA were exposed to four S→US pairings, and groups EXPS and CONS were exposed to four A→US pairings. The pairings were initiated 10, 20, 37, and 50 min into the session.

Reacclimation (Days 9–10). The lick tubes were returned to the experimental chambers. On each of 2 days, all animals received a 60-min session during which no CS or US was presented. This restabilized baseline licking behavior, departure from which served as the dependent variable during testing.

Test with target CS (Day 11). During an 11-min session, the time required for each animal to complete 5 cumulative seconds of drinking in the presence of the target stimulus (i.e., stimulus X) was measured. Stimulus X was presented to each rat on completion of the animal's first 5 cumulative seconds of drinking and was terminated 10 min thereafter. Thus, each rat was drinking at the onset of stimulus X, a condition that we find in general reduces within-group variance.

Test with blocking CS (Day 12). During an 11-min session, each animal was again tested for lick suppression, but this time the test stimulus was the blocking CS. The procedure was the same as that which had been used in testing the target CS on Day 11. Groups EXPA and CONA were tested for time to complete 5 cumulative seconds of drinking in the presence of stimulus A. Groups EXPS and CONS were tested for time to complete 5 cumulative seconds of drinking in the presence of stimulus S.

Preanalysis Treatment of Data

Data from 1 animal from each of groups EXPA, CONA, and EXPS were lost because of an equipment failure. An additional animal was eliminated from group CONA because of illness. Because the test CS was presented on completion of 5 cumulative seconds of licking, all animals were licking at about their species-typical rate of 5.5 licks per second at CS onset. Hence, suppression ratios were not necessary to correct for individual differences in baseline behavior. Analyses were performed on time to complete 5 cumulative seconds of drinking in the presence of the test CS. However, time was transformed to log seconds to improve the normality of the within-group data, thereby enhancing the appropriateness of our using parametric statistics. An alpha level of $p < .05$ was adopted for statistical significance.

Results and Discussion

The main finding of this experiment was blocking of both antecedent and subsequent events: Groups EXPA and EXPS

responded less to the target stimulus (X) than did groups CONA and CONS, respectively.

Target Stimulus (X) Data

Figure 1 depicts mean time to drink for 5 cumulative seconds in the presence of the target stimulus (X) on Day 11. Inspection of Figure 1 reveals little conditioned suppression to the target stimulus in each of the two experimental groups relative to their respective control groups. A 2 (experimental vs. control) \times 2 (antecedent vs. subsequent position of the target event) analysis of variance (ANOVA) on time to drink for 5 cumulative seconds in the presence of the target stimulus was conducted. There was a main effect of experimental versus control treatment, $F(1, 28) = 13.06$, which is indicative of blocking. However, the antecedent versus subsequent factor, $F(1, 28) = 1.88$, and the interaction of these two factors, $F(1, 28) = 0.28$, were not significant. Planned comparisons revealed differences between groups EXPA and CONA, $F(1, 28) = 11.06$, and also between groups EXPS and CONS, $F(1, 28) = 5.08$. Thus, blocking was observed in both the antecedent and subsequent conditions.

This conclusion is consistent with that of Rescorla (1980, pp. 90–97), who studied competition between subsequent events (but not between antecedent events in the same study) by using a second-order conditioning procedure. In second-order conditioning, the first- and second-order CSs are paired after the first-order CS has been paired with the US, rather than before as is the case in sensory preconditioning. Hence, at the time of training, Rescorla's competing subsequent events possessed high affective value, in contrast to Experiment 1 here. The present absence of

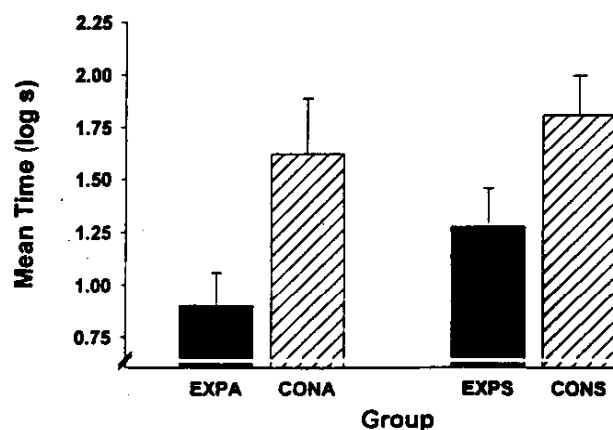


Figure 1. Experiment 1, Day 11—Mean time in log seconds to lick for 5 cumulative seconds in the presence of the target stimulus X (i.e., clicks) as a function of treatment group. The conditioned response was lick suppression; hence, the longer the time the stronger the implicit association. EXPA and CONA demonstrate blocking of an antecedent event, whereas groups EXPS and CONS demonstrate the blocking of a subsequent event. Error brackets represent standard errors of means. EXPA and EXPS = experimental groups; CONA and CONS = control groups.

affective value of the competing subsequent events at the time of training provides a situation more analogous to causal judgment tasks, in which the effects are ordinarily of low affective value. However, our data in conjunction with Rescorla's indicate that competition between subsequent events is not dependent on the use of sensory preconditioning. Denniston et al. (1996) and Miller and Matute (1996) have shown that as the biological significance of stimuli increases, their susceptibility to cue competition decreases. This suggests that blocking between subsequent events should be more readily obtained with neutral events, such as in causal judgment and sensory preconditioning experiments than in second-order conditioning or in situations in which the subsequent events are biologically significant USs.

Blocking Stimulus (A or S) Data

Figure 2 illustrates mean time to drink for 5 cumulative seconds in the presence of the blocking stimuli on Day 12. A 2 (experimental vs. control) \times 2 (antecedent vs. subsequent) ANOVA on time to drink for 5 cumulative seconds in the presence of the blocking stimulus was conducted. No factor proved significant. All groups exhibited suppression appreciably greater than the 0.8–1.0 log s typically observed in untrained rats in our laboratory when presented with physical stimuli identical to the present ones. The nonsignificant tendency of the two experimental groups to respond (i.e., suppress) more than the two control groups to the blocking stimulus is consistent with the experimental

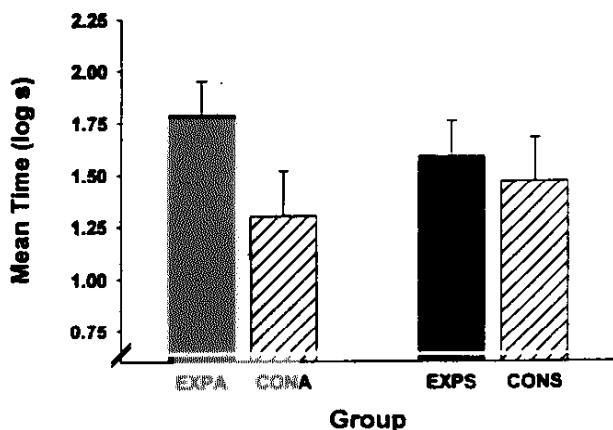


Figure 2. Experiment 1, Day 12—Mean time in log seconds to lick for 5 cumulative seconds in the presence of the blocking stimulus A or S (i.e., tone and buzzer, counterbalanced within groups) as a function of treatment group. Thus, responding to stimulus A is depicted for groups EXPA and CONA, whereas responding to stimulus S is depicted for groups EXPS and CONS. The conditioned response was lick suppression; hence, the longer the time the stronger the implicit association. Error brackets represent standard errors of means. EXPA and EXPS = experimental groups; CONA and CONS = control groups.

groups having received more A–S pairings (during Phase 1) than did the control groups (see Table 1).

The present analysis has assumed that serially paired stimuli form associations but has ignored the possibility that simultaneously paired stimuli may also have entered into associations that influenced the observed behavior. That is, the simultaneous presentation of A and X to the animals in the antecedent condition and S and X to the animals in subsequent condition allowed the possibility of within-compound associations (e.g., Rescorla & Durlach, 1981) between A and X and between S and X, respectively. However, to the extent that such within-compound associations were formed, they would have created a bias toward responding to X resembling responding to A in the antecedent condition and responding to S in the subsequent condition; that is, within-compound associations would tend to mask blocking. Comparison of Figures 1 and 2 indicates that within-group responding to X and its simultaneous companion stimulus was negatively correlated (as expected from stimulus competition) rather than positively correlated (as expected from within-compound associations). Hence, we may conclude that within-compound associations played relatively little role in stimulating responding to X and surely were not the source of the observed blocking of X.

Sensory Preconditioning

Appreciable conditioned responding was observed to the target stimulus in the control groups and to the blocking stimulus in all groups. Responding to these stimuli suggests the occurrence of sensory preconditioning. Notably, in the subsequent condition this responding to stimulus S (and X) constitutes backward sensory preconditioning (i.e., A→S, A→US, test S, in contrast to traditional forward sensory precondition that consists of A→S, S→US, test A). Although we did not include a proper (unpaired) control group for sensory preconditioning because our central concern was with blocking rather than with sensory preconditioning, the present data appear consistent with the occurrence of backward sensory preconditioning. This observation of backward sensory preconditioning is congruent with data reported by Cole, Barnet, and Miller (1995), Silver and Meyer (1954), and Ward-Robinson and Hall (1996), but inconsistent with reports by Brown and King (1969), Tait, Marquis, Williams, Weinstein, and Suboski (1969), and Wynn and Brogden (1962), all of who failed to observe backward sensory preconditioning. The reason for this inconsistency in backward sensory preconditioning is not immediately clear because there were many procedural differences among these studies. However, we suspect that the temporal intervals between the elements in each of the two phases of the sensory preconditioning procedure are critical in determining the outcome.

Although we favor interpreting the results of Experiment 1 in terms of competition between antecedent events and between subsequent events, there are at least three alternative interpretations of these results. The first (suggested by G. Hall, personal communication, September 22, 1994)

posits that presentation of A in Phase 3 reactivated the representations of S and X, which was then immediately followed by presentation of the footshock US. Because group EXPS had received more A→S training than had group CONS because of Phase 1 treatment, activation of the representation of S by A during Phase 3 might have been stronger in group EXPS than in group CONS. This greater activation of S during Phase 3 in group EXPS could have produced more overshadowing of the representation of X by the representation of S, as the representations of X and S competed for association to the US during Phase 3. In this scenario, competition between S and X in the subsequent condition occurred during Phase 3, when each cue had a forward relationship with the US. This is an interesting possibility, but Matzel et al. (1988, Experiment 4) found with these exact parameters (but not a blocking design) that posttraining extinction of the Phase 3 CS eliminated responding to the test CS. This indicates that during Phase 3 the CSs that are not presented are not forming their own direct associations to the US.

The second alternative interpretation is that, because of the brevity of the CSs and lack of any interval between them, the animals may have failed to perceive the difference between our antecedent and subsequent conditions. That is, in both conditions they might have processed the three events (A, X, and S) as simultaneous events. If this were correct, the two conditions for all practical purposes would have constituted a single condition of simultaneous presentations of an AS compound in Phase 1 and of simultaneous presentations of an ASX compound in Phase 2. Consequently, the common outcome of stimulus competition in our antecedent and subsequent conditions would reflect our having run the same condition twice and therefore would not speak to any of the issues of interest in the present report. The current data provide no basis for precluding such a possibility. Experiment 2 was designed to examine this possibility. The third alternative explanation for the results of Experiment 1 is described and tested in Experiment 3.

Experiment 2

To ascertain if animals in Experiment 1 were treating X, A, and S as simultaneous stimuli, Experiment 2 focused on the treatment that had constituted Phase 2 of Experiment 1 and asked if AX→S pairings (where "AX" denotes A and X presented simultaneously) were perceived as different from A→SX pairings. Table 2 illustrates the design of Experiment 2. In Phase 1 of this experiment, half of the rats were first exposed to AX→S pairings, whereas the remaining rats were exposed to A→SX pairings. Then half of the animals in each of these two conditions were exposed to simultaneous pairings of S and the US. These rats (groups X→S and XS, respectively) were then tested on X. The relationship between X and S (and consequently also between X and the US) was predictive for animals that had been exposed to AX→S (group X→S) and was simultaneous for animals that had been exposed to A→SX (group XS). Thus, if the two training conditions were differentially

Table 2
Design Summary of Experiment 2

Group	Treatment		Test
	Phase 1	Phase 2	
X→S	AX→S	S-US	X?
XS	A→SX	S-US	X?
A→X	A→SX	X-US	A?
AX	AX→S	X-US	A?

Note. A and S = antecedent and subsequent stimuli (tone and buzzer, counterbalanced); X = target stimulus (click train); US = unconditioned stimulus (footshock). → = followed immediately by; - = simultaneous with.

perceived, AX→S pairings should have resulted in X having an anticipatory relationship to S (and thus also to the US), which consequently should have supported responding to X in group X→S; whereas A→SX pairings should have resulted in X having a simultaneous relationship with S (and thus also to the US), which consequently should not have supported conditioned responding in group XS. However, if X, A, and S were perceived as simultaneous events, little, and more important, equal conditioned responding to X would be expected. In summary, these two groups assessed whether S and X were perceived as simultaneous or sequential by group X→S.

The other half of the animals in each training condition (AX→S and A→SX) subsequently received simultaneous pairings of X and the US. These rats (groups AX and A→X, respectively) were then tested with A. If the rats perceived the two training conditions differently, we would expect that X-US simultaneous pairings would result in anticipatory responding to A in group A→X, but not in group AX. Thus, these latter two groups assessed whether A and X were perceived as simultaneous or sequential by group A→X.

Method

Animals and Apparatus

The animals were 24 male and 24 female naive rats of the same description and housed in the same fashion as in Experiment 1. Body weights were 200–385 g for males and 170–265 g for females. The apparatus, stimuli, and all parameters except where otherwise noted were identical to those used in Experiment 1.

Procedure

Acclimation (Day 1). This exposure to the experimental apparatus was the same as in Experiment 1.

Phase 1: Training with the compounded stimuli (Day 2). This treatment was identical to Phase 2 in Experiment 1 (see Table 1). During a single 60-min session, groups X→S and AX received four trials consisting of a simultaneous compound of A and X followed immediately by S (i.e., AX→S). Groups A→X and XS received A followed immediately by a simultaneous compound of S and X (i.e., A→SX). This is illustrated in Table 2.

Phase 2: First-order conditioning (Day 3). During a single 60-min session, Groups X→S and XS received S-US pairings.

with simultaneous onset and termination of S and the US. Groups A→X and AX received four X-US pairings, with simultaneous onset and termination of X and the US.

Reacclimation (Days 4 and 5) and testing (Day 6). Reacclimation to the apparatus was intended to restabilize baseline licking. It occurred on Days 4 and 5 just as in Experiment 1. Testing used the same procedure as was used in Experiment 1 except that groups X→S and XS were tested on X, and groups AX and A→X were tested on A.

Results and Discussion

Group X→S responded more to X than did group XS, and group A→X responded more to A than did group AX (see Figure 3). These observations indicate that the rats were able to discriminate between simultaneous and sequential presentations of the stimuli.

As the clicks always served as X and the tone and buzzer (counterbalanced) served as A (and S), it would be inappropriate to make any comparisons between groups tested on X and those tested on A. Consequently, *t* tests were performed between the groups tested on the same physical stimuli. Group X→S differed from group XS, $t(22) = 3.49$, and group A→X differed from group AX, $t(22) = 2.65$, (see Figure 3). The first comparison indicates that X preceding S was perceived as different from X being presented simultaneously with S. The second comparison indicates that X following A was perceived as different from X being presented simultaneously with A. Collectively, these results permit us to reject as an explanation of the blocking observed in both conditions of Experiment 1 the possibility that the rats perceived X, A, and S as all being simultaneous, which would have made the AX→S and A→XS conditions of Phase 2 in Experiment 1 functionally equivalent.

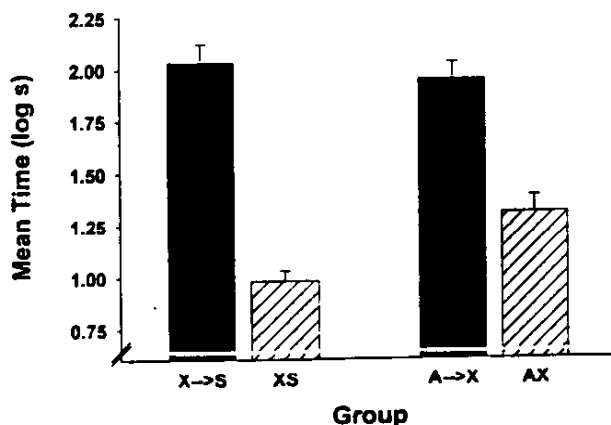


Figure 3. Experiment 2—Mean time in log seconds to lick for 5 cumulative seconds in the presence of the target stimulus, which was X for groups X→S and XS, and A for groups A→X and AX. The conditioned response was lick suppression; hence, the longer the time the stronger the implicit association. Error brackets represent standard errors of means.

Experiment 3

A third alternative explanation for the results of Experiment 1, specifically for the blocking of subsequent events observed in group EXPS relative to group CONS, has been proposed by K. Holyoak (personal communication, August 1, 1995). Holyoak suggested the following: Animals in groups EXPS and CONS learned causal connections from A to S and X during Phases 1 and 2 and from A to the US during Phase 3 (see Table 1). Their response to X at test depended on how likely it was that X signaled that A had just occurred. This judgment depended on the likelihood that X was caused by A. Because X prior to test had always been presented in compound with S, at test X was perceived as "X and not-S," a novel combination of events. The animal then assessed how likely A was to produce "X and not-S." This was estimated as a function of two factors: (a) how likely was A to produce X, and (b) how likely was A to produce not-S. The first factor was equivalent for groups EXPS and CONS. However, the second factor was lower for group EXPS than for group CONS because during Phase 1 group EXPS experienced A as producing S, whereas group CONS experienced A without its being followed by S. That is, there was a higher contingency from A to S in group EXPS than in group CONS. According to this analysis, the blocking of X observed in group EXPS in Experiment 1 reflected the rats' using the entire pattern of relevant stimuli (absences as well as presences) to estimate whether the cause occurred, rather than using only the stimuli that were present and ignoring those that were absent. Similar logic produced a complementary prediction for "X and not-A" in the antecedent condition. In this framework, there is no need to conclude that associative competition between subsequent events occurred in Experiment 1 (or in any prior blocking experiment that used uncorrelated treatment for the control condition). Rather, the apparent associative competition could be explained by contingency theories. Experiment 3 was designed to test this hypothesis.

Holyoak's hypothesis hinges on A being a better predictor of S for groups EXPS and EXPA than for groups CONS and CONA because of the control groups' unpaired experience with A and S during Phase 1. In Experiment 1, following common practice we administered unpaired A and S presentations to the control groups during Phase 1 in order to equate with the experimental groups the total number of exposures to each stimulus. However, this ploy did create the situation in which the experimental groups received A→S pairings, whereas the control groups did not, and the control groups received A and S unpaired, whereas the experimental groups did not. Holyoak's hypothesis essentially views the unpaired exposure of the control groups to A and S during Phase 1 as a confound. Because there are many demonstrations of blocking between antecedent events using different control treatments (e.g., Kamin, 1968), in Experiment 3 we focused on the new result of Experiment 1, blocking between subsequent events, and repeated Experiment 1 for groups EXPS and CONS, omitting the unpaired exposure to A and S. Instead, group CONS simply spent Phase 1 in the experimental apparatus for a

period of time equivalent to that of group EXPS. According to Holyoak's interpretation, this change should have eliminated the blocking previously observed in group EXPS because now A does not predict "not-S" in the control group. In contrast, we predicted blocking in group EXPS of Experiment 3 for the same reasons that we predicted blocking in group EXPS of Experiment 1.

Method

Animals and Apparatus

The animals were 12 male and 12 female naive rats of the same description as those used in the previous experiments. The weight range was 380–490 g for males and 275–315 g for females. Animals were assigned to one of two groups (EXPS and CONS) counterbalanced for sex ($n = 12$). The apparatus was the same as was used in Experiments 1 and 2.

Procedure

The procedure was identical to that for groups EXPS and CONS in Experiment 1 (see Table 1) except that during Phase 1 group CONS did not receive explicitly unpaired presentations of A and S. Instead, this group spent an equivalent period of time in the experimental apparatus to that of group EXPS. One animal in group EXPS was eliminated from the study because of an equipment problem on the first day of testing.

Results and Discussion

Consistent with the outcome of Experiment 1, less responding was seen in group EXPS than in group CONS. Thus, contrary to Holyoak's suggestion, the blocking of subsequent events does not depend on the control group receiving explicitly unpaired presentations of A and S.

Mean responding to the blocked stimulus (X) was 0.97 ($SE = 0.06$) log s for group EXPS and 2.17 ($SE = 0.16$) log s for group CONS. A t test found this difference significant, $t(21) = 6.77$. This difference replicates the blocking of subsequent events that was observed in Experiment 1, thereby demonstrating the reliability of the effect. Furthermore, blocking in the absence of explicitly unpaired exposure of group CONS to A and S refutes Holyoak's hypothesis concerning the blocking of subsequent events that was observed in Experiment 1. Notably, the size of the blocking effect was not even diminished relative to Experiment 1 by the omission of group CONS' Phase 1 treatment as might be expected if Holyoak's hypothesis were partially correct; rather, the absolute size of the blocking effect increased (compare these results with those for groups EXPS and CONS in Figure 1).

Mean responding to the blocking stimulus (S) was 1.87 ($SE = 0.14$) log s for group EXPS and 1.29 ($SE = 0.11$) log s for group CONS. A t test found this difference significant, $t(21) = 3.23$. This latter difference is consistent with the greater number of A→S pairings received by group EXPS relative to group CONS because of difference in Phase 1 treatment.

General Discussion

Implications for Pavlovian Conditioning and Causal Judgments

The main finding of this research is that blocking was observed when the target event was a subsequent event tested in the diagnostic direction as well as when it was an antecedent event tested in the predictive direction. This indicates that antecedent versus subsequent position is not a critical determinant of stimulus competition.

Our finding that one antecedent stimulus can compete with (in this case, block) another antecedent stimulus has frequently been observed in both animals (e.g., Kamin, 1968; Wagner, Logan, Haberlandt, & Price, 1968; Wasserman, 1974) and humans (e.g., Arcediano, Matute, & Miller, in press; Chapman & Robbins, 1990; Jones et al., 1990; Waldmann & Holyoak, 1992). In causal terminology, one would say that a more predictive stimulus presented simultaneously with a less predictive stimulus interferes with the perception of the less predictive stimulus as a predictor or, arguably, as a cause of the subsequent event (i.e., the US or effect). Although competition between antecedent stimuli is not a ubiquitous finding, it is commonly observed. The only novel aspect of this component of the present results is that it is the first demonstration of competition between antecedent stimuli in a sensory preconditioning preparation, a situation in which both the antecedent and subsequent events are neutral stimuli at the time of the treatment that induces stimulus competition (i.e., Phase 2).

More important is our observation that one subsequent stimulus can compete with another subsequent stimulus. To our knowledge, the only prior investigations of this issue in nonhuman animals were Kamin's (1969), which did not obtain blocking, and Rescorla's (1980), which did obtain blocking. In Kamin's study the competing stimuli were USs of high biological significance (i.e., capable of eliciting vigorous responding) at the time of blocking treatment, whereas in Rescorla's study the competing events were first-order CSs in Phase 2 of a second-order conditioning procedure, that is, presumably stimuli with a moderate degree of acquired biological significance at the time of blocking treatment. In the present study, the competing subsequent stimuli were neutral stimuli of low biological significance (i.e., they did not elicit any appreciable responding at the time of blocking treatment) because of our use of a sensory preconditioning procedure. The opportunity for stimulus competition between events occurred when the events were all of low biological significance (i.e., prior to the introduction of footshock in Phase 3). Thus, this cross-experiment comparison of attempts to observe blocking of subsequent stimuli suggests that as the biological significance of the competing stimuli increases, blocking is less likely to be observed. Consistent with this, other research conducted in our laboratory has found that increasing the biological significance of antecedent stimuli decreases the vulnerability of those stimuli to stimulus competition (Denniston et al., 1996; Miller & Matute, 1996). In view of this evidence, competition between antecedent or between

subsequent events would not be expected if the competing events were of inherent biological significance (i.e., USs in antecedent or subsequent position, e.g., Denniston et al., 1996; Hall et al., 1977; Kamin, 1969; Miller & Matute, 1996), would be expected as somewhat more likely to occur if the competing events had acquired biological significance after pairings with USs (i.e., CSs in antecedent or subsequent position; e.g., Denniston et al., 1996, did not observe blocking, but Rescorla, 1980, did observe blocking), and would be strongly expected between events of low biological significance (e.g., the present research; Denniston et al., 1996; Miller & Matute, 1996).

The relationship of the present observation of competition between subsequent events to the results of Chapman (1991), Price and Yates (1993), Shanks (1991), and Shanks and Lopez (1996), all of who reported competition between effects in human causal judgment, is not immediately clear. In each of those studies, participants were asked to diagnose the likelihood of a cause (e.g., disease in a fictitious patient) based on the presence or absence of several effects (e.g., symptoms), presumably of low biological significance because the cause and effect applied to fictitious patients. The competition between effects that was observed in those studies could be interpreted as competition between subsequent events because the cover stories used in those studies suggested that symptoms were a consequence of the disease even though the symptoms were revealed to the participants before the presence of the disease. In this framework, the present results would serve as a Pavlovian analogue that also demonstrates competition between subsequent events. However, competition between effects in these studies of causal judgment has also been interpreted as competition between antecedent events because effects were always presented prior to causes (see Shanks & Lopez, 1996). In this framework, our demonstration of competition between subsequent events of low biological significance has no counterpart in the causal judgment literature (but see Arce-diano, Matute, & Miller, 1996, for new data demonstrating this phenomenon in humans).

Associative Versus Rule-Based Models

Associative analyses (such as the Rescorla-Wagner model, 1972) have generally been better received as explanations of Pavlovian learning than have normative/rule-based analyses (such as Rescorla's contingency theory, 1968; see Papini & Bitterman, 1990). In contrast, within the causal judgment literature, both associative and normative analyses have been advanced in recent years. (For detailed comparisons of rule-based models and associative models of causal judgment, see Allan, 1993; Shanks, 1993a, 1993b.)

Waldmann and Holyoak (1992) proposed that the difference they observed between causes and effects in susceptibility to stimulus competition could not be explained by associative theories (e.g., Rescorla & Wagner, 1972) because, in their view, these theories predict competition between effects if effects are presented before causes during

training. In contrast, their rule-based model predicts no competition between effects regardless of when the effects are presented during causal training. Thus, because they failed to observe competition between effects, Waldmann and Holyoak rejected all associative models as complete explanations of causal judgment. In making this assertion, they used the Rescorla-Wagner (1972) model to represent associative models in general. However, as previously mentioned, many other researchers have observed competition between effects when the effects were presented before the cause (e.g., Chapman, 1991; Price & Yates, 1993, 1995; Shanks, 1991; Shanks & Lopez, 1996) or simultaneously with the cause (Matute et al., 1996). Additionally, the competition between subsequent events observed in Experiments 1 and 3 of the present research using a diagnostic test can be explained by neither the Rescorla-Wagner associative model, which was developed to apply only to predictive situations, nor Waldmann and Holyoak's (1992) rule-based cognitive-causal model. Neither model predicts competition between subsequent events.¹

In contrast, the temporal coding hypothesis (Barnet et al., 1991; Matzel et al., 1988), Wagner's (1981) SOP model, and Gallistel's (1990) rate estimation theory are compatible with the present observation of blocking of both antecedent and subsequent events. For example, the temporal coding hypothesis assumes that temporal contiguity between two events is not only a catalyst for forming an association but that the temporal relationship between the events is an attribute of that association and that this attribute strongly influences the nature of conditioned responding (see Gallistel, 1990, for a similar view). Thus, the temporal coding hypothesis predicts acquisition of bidirectional associations and otherwise equivalent processing of antecedent and subsequent event representations. Although the temporal coding hypothesis assumes all associations are bidirectional, it further assumes that there are potentially different conditioned responses as a function of the direction of the association that is activated by the test stimuli. That is, the behavior produced by an activated association predicting that an event is about to occur is potentially different from the behavior (if any) produced by an activated association that some event should have just occurred. In Experiments 1 and 3, the use of a sensory preconditioning paradigm complemented the A→SX pairings of condition S with an experience in which a US was anticipated (i.e., A→US), thereby permitting traditional assessment of stimulus X dependent on anticipation of the US.

Although the present observations are inconsistent with both the Rescorla-Wagner associative model (1972) and the rule-based cognitive-causal model of Waldmann and Ho-

¹ The Rescorla-Wagner (1972) model was not intended to address situations in which multiple USs occur in a single trial nor situations in which the test phase requires diagnostic rather than predictive reasoning. Hence, our statement that it does not predict competition between subsequent events is predicated on our extrapolation of it to this situation. Other extrapolations of it might well be able to accommodate the present blocking of subsequent events.

lyoak (1992), we suspect that other models, both associative and rule-based, could be created that would explain these results. As a constraint on any model, associative or rule-based, we suggest that stimulus competition is likely to occur whenever the target stimulus during training is redundant and of relatively low biological significance. Further progress on this problem requires research specifically designed to better determine the controlling conditions under which stimulus competition is favored. Temporal position of the target stimulus (i.e., antecedent vs. subsequent event, as seen in the present research) and status as cause or effect (Matute et al., 1996) do not appear critical to the occurrence of stimulus competition. Rather, the present research suggests that antecedent and subsequent events are processed in a symmetrical manner.

References

- Allan, L. G. (1993). Human contingency judgments: Rule based or associative? *Psychological Bulletin*, *114*, 435-448.
- Arcediano, F., Matute, H., & Miller, R. R. (1996). *Competition between antecedent and between subsequent stimuli in causal situations*. Manuscript submitted for publication.
- Arcediano, F., Matute, H., & Miller, R. R. (in press). Blocking of Pavlovian conditioning in humans. *Learning and Motivation*.
- Barnet, R. C., Arnold, H. M., & Miller, R. R. (1991). Simultaneous conditioning demonstrated in second-order conditioning: Evidence for similar associative structure in forward and simultaneous conditioning. *Learning and Motivation*, *22*, 253-268.
- Brown, C., & King, M. G. (1969). Backward sensory preconditioning: The ineffectiveness of the procedure under optimal conditions. *Australian Journal of Psychology*, *21*, 55-58.
- Chapman, G. B. (1991). Trial order affects cue interaction in contingency judgment. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 837-854.
- Chapman, G. B., & Robbins, S. J. (1990). Cue interaction in human contingency judgment. *Memory & Cognition*, *18*, 537-545.
- Cole, R. P., Barnet, R. C., & Miller, R. R. (1995). Temporal encoding in trace conditioning. *Animal Learning & Behavior*, *23*, 144-153.
- Denniston, J. C., Miller, R. R., & Matute, H. (1996). Biological significance as a determinant of cue competition. *Psychological Science*, *7*, 325-331.
- Dickinson, A., Shanks, D. R., & Evenden, J. L. (1984). Judgement of act-outcome contingency: The role of selective attribution. *Quarterly Journal of Experimental Psychology*, *36A*, 29-50.
- Gallistel, C. R. (1990). *The organization of learning*. Cambridge, MA: MIT Press.
- Hall, G., Mackintosh, N. J., Goodall, G., & Dal Martello, M. (1977). Loss of control by a less valid or by a less salient stimulus compounded with a better predictor of reinforcement. *Learning and Motivation*, *8*, 145-158.
- Hinchy, J., Lovibond, P. F., & Ter-Horst, K. M. (1995). Blocking in human electrodermal conditioning. *Quarterly Journal of Experimental Psychology*, *48B*, 2-12.
- Jones, S. H., Gray, J. A., & Hemsley, D. R. (1990). The Kamin blocking effect, incidental learning and psychoticism. *British Journal of Psychology*, *81*, 95-110.
- Kamin, L. J. (1968). "Attention-like" processes in classical conditioning. In M. R. Jones (Ed.), *Miami Symposium on the Prediction of Behavior: Aversive stimulation* (pp. 9-31). Miami, FL: University of Miami Press.
- Kamin, L. J. (1969). Predictability, surprise, attention, and conditioning. In B. A. Campbell & M. R. Church (Eds.), *Punishment and aversive behavior* (pp. 279-296). New York: Appleton-Century-Crofts.
- Martin, I., & Levey, A. B. (1991). Blocking observed in human eyelid conditioning. *Quarterly Journal of Experimental Psychology*, *43B*, 233-256.
- Matute, H., Arcediano, F., & Miller, R. R. (1996). Tert question modulates cue competition between causes and between effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 182-196.
- Matzel, L. D., Held, F. P., & Miller, R. R. (1988). Information and expression of simultaneous and backward associations: Implications for contiguity theory. *Learning and Motivation*, *19*, 317-344.
- Miller, R. R., & Barnet, R. C. (1993). The role of time in elementary associations. *Current Directions in Psychological Science*, *2*, 106-111.
- Miller, R. R., & Matute, H. (1996). Biological significance in forward and backward blocking: Resolution of a discrepancy between animal conditioning and human causal judgment. *Journal of Experimental Psychology: General*, *125*, 370-386.
- Papini, M. R., & Bitterman, M. E. (1990). The role of contingency in classical conditioning. *Psychological Review*, *97*, 396-403.
- Price, P. C., & Yates, J. F. (1993). Judgmental overshadowing: Further evidence of cue interaction in contingency judgment. *Memory & Cognition*, *21*, 561-572.
- Price, P. C., & Yates, J. F. (1995). Associative and rule-based accounts of cue interaction in contingency judgment. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*, 1639-1655.
- Rescorla, R. A. (1968). Probability of shock in the presence and absence of CS in fear conditioning. *Journal of Comparative and Physiological Psychology*, *66*, 1-5.
- Rescorla, R. A. (1980). *Pavlovian second-order conditioning: Studies in associative learning*. Hillsdale, NJ: Erlbaum.
- Rescorla, R. A., & Durlach, P. J. (1981). Within-event learning in Pavlovian conditioning. In N. E. Spear & R. R. Miller (Eds.), *Information processing in animals: Memory mechanisms* (pp. 81-112). Hillsdale, NJ: Erlbaum.
- Rescorla, R. A., & Wagner, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II: Current research and theory* (pp. 64-99). New York: Appleton-Century-Crofts.
- Rizley, R. C., & Rescorla, R. A. (1972). Associations in second-order conditioning and sensory preconditioning. *Journal of Comparative and Physiological Psychology*, *81*, 1-11.
- Shanks, D. R. (1991). Categorization by a connectionist network. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *17*, 433-443.
- Shanks, D. R. (1993a). Associative versus contingency accounts of category learning: Reply to Melz, Cheng, Holyoak, and Waldmann (1993). *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *19*, 1411-1423.
- Shanks, D. R. (1993b). Human instrumental learning: A critical review of data and theory. *British Journal of Psychology*, *84*, 319-354.
- Shanks, D. R., & Dickinson, A. (1987). Associative accounts of causality judgment. In G. H. Bower (Ed.), *The psychology of learning and motivation* (Vol. 21, pp. 229-261). San Diego, CA: Academic Press.
- Shanks, D. R., & Lopez, F. J. (1996). Causal order does not affect

- cue selection in human associative learning. *Memory & Cognition*, 24, 511-522.
- Silver, C. A., & Meyer, D. R. (1954). Temporal factors in sensory preconditioning. *Journal of Comparative and Physiological Psychology*, 47, 57-59.
- Tait, R. W., Marquis, H. A., Williams, R., Weinstein, L., & Suboski, M. D. (1969). Extinction of sensory preconditioning using CER training. *Journal of Comparative and Physiological Psychology*, 69, 170-172.
- Van Hamme, L. J., Kao, S-F., & Wasserman, E. A. (1993). Judging interevent relations: From cause to effect and from effect to cause. *Memory and Cognition*, 21, 802-808.
- Wagner, A. R. (1981). SOP: A model of automatic memory processing in animal behavior. In N. E. Spear & R. R. Miller (Eds.), *Information processing in animals: Memory mechanisms* (pp. 5-47). Hillsdale, NJ: Erlbaum.
- Wagner, A. R., Logan, F. A., Haberlandt, K., & Price, T. (1968). Stimulus selection and a "modified continuity theory." *Journal of Experimental Psychology*, 76, 171-180.
- Waldmann, M. R., & Holyoak, K. J. (1992). Predictive and diagnostic learning within causal models: Asymmetries in cue competition. *Journal of Experimental Psychology: General*, 121, 222-236.
- Ward-Robinson, J., & Hall, G. (1996). *Backward sensory preconditioning*. Manuscript submitted for publication.
- Wasserman, E. A. (1974). Stimulus-reinforcer predictiveness and selective discrimination learning in pigeons. *Journal of Experimental Psychology*, 103, 284-297.
- Wynn, J. D., & Brogden, W. J. (1962). Supplementary report: Effect upon sensory preconditioning of backward, forward, and trace preconditioning training. *Journal of Experimental Psychology*, 64, 422-423.

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