

Unblocking with Qualitative Change of Unconditioned Stimulus

Aaron P. Blaisdell, James C. Denniston, and Ralph R. Miller

State University of New York at Binghamton

Conditioned barpress suppression was used to examine the effects of qualitative changes in the unconditioned stimulus (US) between Phases 1 and 2 of a blocking paradigm. In Phase 1, rats received pairings of a conditioned stimulus (CS) with footshock. In Phase 2, experimental subjects received a single trial of the same CS or a different CS compounded with a second stimulus and followed either by a footshock or an ice water dunking. These two USs were equated in their potential to elicit conditioned suppression of barpressing. Less blocking of the second stimulus (i.e., unblocking) was observed in subjects that received a qualitative change in US between phases than in subjects for which the US was consistent between phases. This unblocking effect is discussed with respect to the differences between various models of conditioning and several prior successes and failures to demonstrate unblocking. © 1997 Academic Press

One important issue within contemporary analyses of the acquisition and subsequent expression of information is that of cue-competition effects. Cue-competition effects refer to situations in which multiple antecedent events (i.e., conditioned stimuli [CSs]) are presented simultaneously in a predictive relationship with some subsequent event (i.e., an unconditioned stimulus [US]). Cue-competition effects are demonstrated by a deficit in behavioral control by one of those antecedent events relative to behavioral control observed when that antecedent event is the sole predictor of the subsequent event. Blocking is one example of a cue-competition effect. Blocking is said to occur when a stimulus fails to elicit a conditioned response (CR) after it has been paired with a US as a consequence of the pairings having occurred in the presence of a previously trained CS (Kamin,

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Address reprint requests to Ralph R. Miller, Department of Psychology, SUNY—Binghamton, Binghamton, NY 13902-6000.

1968, 1969). The procedure for blocking typically consists of two phases: reinforcement of A in Phase 1 (A+) followed by reinforcement of the simultaneous compound of A and X in Phase 2 (AX+). The stimulus added in Phase 2 is conventionally said to be redundant in that it provides no new information concerning the forthcoming US.

One important feature shared by almost all reported examples of blocking and theories of blocking is the presence of the same reinforcer or US during both phases of conditioning. Notably, *quantitative* changes in the US between Phase 1 and Phase 2 of the blocking procedure have often been reported to attenuate blocking (but see Kremer, 1979). For example, increases in US intensity between Phases 1 and 2 (Bakal, Johnson, & Rescorla, 1974; Kamin, 1969), increases or decreases in the number of USs per trial (Dickinson, Hall, & Mackintosh, 1976; Holland, 1984; Khallad & Moore, 1996; Kremer, Specht, & Allen, 1980), changes in spatial locus of US delivery (Stickney & Donahoe, 1983), and changes in the interval between CSs and USs (Barnet, Grahame, & Miller, 1993; Dickinson *et al.*, 1976; but see Maleske & Frey, 1979; although one might dispute whether the CS-US temporal relationship is a quantitative aspect of the US), all lead to attenuation of blocking. Although many different explanations have been put forth to explain this unblocking phenomenon (Kamin, 1968, 1969; Mackintosh, 1975; Pearce & Hall, 1980; Rescorla & Wagner, 1972), most of the explanations incorporate some notion of "surprise." Presumably the occurrence of a surprising event on a trial facilitates learning on that or subsequent trials. Blocking is assumed to arise from the associative status of the CS that was trained in Phase 1 decreasing the surprise value of the US in Phase 2, thereby attenuating learning (or behavior control) with respect to the CS introduced in Phase 2. Thus a change in the qualitative nature of the US between Phases 1 and 2 might be expected to reintroduce the surprise some models believe is necessary for learning to occur during Phase 2 (e.g., Kamin, 1968, 1969).

Changes in US *quality* between phases of blocking treatment have proven another way to produce unblocking. However, because qualitative changes between appetitive and aversive USs introduces the problem of counterconditioning, all studies of unblocking that have examined qualitative changes in the US between phases of blocking treatment have used USs of similar affective value and thus ordinarily support similar CRs (e.g., changing from one appetitive US to a second appetitive US or changing from one aversive US to another aversive US). For example, Bakal *et al.* (1974) reported unblocking with qualitative changes in the US when the US was changed from a loud auditory stimulus (i.e., a klaxon) to a footshock between Phases 1 and 2 of conditioning, but not in the reverse condition (i.e., not with a change from a footshock to a klaxon). They reasoned that this asymmetrical unblocking effect was due to the klaxon US being unable to support as much associative strength as the footshock US and therefore there being an *increase* in the total amount of associative strength available during Phase 2 trials

involving the shock but a *decrease* in the total amount of associative strength available during Phase 2 trials involving the klaxon. That is, they speculated that the footshock was quantitatively more aversive than the klaxon. Bakal *et al.* concluded that US intensity (quantity) and not US quality controls the phenomena of blocking and unblocking. (However, this conclusion is not well supported due to their failure to systematically vary US intensity while holding qualitative attributes of the US constant.) The Rescorla–Wagner (1972) model predicts excitatory conditioning with increases in the reinforcing value of the US and inhibitory conditioning with decreases in the reinforcing value of the US (Wagner, Mazur, Donegan, & Pfautz, 1980). Thus, the conclusions of Bakal *et al.* are consistent with the Rescorla–Wagner model.

In contrast with Bakal *et al.* (1974), Ganesan and Pearce (1988), using a Pavlovian preparation, failed to attenuate blocking in rats with qualitative changes in appetitive reinforcers (food and water) between Phases 1 and 2. This failure to observe unblocking as a result of qualitative changes in the nature of the US between phases of blocking training is consistent with the data of Bakal *et al.* and Rescorla and Wagner's (1972) suggestion that unblocking depends on quantitative rather than qualitative changes in the US between Phases 1 and 2. Support for this position can also be found in instrumental situations. For example, Williams (1994) failed to observe unblocking in rats when the reinforcer was changed from sucrose to chow pellets (or from chow to sucrose) between Phases 1 and 2 of his blocking procedure.

Both Ganesan and Pearce (1988) and Williams (1994) speculated that their failures to observe unblocking arose from qualitative US (or reinforcer) attributes being less salient and consequently forming weaker associations with the CSs than did other reinforcer attributes (e.g., intensity and affective properties). Williams further suggested that these more salient cues may compete with US quality for associative representation, possibly overshadowing US quality during acquisition. Contrary to this position, Holland (1988) found that unblocking resulting from the addition of a second US (with retention of the first US) during Phase 2 trials was greater if the second US was qualitatively different from the first US. Therefore, there appears to be a discrepancy in the literature regarding the unblocking phenomenon with qualitative changes in the US. However, Holland's experimental design did not incorporate qualitative changes in the US independently of quantitative changes in the US. Thus, his design cannot be directly compared to the experimental designs used by Ganesan and Pearce or by Williams and cannot speak directly to their failures to observe unblocking with qualitative shifts in the US. The present experiment was designed to further examine this issue.

The absence of unblocking in the two appetitive designs described above (i.e., Ganesan & Pearce, 1988; Williams, 1994) would be more compelling if corresponding data from an aversively motivated task were obtained. Bakal *et al.* (1974) used aversive USs; however, the title of their paper notwithstanding, their data and interpretation indicated that their USs were also quantita-

tively different (but see Parker, 1986, for a demonstration of unblocking in taste aversion conditioning using qualitatively different drug USs). The present experiment attempted to produce unblocking with qualitative changes in aversive reinforcers using footshock as one US and ice water dunking as the other US, while holding constant the (quantitative) degree of aversiveness of the two USs. The parameters used to equate the intensity of the USs were established in pilot studies and were incorporated into previous research reported from this laboratory (Kaspro, Schachtman, & Miller, 1985). Kaspro *et al.* observed equal suppression to a tone by rats that received click–shock pairings in Phase 1 followed by tone–ice water pairings in Phase 2 and rats that received tone–shock pairings in Phase 1 followed by tone–ice water pairings in Phase 2. In the current study, we used exactly the same training procedures as were used by Kaspro *et al.*

Kamin's (1968, 1969) concept of surprise predicts unblocking with any change in the US between Phases 1 and 2 of conditioning that makes the original CS element less informative concerning the US in Phase 2. This position is inconsistent with the data reported by Ganesan and Pearce (1988) and Williams (1994). Although the Rescorla–Wagner (1972) model was based on Kamin's speculations, the model predicts unblocking only when the asymptotic level of conditioning supportable by the US increases between Phases 1 and 2 of conditioning. In the Rescorla–Wagner framework, asymptotic associative value is a direct function of the affective value of the US. But if affective value is the sole determinant of the amount of associative strength that can be supported by the US, then the present qualitative changes in USs of equal affective value at the initiation of Phase 2 should have little or no effect. Such a finding would lend further support to a version of the Rescorla–Wagner model which assumes affective value to be the only US attribute encoded during conditioning. Therefore, such a version of the Rescorla–Wagner model can account for the data of Ganesan and Pearce and the data of Williams. However, if aspects of the US in addition to affective value are encoded in associations with other stimuli, as has been suggested by Barnet *et al.* (1993), Stickney and Donahoe (1983), and Holland (1988), then we would expect to observe an attenuation of blocking when qualitative aspects of the US are changed between Phases 1 and 2 of blocking treatment.

METHOD

Subjects

Twenty-four male (380–515 g) and 24 female (210–330 g) naive Sprague-Dawley rats, bred in our colony from Holtzman stock (Madison, WI), served as subjects. Subjects were randomly assigned ($ns = 12$) to one of four groups (Blocking–Same, Control–Same, Blocking–Diff, and Control–Diff) counterbalanced for sex. Animals were individually housed in standard hanging, stainless steel, wire mesh cages in a vivarium maintained on a 16 h:8 h

light:dark cycle. Experimental manipulations occurred near the middle portion of the light phase. Free access to Purina Lab Chow was provided in the home cage. All animals were progressively deprived of water 1 week prior to the start of the study such that water availability was limited to 10 min per day by the initiation of the experiment. All animals were handled three times per week for 30 s from the time of weaning to the start of the study.

Apparatus

Twelve operant chambers each measuring 30.5 cm \times 27.5 cm \times 27.3 cm (l \times w \times h) served as the apparatus. All chambers had clear Plexiglas ceilings and side walls and metal front and back walls. On one metal wall of each chamber, there was an operant lever and a reinforcement niche served by a 0.4-cc cup which could deliver tap water. Chamber floors were 4-mm grids spaced 1.7 cm apart and connected by NE-2 neons, which allowed constant-current footshock to be delivered by means of a high voltage AC circuit in series with a 1.0-M Ω resistor. All chambers were housed in sound- and light-attenuating cubicles. Two 45- Ω speakers mounted on two different interior walls of each environmental chest could deliver a tone (3200 Hz) and a click train (6/s). All auditory stimuli were presented 8 dB(C) re SPL above background noise provided primarily by a ventilation fan (78 dB[C]). A flashing (0.25 s on/0.25 s off) 15-W light (nominal at 120 VAC driven at 75 VAC) was mounted to the ceiling of each chamber. A houselight (28-W shaded bulb) served as a constant source of light, but was turned off whenever the flashing light was activated. The tone and click train served as the blocking CS (A) and blocking control CS (B), counterbalanced within groups. The flashing light served as the to-be-blocked stimulus (X). CS durations during conditioning were 5 s and during test were 60 s. All footshocks were 1 s, 1.2 mA.

A 50-gallon plastic barrel fitted with a 35.5-cm diameter, 45.75-cm deep cylindrical sheet metal interior sleeve was filled with water. Crushed ice was packed in the space between the sleeve and the sides of the barrel. This created a pool of water 35.5 cm in diameter and 27.0 cm deep which remained at a constant temperature of 2°C. On top of the plastic barrel rested a 25.5 \times 22.5 \times 25.5 cm chamber with a Plexiglas lid and end walls, stainless steel side walls, and a stainless steel grid floor, which could be used to deliver footshock during Phase 2. Removal of the grid floor caused subjects to drop into the ice water bath where they were left to swim for 30 s before being removed and towel dried. Importantly, exactly these parameters for shock and ice water treatment had been previously shown to have equal reinforcing properties as measured by conditioned barpress suppression in this particular strain of rat (Kasproff *et al.*, 1985).

Procedure

Acclimation and shaping. On Days 1–6, subjects were acclimated to the experimental context and trained to barpress for water during 60-min daily

sessions. Barpressing was established on Day 1 through the use of a variable-time 2-min schedule of noncontingent dipper operation concurrent with a continuous reinforcement (CRF) schedule for barpressing. Noncontingent reinforcement was discontinued after Day 1. On Days 2 and 3, subjects received only CRF training. By this time all subjects were responding with at least 50 barpresses per session. On Days 4–6, training was continued on a variable-interval (VI) 20-s schedule of reinforcement. By Day 6, all subjects emitted at least 50 barpresses per session. No CSs or USs were presented during this phase of the study. The VI 20-s schedule was maintained throughout the remainder of the experiment.

Conditioning (Phase 1). On Days 7–9, subjects were given daily sessions of Pavlovian conditioning. Five CS–US pairings were administered 11.0, 27.5, 37.5, 43.5, and 55.0 min into each 60-min session. Groups Blocking–Same and Blocking–Diff received 5-s presentations of CS A, each followed with a footshock US; Groups Control–Same and Control–Diff received a 5-s presentation of CS B paired with a footshock US. For all conditions, US onset occurred at CS termination.

Compound conditioning (Phase 2). On Day 10, a single compound conditioning trial was administered to each subject. After 5 min in the conditioning chamber, each rat received a 5-s presentation of the compound stimulus AX, with A being either the Phase 1 CS (Groups Blocking–Same and Blocking–Diff) or a novel cue (Groups Control–Same and Control–Diff). Approximately 1 s before termination of the compound stimulus, the doors to the conditioning chamber were opened. The subject was immediately removed and placed in the footshock chamber. Animals in Groups Blocking–Same and Control–Same then received a footshock and after a 10-s delay were returned to their home cages. For animals in Groups Blocking–Diff and Control–Diff, the floor to the footshock chamber was absent. This allowed subjects to immediately fall into the bucket of ice water where they remained for 30 s. Immediately after removal from the ice water, each animal was dried with a towel and returned to its home cage.

Restabilization. On Days 11 and 12, subjects received daily sessions that allowed barpressing on the VI 20-s schedule of reinforcement. Our intent was to restabilize baseline levels of barpressing to a minimum criterion of 50 barpresses per session. No nominal stimulus other than water was presented during these sessions.

Testing. On Days 13 and 14, animals were tested for barpress suppression. During both days of testing, the VI 20-s schedule of reinforcement was in effect. On Day 13, all subjects were tested for conditioned suppression of barpressing in the presence of X. Testing consisted of presenting the test stimulus alone for 60 s at 11, 21, and 31 min into the 60-min session. Conditioned suppression was assessed by calculating a $CS/(CS + \text{pre-CS})$ suppression ratio for pooled CS and pooled pre-CS periods across trials during testing. CS represents the number of barpresses emitted during the 60-s CS period,

pre-CS represents the number of barpresses during the 60-s period immediately preceding the onset of the CS. Any animal failing to make 50 barpresses during the test session was eliminated from the experiment. No subject met this criterion.

On Day 14, all subjects were tested for conditioned suppression to A using a procedure otherwise identical to that of Day 13. An alpha level of .05 was adopted for all statistical analyses. One subject from Group Control-Diff died before the completion of the experiment. Data from four other subjects (one from each group) were lost due to equipment failures.

RESULTS

The central observation from this experiment was that blocking of the added cue (X) was observed when subjects received the same US in both phases of training (Group Blocking-Same) but not when subjects experienced a qualitative change in the US between Phases 1 and 2 (Group Blocking-Diff). The solid bars in Fig. 1 depict mean suppression ratios to the blocked stimulus (X). Greater conditioned suppression (smaller ratio values) by Group Control-Same relative to Group Blocking-Same demonstrates the basic blocking effect. Group Blocking-Diff, which received a different US in Phase 2 than in Phase 1, did not differ statistically from its control (Group Control-Diff) in suppression to X. These findings indicate that unblocking occurred when qualitative aspects of the US were changed between Phases 1 and 2 of blocking treatment.

A two-way ([Block vs. Control] \times [Same vs. Diff]) analysis of variance (ANOVA) conducted on suppression ratios to the *blocked* CS (X) revealed no effect of CS received in Phase 1 of conditioning (Blocking vs. Control, $F(1,35) < 1.0$), nor of US received in Phase 2 of conditioning (Same vs. Diff, $F(1,35) < 1.0$), but an interaction between the two conditions was detected, $F(1,35) = 10.91$, $p < .01$. To better appreciate the source of this interaction, a Newman-Keuls analysis was performed. This analysis found that Group Blocking-Same suppressed less to X than did Group Control-Same, thereby demonstrating blocking, $p < .05$; whereas Group Blocking-Diff did not differ from Group Control-Diff, $p > .10$. Thus, the interaction arose primarily from blocking when a consistent US was used in Phases 1 and 2, but not when there was a qualitative change in the US between phases. Consistent with this interpretation, there was a tendency, albeit just short of significant, for Group Blocking-Same to suppress less than did group Blocking-Diff, $p < .06$. A similar analysis of pre-CS (X) rates of responding found no differences between groups, range of means from 12.56 to 14.52 barpresses/min, all $F_s(1,35) < 1.0$.

The tendency toward a difference in suppression to the blocked stimulus between Groups Control-Same and Control-Diff is surprising in light of Kasproff *et al.*'s (1985) data showing that shock and ice water immersion with these parameters produced equivalent behavior. However, this tendency

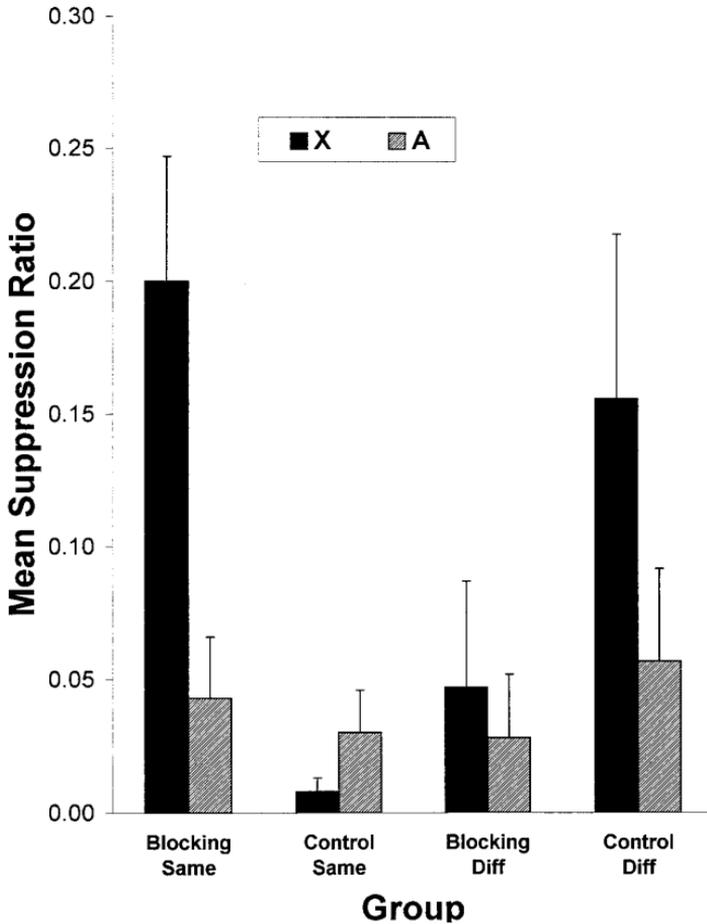


FIG. 1. Mean suppression ratio for each group. Solid bars depict suppression to the blocked stimulus (X), and striped bars depict suppression to the blocking stimulus (A). Error bars represent standard errors of means.

was not significant, $p > .05$, and consequently not directly contrary to the findings of Kasprow *et al.* More important, this tendency suggests a difference in the response-controlling potential of the shock and water USs that is contrary to that which might explain the difference between Groups Blocking-Diff and Blocking-Same in suppression to X (see Fig. 1). That is, if the ice water US was less aversive than the footshock US, this difference would have created a bias toward less suppression in Group Blocking-Diff than in Group Blocking-Same, which is contrary to our results.

A 2×2 ANOVA of suppression ratios for the *blocking* CS (A) indicated equivalent (and high) suppression for all subjects, with no differences between groups. There was no main effect of the pretrained CS (i.e., Groups Blocking-Same and Blocking-Diff vs. Groups Control-Same and Control-Diff) nor

US in Phase 2 (i.e., Groups Blocking–Same and Control–Same vs. Groups Blocking–Diff and Control–Diff), nor was there an interaction between these two variables, all $F_s(1,35) < 1.0$ (see striped bars in Fig. 1). This finding is consistent with that of Kaspro *et al.* (1985) and, contrary to the suggestion based on our X data, supports the view that the two USs were equally aversive. Notably, responding to A was near maximal with either one training trial (blocking condition) or 16 training trials (control condition). Whether such strong conditioning of A is necessary to obtain the present results cannot be determined from the present data. However, we can think of no theoretical reason to suspect that this variable would be important. A similar statement holds for our use of a single Phase 2 trial, which was dictated purely by pragmatic considerations. An analysis of pre-CS (A) rates of responding found no differences between groups, range of means from 10.09 to 14.41 barpresses/min, all $F_s(1,35) \leq 2.03$.

DISCUSSION

The observation that Group Blocking–Same suppressed barpressing less than its control (Group Control–Same) in the presence of X demonstrates that conditioning with A in Phase 1 blocked responding to X which was added in Phase 2. Moreover, a qualitative change in the US between phases prevented blocking of X by A when A had previously been paired with shock in Group Blocking–Diff relative to the blocking observed in Group Blocking–Same when the US was unaltered between Phases 1 and 2. Kaspro *et al.* (1985) observed that, with their procedure, the strong shock and the ice water used during Phase 2 training had similar reinforcing properties. In fact, they reported extinction rates to the tone paired with ice water being more rapid than for the tone paired with shock, indicating that, if anything, ice water served as a slightly weaker US, though this difference was not reflected in suppression ratios. However, this difference must be viewed with caution because it depended upon a cross-experimental comparison. Although it is unclear whether our Phase 2 US was equal or less aversive than our Phase 1 US in the Different condition, there is no basis for thinking that it was more aversive. Thus, our results do not depend upon a more aversive US in Phase 2 to produce unblocking, only one that is qualitatively different from the Phase 1 US.

These results lend support to prior reports that have suggested that changes in the qualitative aspects of a US can produce unblocking (e.g., Holland, 1988). Unfortunately, these previous efforts to study this issue sometimes confounded potentially qualitative changes in the US between Phases 1 and 2 with quantitative changes in the US (e.g., Bakal *et al.*, 1974). The present study avoided such a confound and still yielded unblocking. Thus, these data are compatible with Holland's (1988) findings and extend them to include situations in which experimental manipulations involve changes exclusively in US quality (as opposed to quantity).

The current results appear inconsistent with the data of Ganesan and Pearce (1988) and Williams (1994) and their conclusion that aspects of the reinforcer other than intensity or affective value play only a minor role in associative learning and subsequent behavioral control. What could be the cause of this inconsistency in whether qualitative changes in the US produce unblocking? Perhaps qualitative aspects of the US extend beyond the physical characteristics of the US to include feedback from the unconditioned response (UR) to the US. Williams, on the basis of his findings and those of Ganesan and Pearce, suggested that the pairs of reinforcers used in both studies (chow pellets versus sucrose pellets in the former and chow pellets versus water in the latter) were not sufficiently discriminable to attenuate blocking (even though Williams found evidence of their discriminability in a contingency paradigm). Possibly the URs to these various appetitive reinforcers were too similar to differentially affect conditioned responding with respect to the dependent variables used in these studies. Holland's data might be viewed as refuting this notion because his subjects exhibited unblocking when the two USs used during blocking treatment were food pellets of different flavors (i.e., presumably two USs that elicit similar URs). However, Holland's dependent variable was head-jerks, whereas Williams's and Ganesan and Pearce's dependent variables were barpressing and magazine approach, respectively. The associations that support conditioned head-jerks might involve a US representation that incorporates (or emphasizes) qualitative aspects of the US to a greater degree than do the associations that support barpressing and magazine approach.

In the present experiment, we measured suppression of bar pressing in our subjects and we were able to obtain unblocking. As we have suggested, qualitative aspects of the US might not only include the physical stimulus attributes of the US, but also feedback from the UR that the subject makes to it. The URs to each of our two USs are vastly different from each other, unlike the case with the appetitive USs that were used in the previously described studies (e.g., Williams, 1994; Ganesan & Pearce, 1988). Rats run, leap, and vocalize in response to a footshock but swim and try to climb up the sides of the barrel when dropped in a bucket of ice water. In contrast, the CRs to appetitive reinforcers such as food and water are limited primarily to consummatory behaviors. This difference in the variation of URs elicited by pairs of USs might reconcile the discrepancy between the present results and those of Williams and Ganesan and Pearce. It is possible that, with a lesser difference between USs and their accompanying URs as in an appetitive situation, a more sensitive measure of responding (e.g., Holland, 1988) would be required to uncover unblocking, whereas, with greater differences between USs (and consequently their URs), such as footshock and ice water, measures such as conditioned suppression will suffice.

In summary, the present data suggest that qualitative changes in the US between Phases 1 and 2 will suffice to produce unblocking if the changes in

the US and its resultant UR are of a large magnitude. This conclusion is congruent with Kamin's (1968, 1969) early view of blocking. In Kamin's framework, surprise arising from any change in US properties between Phase 1 and Phase 2 trials should lead to conditioning to the added stimulus. Moreover, these results are consistent with an extension of the Rescorla–Wagner (1972) model in which qualitatively distinct USs independently condition a common CS. If one considers the parenthetical term of the Rescorla–Wagner formula ($\lambda - V_{\text{Total}}$), the conditioned cues completely predict the US when V_{Total} equals λ . Thus, during Phase 2 of blocking, the US should no longer be surprising and there should be no learning to the added CS. However, the Rescorla–Wagner model may be extended in such a way that a qualitative change in US between phases now requires a new λ , even if the Phase 2 US is as effective a reinforcer as the Phase 1 US (i.e., $|\lambda_{\text{Phase 1}}| = |\lambda_{\text{Phase 2}}|$). Thus, conditioning of the added CS (as well as the initial CS) can proceed with respect to the Phase 2 US due to the Phase 2 US being surprising. Acceptance of this type of extension of the Rescorla–Wagner model awaits further study.

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