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Failure of Retrospective Revaluation to Influence Blocking

Jemma C. Dopson and John M. Pearce
Cardiff University

Mark Haselgrove
The University of Nottingham

In the blocking paradigm, subjects receive reinforced presentations of a compound, AX, after reinforced presentations of A alone. Following this training, responding to X is often diminished relative to a control group, which did not receive the prior training with A. Standard associative theories of learning such as the Rescorla–Wagner model (Rescorla & Wagner, 1972) explain this effect by assuming that A and X compete for control over behavior. In contrast, theories such as the comparator hypothesis assume that learning about X is unaffected by the properties of A, but it is the expression of this learning at test that is affected by the blocking manipulation. The aim of the 3 reported experiments was to distinguish between these 2 accounts. According to the comparator hypothesis, devaluing A following blocking should increase subsequent responding to X. In all 3 experiments the blocking effect was found to persist following devaluation of A, providing support for standard associative theories.

Keywords: conditioning, blocking, comparator hypothesis

Effects such as blocking (Kamin, 1969) have been taken as evidence that cues compete for the control they acquire over behavior. In a typical blocking experiment, pairings of a compound comprising two stimuli, A and X, with an unconditioned stimulus (US) are preceded by pairings of just A with the US (A+ then AX+). Subsequent responding to X is then found to be weaker than if the original training with A is omitted. According to one influential class of theories, blocking is a consequence of cues competing for a limited pool of associative strength (e.g., Pearce, 1994; Rescorla & Wagner, 1972). The Rescorla–Wagner theory, for example, explains blocking by assuming that the initial training with A allows this stimulus to acquire considerable associative strength, leaving little to be gained by X during compound conditioning. This idea is expressed formally by Equation 1, in which the rate of learning about X, ΔV_X, is determined by the discrepancy between the maximum associative strength that the US is able to support on a given trial, λ, and the aggregate associative strength of all cues present on that trial, ΣV. The learning rate parameters α and β represent the salience of X and the US respectively. If pretraining with A results in it gaining high associative strength, then the value of ΣV will be close to λ when X is introduced and according to Equation 1 there will be little scope for conditioning with X.

$$\Delta V_X = \alpha\beta(\lambda - \sum V). \qquad (1)$$

Jemma C. Dopson and John M. Pearce, School of Psychology, Cardiff University; Mark Haselgrove, School of Psychology, The University of Nottingham, Nottingham.

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Correspondence concerning this article should be addressed to Jemma Dopson, School of Psychology, Cardiff University, Tower Building, Park Place, Cardiff, CF10 3AT, Wales. E-mail: dopsonj@cardiff.ac.uk

An implication of the foregoing explanation concerns the effect on X of presenting A by itself after the blocking treatment. Standard theories of associative learning, including the Rescorla-Wagner (1972) theory, assume that the associative strength of a stimulus can be modified only if it is physically present. Thus presentations of A, either by itself or paired with the US, after blocking should have no impact on responding to X. In contrast, other theories allow that performance to X can be affected by subsequent manipulations of the associative strength of A.

The first theory to make this prediction was the comparator hypothesis, which was proposed by Miller and Schachtman (1985; see also Miller & Matzel, 1988). This hypothesis is based on the assumption that conditioning results in the growth of associations between conditioned and unconditioned stimuli, but the development of these associations is not governed by a competitive learning rule. Instead, the growth of an association between two stimuli is believed to be unaffected by the associative properties of any other stimuli that are present at the time of conditioning. Effects such as blocking are instead attributed to a comparison that takes place at test, between the associative strength of the stimulus that is presented, known as the target, and the associative strength of other cues, known as comparator stimuli, that accompanied the target during training. An information flowchart of this comparison process is shown in Figure 1, which is adapted from Pineño, Urushihara, and Miller (2005).

According to Savastano et al. (2003), conditioned responding is a function of the strengths of Links 1, 2, and 3. Excitatory responding is directly related to the strength of the target-US association (Link 1), and inversely related to the product of the associations between the target and the comparator stimulus (Link 2) and between the comparator stimulus and the US (Link 3). That is, the stronger the target-comparator and comparator-US associations, the weaker the conditioned response (CR). Applied to blocking, the target stimulus is X and the comparator stimulus is A. Conditioning X in compound with A will establish associations between X and the US (Link 1) and X and A (Link 2), and will strengthen further the association between A and the US estab-

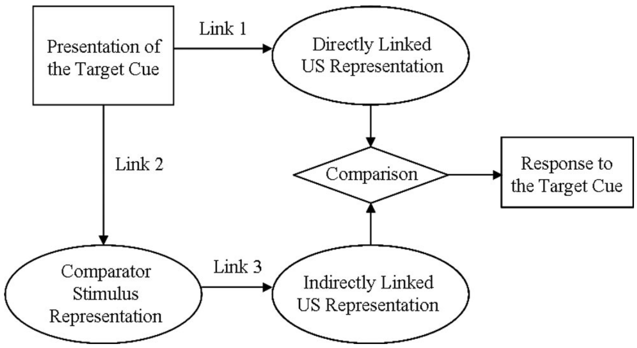

Figure 1. The comparator hypothesis. Link 1 is determined by the strength of the target stimulus-US association, Link 2 by the strength of the target-comparator stimulus association, and Link 3 by the comparator stimulus-US association. US = unconditioned stimulus.

lished during the initial training with A (Link 3). Thus, on test, because responding is inversely related to the strengths of Links 2 and 3, a small CR is expected to X, compared to a control group that does not receive pretraining with A, and for whom Link 3 is relatively weak.

This explanation has implications for responding to X if, following A+ then AX+ training, A is presented without the US before X is then tested alone. Presenting A in extinction will weaken the A–US association (Link 3) so that when X is subsequently presented it will now weakly activate the indirectly linked US representation and be capable of eliciting a stronger response than if the extinction treatment with A had been omitted. The opposite outcome is expected if conditioning rather than extinction trials are given with A after the A+ and AX+ training.

Following the development of the comparator hypothesis, other theories were proposed that also predict that the properties of a blocked cue might be affected by subsequent training with the blocking stimulus (Dickinson & Burke, 1996; Van Hamme & Wasserman, 1994). According to Van Hamme and Wasserman, this effect can be explained with a simple modification to Equation 1. Suppose that animals receive conditioning with A+ and then AX+ before extinction trials with A. Van Hamme and Wasserman suggested that the acquisition of associative strength by A and X during compound conditioning, and the loss of associative strength by A during extinction, will be governed by the Rescorla–Wagner (1972) equation. Their novel proposal was that during extinction training with A, the associative strength of X will also be modified according to this equation, because X had previously been paired with A. However, because X is not physically presented during this stage, the value of α associated with this stimulus will be negative. Thus the change in the associative strength of X will be in the opposite direction to that of A. If A is presented without the US, X will gain associative strength as A loses it. Conversely, if A is paired with the US, then X will lose associative strength as A gains it. Dickinson and Burke developed a similar explanation, but it was couched in terms of Wagner's (1981) theory. In addition, they argued that learning about X on trials when A is presented by itself would take place only if there was a strong association between these stimuli.

Despite their differences, these two theories, along with the comparator hypothesis, make the same prediction that manipulating the associative properties of A after A+ then AX+ training will retrospectively affect the influence of X on behavior during a subsequent test of this stimulus. Specifically, the three theories collectively predict that reducing the associative strength of A will strengthen the influence of X, whereas increasing the associative strength of A will have the opposite effect. In contrast, standard theories of associative learning such as the Rescorla–Wagner (1972) theory predict that administering these treatments with A will have no effect on the influence of X relative to when these treatments are omitted.

Several experiments have attempted to evaluate these contrasting predictions. Blaisdell, Gunther, and Miller (1999) reported results that are consistent with the claim that training with A following blocking should give rise to what is referred to as a retrospective revaluation effect. In their experiment, a blocking group received pairings of A and footshock prior to conditioning with AX before 800 nonreinforced trials with A were given. In keeping with the accounts just considered, this treatment resulted in retrospective revaluation and enhanced the strength of the response elicited by X.

In contrast to this result, Miller, Schachtman, and Matzel (1988, unpublished study as cited in Blaisdell et al., 1999) failed to find any evidence of retrospective revaluation following blocking. A similar failure was reported by Holland (1999) using similar training to that given by Blaisdell et al., but with an appetitive US. Comparable findings were reported in an experiment by Rauhut, McPhee, DiPietro, and Ayres (2000), which involved aversive conditioning with A+ and then AX+ followed by training designed to convert A into a conditioned inhibitor. Despite this attempt to counter the excitatory A–US association, there was no hint that the treatment affected responding on a subsequent test of X alone.

A possible explanation for these conflicting results is that the attempt to abolish the excitatory influence of the comparator cue may not have been effective in the studies of Holland (1999) and Rauhut et al. (2000). Holland gave over 500 extinction trials with this cue to reduce its associative strength before testing the target and, as just noted Rauhut et al. went one step further by training the comparator cue as a conditioned inhibitor. Nonetheless, it is possible that these treatments did not have the intended effect on the excitatory properties of the target cue, with the result that retrospective revaluation was not observed. Taking this possibility into consideration, a different method for testing for retrospective revaluation was used in the present experiments. The rationale behind the method can be appreciated by considering the design of Experiment 1, which is shown in Table 1.

During Stage 1, a blocking group received discrimination training in which A was paired with food and B was not. A control

Table 1
Design of Experiment 1

Group	Stage 1		Stage 2	Test 1	Stage 3		Test 2
Blocking	A+	B–	AX+	X–	A–	B+	X–
Control	A–	B+	AX+	X–	A+	B–	X–

Note. A and B were counterbalanced as a tone and a clicker, X was the illumination of a thin film transistor screen to white. A plus sign (+) = reinforcement; a minus sign (−) = nonreinforcement.

group received the opposite discrimination. Both groups then received conditioning with AX during Stage 2, followed by a test with X alone, which was expected to reveal stronger responding in the control than in the blocking group. A reversal of Stage 1 training was given in Stage 3, to reverse the significance of A in both groups. Thus Stage 3 involved an A– B+ discrimination for the blocking group and an A+ B– discrimination for the control group. Finally, both groups received a second test with X by itself.

According to the comparator hypothesis, the training given in Stage 2 will ensure that the associative strength of the blocked stimulus X, will not differ between the two groups during either Test 1 or Test 2. Performance on these tests will then depend on the associative strength of A at the time of testing. Due to the discrepant training received by the two groups during Stage 1, on Test 1 A will have more associative strength in the blocking group than in the control group. As the strength of the A–US association is assumed to have an inverse effect on responding to X, responding on Test 1 should be weaker in the blocking group than in the control group. As a result of the Stage 3 training, on Test 2 A will have weak associative strength in the blocking group and high associative strength in the control group. Therefore this training should result in the outcome of Test 2 being opposite to that of Test 1, with weaker responding to X in the control group than in the blocking group. A particular advantage of this design is that it will be possible to compare the associative strengths of A between the two groups during Stage 3. In contrast to the studies by Holland (1999) and Rauhut et al. (2000), it will therefore not be possible to attribute a failure to confirm the prediction from the comparator hypothesis to a failure to manipulate adequately the associative strength of A.

The predictions from the theories of Van Hamme and Wasserman (1994) and Dickinson and Burke (1996) are not as clear cut as those from the comparator hypothesis concerning the design in Table 1. Further discussion of these theories will therefore be postponed to the General Discussion where they will be evaluated in the light of the experimental findings.

In summary, if a stronger conditioned response to X is observed during the second test in the blocking group than in the control group after the demonstration of a standard blocking result on Test 1, it can be inferred that retrospective revaluation has occurred. Such an outcome would not be compatible with the Rescorla–Wagner theory (1972), which predicts that responding to the target will be weaker in the blocking than the control group during both the first and the second test. The results from Experiment 1 were in keeping with this prediction. The remaining two experiments, which were based on the design in Table 1, were conducted to confirm the reliability of the outcome from the first experiment.

Experiment 1

Method

Subjects. The subjects were 16 experimentally naïve male, hooded Lister rats maintained at Cardiff University, Wales, United Kingdom. They were approximately 6 months old at the start of the experiment. Prior to the experiment they were gradually reduced to 80% of their free-feeding weights and were maintained at this level throughout the experiment by being fed a restricted amount after each experimental session. The rats were housed in pairs in a light-proof room in which the lights were on for 14.5 hr each day. They were tested at the same time on successive days during the period when the lights were on in their holding room.

Apparatus. Four identical conditioning chambers were used. The side walls and ceiling of each chamber were constructed from clear Perspex. Each wall had a height of 28 cm and a width of 30 cm. There was a grid floor positioned 5 cm above the base of the chamber. In the center of the back wall, there was a circular hole, diameter 3 cm, the center of which was 3 cm above the grid floor. The circular hole allowed access to a well into which sucrose solution (8% sugar, 92% water) was delivered. This area is henceforth referred to as the magazine. A peristaltic pump was located beneath each conditioning chamber that delivered the sucrose solution via a plastic tube into the well. The arrangement of this apparatus is shown in Figure 2. A PC computer with Whisker software (Camden Instruments, Loughborough), and programmed in Visual Basic 6.0, controlled the experimental events and recorded the duration of entries into the magazine from infrared sensors that were set into each chamber. Barriers were placed between the chambers to prevent the animals seeing each other.

Auditory stimuli were delivered simultaneously to all chambers from a 5-ohm speaker located on the ceiling of each chamber. Visual stimuli appeared on two flat-screen thin film transistor (TFT) monitors that had a width of 33 cm and a height of 27 cm. These were placed side by side at an angle of 90°, and positioned in front of each chamber. The screens joined at 25 cm in front of each conditioning chamber, in line with the center of the hole in the back wall. The bottom edge of each screen was level with the floor of the chamber.

The auditory stimuli were a 10-Hz, 70-dB clicker and a 2-kHz, 70-dB tone. The visual stimulus was the illumination of one of the screens to white. For half of the animals, this was the left-hand screen, for the others it was the right-hand screen. The stimuli were counterbalanced, such that for half of the animals within each Group A was the clicker and B the tone, and for the other half A was the tone and B the clicker. X was always the white stimulus.

Procedure. All rats initially received two sessions of magazine training. During each of these 1-hr sessions, 0.2 ml sucrose solution was delivered into the well over a period of 3 s, every 1 min

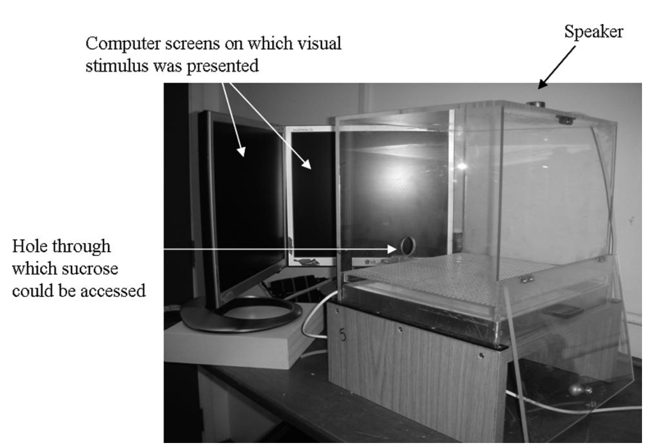

Figure 2. Arrangement of the apparatus used in Experiments 1 to 3.

for 30 min. The rat remained in the conditioning chamber for a further 30 min. Following magazine training, the animals were divided into two groups, with eight animals in each.

There were 24 trials in each of the 10 sessions of Stage 1. All animals received 12 trials during which the clicker was presented for 10 s, and 12 trials during which the tone was presented for 10 s. Unless otherwise stated, the following details applied to all stages of this experiment and subsequent experiments. The intertrial interval (ITI) ranged from 80 s to 160 s, with a mean of 120 s. For all groups, the sequence of reinforced and nonreinforced trials was random, with the constraint that no more than two trials of the same type could occur in succession. The duration spent in the magazine was recorded during each 10-s presentation of the stimulus. Reinforcement constituted a 0.2 ml delivery of sucrose into the well over a period of 3 s. In the blocking group, presentations of stimulus A were immediately followed by reinforcement. These trials were nonreinforced for the control group. Presentations of stimulus B were reinforced for the control group, and nonreinforced for the blocking group.

The first session of Stage 2 began on the day after the final session of Stage 1. In each of the four sessions of Stage 2, animals received eight trials during which presentations of a compound stimulus were reinforced. For all animals, this compound consisted of the simultaneous presentation of A (the stimulus that had been reinforced in the blocking group in Stage 1, and nonreinforced in the control group), and X, the white stimulus. Although a third of the number of trials was presented, the sessions were the same length as those from Stage 1. For this reason, during the four sessions of this stage the ITI ranged from 230 s to 390 s with a mean of 313 s.

The next session, which was on the day following the final session of Stage 2, served as a test of the white stimulus (X). Both groups first received five reinforced trials with AX, which were followed by three trials during which 10-s presentations of the white stimulus were nonreinforced. As in Stage 2, the mean ITI during this test session was 313 s.

On the following day, each group received the first of seven sessions that involved a reversal of the training they had received in Stage 1. Presentations of stimulus B were reinforced in the blocking group, and nonreinforced in the control group. Presentations of A were reinforced in the control group, and nonreinforced in the blocking group. The remaining procedural details were the same as for Stage 1.

Subjects were returned to the apparatus for a final test session on the day after session seven of Stage 3. During this session, each group received 21 trials made up of the trial types they received in Stage 3. Both groups then received 3 trials on which the white stimulus was presented for 10 s. As in Stage 3, the ITI ranged from 80 s to 160 s, with a mean of 120 s.

Results and Discussion

A Type I error rate of $p < .05$ was adopted for all of the statistical tests in this experiment and those that follow. The results from the three stages of training are shown in Figure 3.

For both groups, the mean duration of magazine activity during presentations of each CS for every session of Stage 1 is presented in the left-hand panel of Figure 3. By the end of Stage 1, blocking and control animals were spending a comparable amount of time in the magazine during presentations of the reinforced stimulus, and this was considerably longer than the duration spent in the magazine during nonreinforced trials. The mean duration of magazine activity during each trial type on the final two sessions was calculated for every subject. A two-way analysis of variance (ANOVA) of individual mean durations of magazine activity was conducted with the factors of trial type (reinforced and nonreinforced) and group (blocking or control). This analysis revealed a significant effect of trial type, $F(1, 14) = 370.30$, but no effect of group and no Trial-Type × Group interaction, $F\text{s} < 1$.

The data for the four sessions of Stage 2, in which reinforced trials with AX were given, are presented in the center panel of Figure 3. The mean duration of magazine activity during presentations of AX in the control group was initially less than in the blocking group, presumably due to the fact that A was nonreinforced in the control group in Stage 1, and reinforced in the blocking group. However, by the end of training, both groups

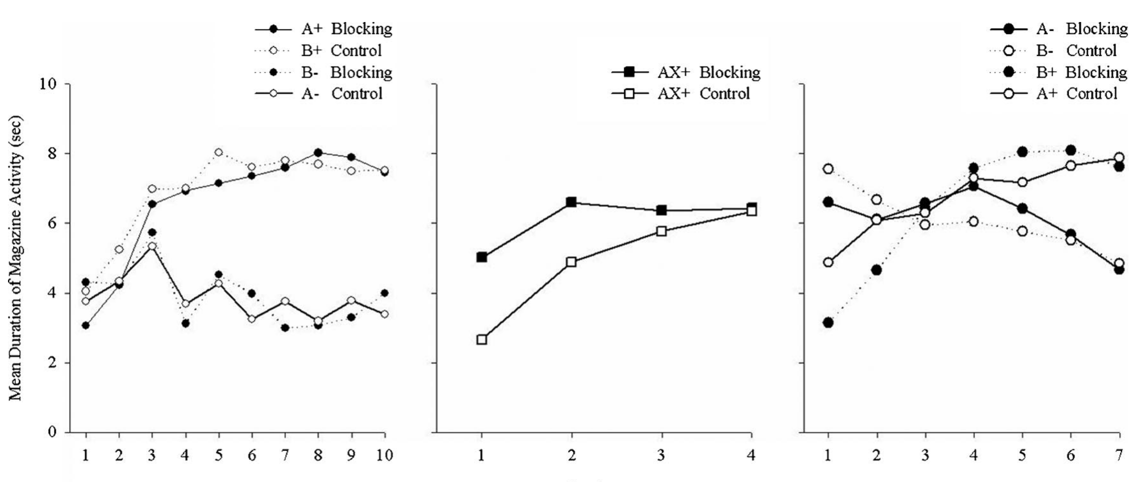

Figure 3. Mean duration of magazine activity for both groups during presentations of each trial type on each session of Stage 1 (left-hand panel), Stage 2 (center panel) and Stage 3 (right-hand panel) of Experiment 1.

responded at the same high level to AX. A *t* test based on mean individual durations of responding during the final two sessions of this stage confirmed that there was no significant effect of group, $t(14) = .44$.

The mean durations of magazine activity for both groups during presentations of the stimuli in Stage 3 are presented in the right-hand panel of Figure 3. Stage 3 involved a reversal of Stage 1 training. A *t* test conducted on the mean individual durations of magazine activity during presentations of A on the final two sessions confirmed that the reversal treatment was effective, such that by the end of this stage the control group spent significantly longer in the magazine during presentations of A than the blocking group, $t(14) = 5.20$. A corresponding analysis revealed that the treatment had also effectively reversed the significance of B in the two groups, with the blocking group spending significantly longer in the magazine during presentations of this stimulus than the control group, $t(14) = 3.57$.

The mean durations of magazine activity during presentations of X for Test 1 and Test 2 were calculated for both groups. These data are presented in Figure 4. From this figure it is evident that responding to X was stronger in the control group than the blocking group on both the first and the second test of this stimulus. A two-way ANOVA with the factors of group (blocking or control) and test (1 and 2) confirmed this observation, revealing a significant effect of group, $F(1, 14) = 6.16$ and a nonsignificant Test $\times$ Group interaction, $F(1, 14) = 1.25$. Thus the blocking of X caused by conditioning in Stages 1 and 2 was not affected by the reversal training with A in Stage 3. The ANOVA also revealed a significant effect of test, $F(1, 14) = 8.02$, reflecting the decrement in responding observed on Test 2 relative to that seen on Test 1. This effect can be explained either by the extinction trials with X received during Test 1, or simply by the passage of time between the two tests.

The results of the first test of X in Experiment 1 support standard associative models of learning (e.g., Rescorla & Wagner, 1972) and the comparator hypothesis in that reinforced trials with A, followed by conditioning with the compound AX resulted in responding to X that was diminished relative to that observed in a control group. However, the comparator hypothesis is unable to explain the finding that following revaluation of A, this pattern of responding remained. Standard associative models on the other hand predict this finding. Experiment 2 was conducted to test the generality of this effect with a different blocking design.

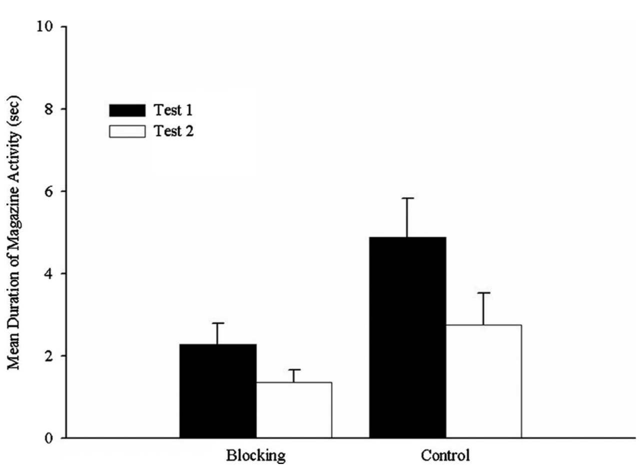

Figure 4. Mean duration of magazine activity (plus *SEM*) for both groups during presentations of X on Tests 1 and 2 of Experiment 1.

Experiment 2

The design of Experiment 2 was based on Experiment 1 with two key differences. First, for both groups, presentations of the compound in Stage 2 were intermixed with the training trials received in Stage 1 (see Table 2). This training was given to maximize the associative strength gained by A in the blocking group and minimize that gained by A in the control group, with the aim of strengthening any blocking effect. Second, just two trials with X were given during the first test in an attempt to reduce the effect of these extinction trials with X on the second test of this stimulus. In keeping with the results of Experiment 1, a blocking effect with X was expected on both Test 1 and Test 2.

Method

Subjects. The subjects were 16 male, naïve hooded Lister rats. They were approximately 6 months old at the start of the experiment. They were maintained in the same manner as in Experiment 1.

Apparatus. The same apparatus was used in Experiment 2 as in Experiment 1. In addition a further four conditioning chambers of the same design were used, each of which was arranged in relation to two flat-screen TFT monitors in the same way as in Experiment 1. The same stimuli as in Experiment 1 were used, and these were counterbalanced in the same way.

Procedure. Magazine training and the 10 sessions of Stage 1 were conducted in the same manner as for Experiment 1 for both the blocking and control groups. The first session of Stage 2 began on the day after the final session of Stage 1. There were 24 trials in each of the 15 sessions of Stage 2. Both groups received eight of each of the trial types presented in Stage 1, in addition to reinforced presentations of the AX compound on the remaining 8 trials. The sequence of trials was random, with the constraint that no more than 2 trials of the same type could occur in succession.

The next session, which was on the day following the final session of Stage 2, served as a test of the white stimulus (X). All animals received 22 trials made up of the trial types they received in Stage 2. The final 2 trials in the session were 10-s nonreinforced presentations of the white stimulus.

Stage 3 proceeded in the same manner as in Experiment 1, with all animals receiving seven sessions that involved a reversal of the training they had received in Stage 1. On the day after Session 7 of Stage 3, subjects were returned to the apparatus for a final test session that was identical to that given in Experiment 1. For all stages of the experiment the mean ITI was 120 s (range 80 to 160 s). The remaining procedural details were the same as for Experiment 1.

Results and Discussion

The results from the three stages of training are shown in Figure 5. For both groups, the mean duration spent in the magazine during presentations of each CS for every session of Stage 1 is presented

Table 2
Design of Experiment 2

Group	Stage 1		Stage 2			Test 1	Stage 3		Test 2
Blocking	A+	B–	A+	B–	AX+	X–	A–	B+	X–
Control	A–	B+	A–	B+	AX+	X–	A+	B–	X–

Note. A and B were counterbalanced as a tone and a clicker, X was the illumination of a thin film transistor screen to white. A plus sign (+) = reinforcement; a minus sign (−) = nonreinforcement.

in the left-hand panel. By the end of Stage 1, blocking and control animals were spending a comparable amount of time in the magazine during presentations of the reinforced stimulus, and this was considerably longer than the duration spent in the magazine during nonreinforced trials. The mean duration of magazine activity during each trial type on the final two sessions was calculated for every subject. A two-way ANOVA of individual mean durations of responding was conducted, with the factors of trial type (reinforced and nonreinforced) and group (blocking or control). This revealed a significant effect of trial type, $F(1, 14) = 74.92$, but no effect of group, $F(1, 14) = 2.63$, and no Trial-Type × Group interaction ($F < 1$).

The mean durations of magazine activity during the three trial types of Stage 2 are presented in the center panel of Figure 5. During the final two sessions of this stage both groups were spending considerably longer in the magazine during the reinforced trials than during the nonreinforced trials. A two-way ANOVA with the factors of trial type (reinforced element, nonreinforced element, and reinforced compound) and group (blocking or control) revealed a significant effect of trial type, $F(2, 28) = 80.17$, but no effect of group, $F(1, 14) = 2.58$, and no Trial-Type × Group interaction, $F < 1$. Bonferroni corrected pairwise comparisons revealed that responding to both the reinforced element and the reinforced compound was significantly higher than responding to the nonreinforced element for both groups. There was also a significant difference between responding to the reinforced compound and reinforced element. This difference in responding to the two reinforced stimuli shown by both groups was presumably due to the compound being a combination of a visual and an auditory stimulus. It is widely acknowledged that orienting responses are displayed toward visual stimuli (e.g., Kaye & Pearce, 1984), which might result in the animal spending less time in the magazine during their presentation.

The mean durations of magazine activity for both groups during presentations of the stimuli in Stage 3 are presented in the right-hand panel of Figure 5. From this figure it appears that the training was effective in reversing the significance of A in the two groups. A *t* test conducted on the mean individual durations of magazine activity during presentations of A confirmed that during the final two sessions, the control group spent significantly longer in the magazine during presentations of A than the blocking group, $t(14) = 4.35$. Inspection of the right-hand panel of Figure 5 indicates that the reversal treatment was not effective for stimulus B. This observation was confirmed by a *t* test conducted on the mean individual durations of magazine activity during presentations of B during the final two sessions, $t(14) = .19$. This finding could be explained by the larger difference between the groups in responding to B than in responding to A at the beginning of Stage 3. It could be that the seven sessions of Stage 3 were not sufficient for the reversal of B to occur. Whatever the reason for this result, it must be noted that the critical comparison in this stage is between responding to A in the two groups, as A is the comparator for X, and the reversal treatment was effective for this stimulus.

The mean durations of magazine activity for both groups during presentations of X on Tests 1 and 2 are presented in Figure 6. In keeping with the results of Experiment 1, the control group responded more strongly in the presence of X than the blocking group on both tests. Responding on Test 2 was also similarly reduced relative to responding on Test 1. These observations were confirmed by a two-way ANOVA with the factors of group (blocking or control) and test (1 or 2), which revealed a significant effect

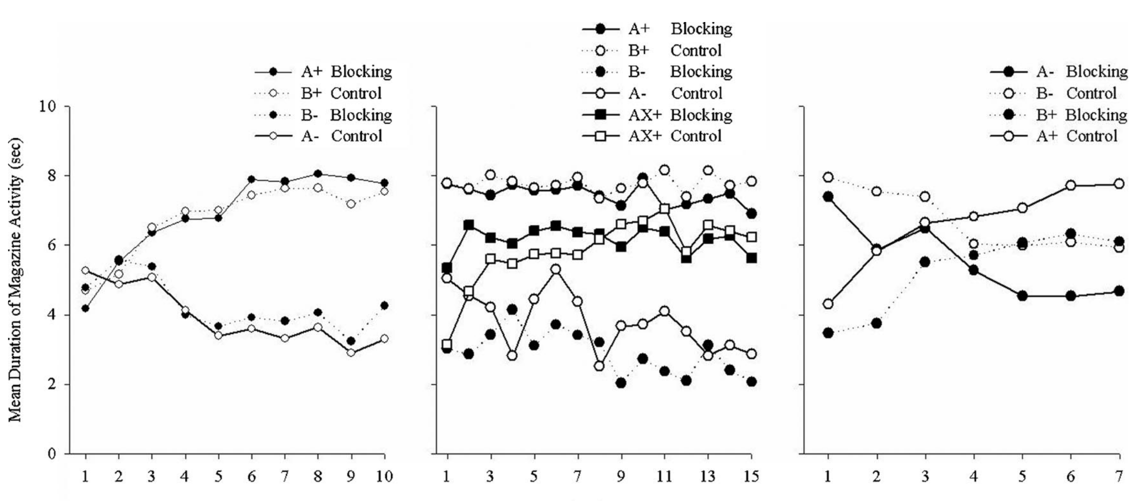

Figure 5. Mean duration of magazine activity for both groups during presentations of each trial type on each session of Stage 1 (left-hand panel), Stage 2 (center panel) and Stage 3 (right-hand panel) of Experiment 2.

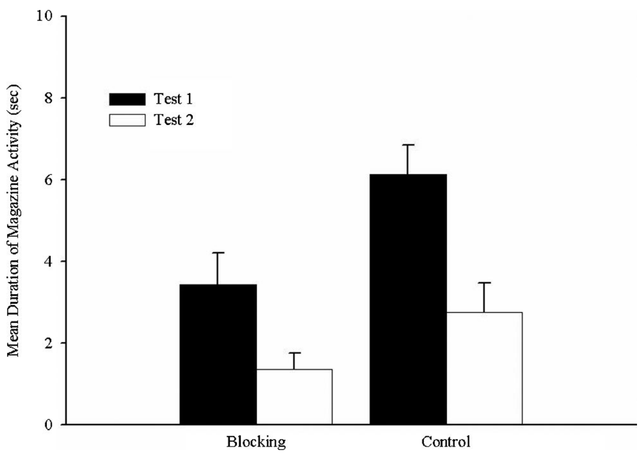

Figure 6. Mean duration of magazine activity (plus *SEM*) for both groups during presentations of X on Tests 1 and 2 of Experiment 2.

of group, $F(1, 14) = 7.62$, and test $F(1, 14) = 21.90$, but no Test × Group interaction, $F < 1$.

The results replicated those of Experiment 1, showing that blocking was unaffected by subsequent training in which the competing cue was nonreinforced in the blocking group and reinforced in the control group. The results of Experiment 2 therefore provide further support in favor of standard associative accounts of blocking (e.g., Rescorla & Wagner, 1972).

In Stage 3, both groups received a reversal of the training given in Stage 1. Unexpectedly, this treatment successfully reversed the significance of A in the two groups, but did not have this effect on the significance of B. It is difficult to provide a suitable explanation for this finding, and it should be noted that a reversal in responding to B in the two groups is not required for the predictions of the comparator hypothesis to be realized. The fact the reversal was not observed in Experiment 1 suggests that the training schedule used in Stage 2 of this experiment may have been accountable. However, this effect was not replicated when the same training procedure for Stage 2 was used in Experiment 3.

Experiment 3

In other experiments that have looked for retrospective revaluation only one test of X has been administered, following the stage in which extinction trials with the comparator cue were presented (e.g., Blaisdell et al., 1999; Holland, 1999). In Experiments 1 and 2, an additional test of X was administered prior to this stage to confirm the effectiveness of the Stage 2 blocking treatment. It is conceivable that this initial test might somehow influence responding to X on Test 2, and by doing so prevent observation of the reversed blocking effect that is predicted by the comparator hypothesis. For example, pairing X with a low level of responding in the blocking group, and a (relatively) high level of responding in the control group may have established S–R associations between the test stimuli and these levels of responding that persisted until the second test session. For this reason, Experiment 3 was conducted. Two groups received the same design as that used in Experiment 2. Another two groups received the same training, but Test 1 was omitted (See Table 3).

Method

Subjects. The subjects were 64 male, naïve hooded Lister rats. They were approximately 6 months old at the start of the experiment. They were maintained in the same manner as in Experiments 1 and 2.

Apparatus. The same apparatus was used in Experiment 3 as in Experiment 2. The auditory stimuli were the same 10-Hz, 70-dB clicker that was used in the previous experiments, and a 500-Hz, 70-dB tone that was repeated at a rate of 2.5 times per second 10 times during a 10-s trial. Again, the visual stimulus was the illumination of one of the screens to white. The position of this stimulus and the manner in which the stimuli were counterbalanced was the same as in Experiments 1 and 2.

Procedure. Magazine training was conducted in the same way as in Experiments 1 and 2. In Stage 1 and Stage 2 training, both blocking and both control groups received the same training as the blocking and control group respectively in Experiment 1.

On the day following the final session of Stage 2 all four groups received 21 training trials from this stage. Blocking-2 and Control-2 then received an additional three test trials with the white stimulus, as in Test 1 from Experiment 1. Blocking-1 and Control-1 did not receive any test trials following the training trials, but remained in the apparatus for the same amount of time as the other two groups.

As in the previous experiments, on the following day, each group received the first of seven sessions that involved a reversal of the training they had received in Stage 1. All four groups then received a test session which was conducted in the same manner as Test 2 in Experiments 1 and 2. Procedural details that have been omitted were the same as for Experiment 1.

Results and Discussion

The results from the three stages of training are shown in Figure 7. Data for the Blocking-1 and Control-1 groups are shown in the upper panels of the figure, and data for the Blocking-2 and Control-2 groups are shown in the lower panels. For all four groups, the mean duration spent in the magazine during presentations of each CS for every session of Stage 1 is presented in the left-hand panels of Figure 7. By the end of Stage 1, both blocking and both control groups were spending a comparable amount of time in the magazine during presentations of the reinforced stimulus, and this was substantially longer than the duration spent in the magazine during presentations of the nonreinforced stimulus. The mean duration of magazine activity during each trial type on the final two sessions of Stage 1 was calculated for every

Table 3
Design of Experiment 3

Group	Stage 1		Stage 2			Test 1	Stage 3		Test 2
Blocking 1	A+	B–	A+	B–	AX+		A–	B+	X–
Control 1	A–	B+	A–	B+	AX+		A+	B–	X–
Blocking 2	A+	B–	A+	B–	AX+	X–	A–	B+	X–
Control 2	A–	B+	A–	B+	AX+	X–	A+	B–	X–

Note. A and B were counterbalanced as a tone and a clicker, X was the illumination of a thin film transistor screen to white. A plus sign (+) = reinforcement; a minus sign (−) = nonreinforcement.

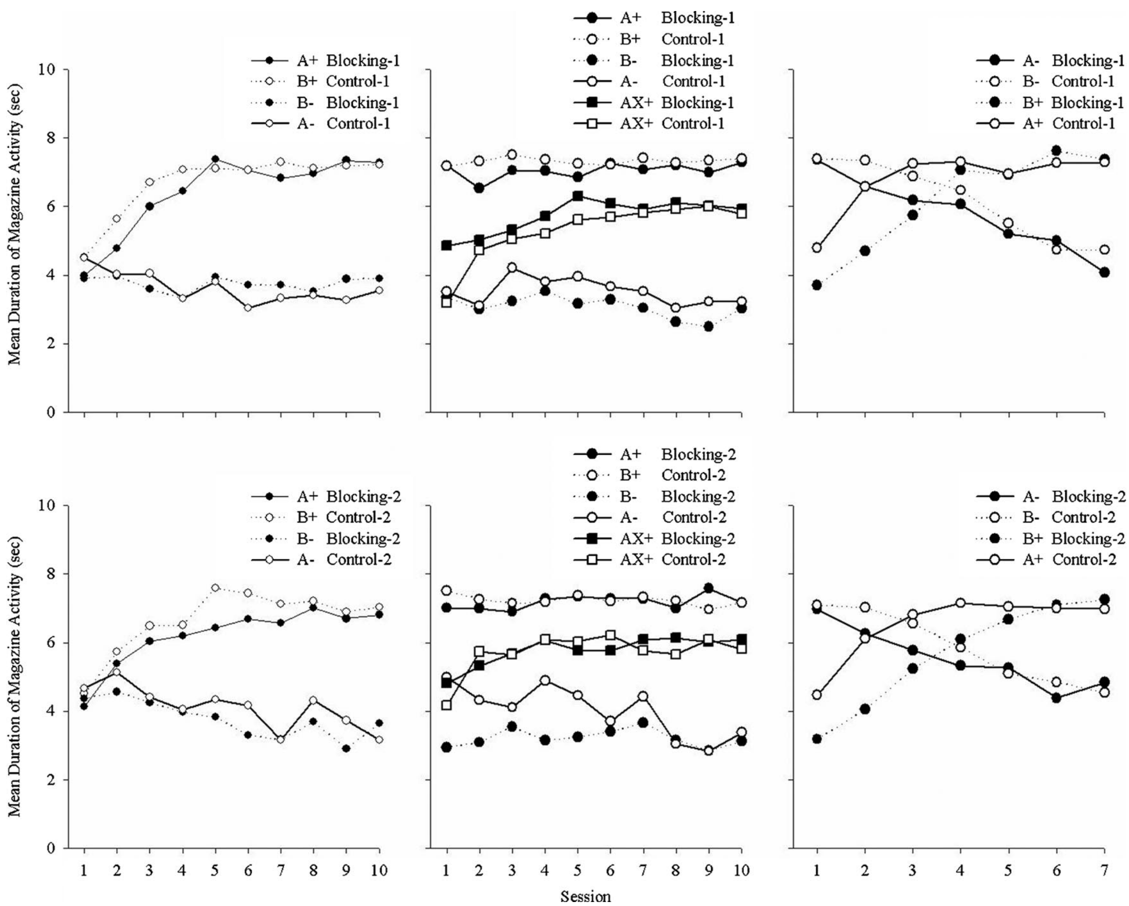

Figure 7. Mean duration of magazine activity for the four groups during presentations of each trial type on each session of Stage 1 (left-hand panel), Stage 2 (center panel) and Stage 3 (right-hand panel) of Experiment 3.

subject. A three-way ANOVA of individual mean durations of magazine activity was conducted with the factors of trial type (reinforced and nonreinforced), group (blocking or control) and number of tests (1 or 2). The analysis revealed a significant effect of trial type, $F(1, 60) = 206.34$, but no effect of group, $F < 1$, or number of tests, $F(1, 60) = 1.11$. None of the interactions was significant (Fs < 1).

The data for the three trial types of Stage 2 are presented in the center panels of Figure 7. By the end of training, both blocking and control groups were spending considerably longer in the magazine during presentations of both reinforced trial types than during presentations of the nonreinforced stimulus, although the duration of responding to the compound stimulus was slightly less than to the stimulus reinforced during Stage 1. A three-way ANOVA of mean individual durations of magazine activity during the final two sessions of Stage 2 was conducted, with the factors of trial type (reinforced element, nonreinforced element, and reinforced compound), group (blocking or control) and number of tests (1 or 2). This revealed a significant effect of trial type, $F(2, 120) = 251.05$, but there was no effect of group or number of tests and none of the interactions was significant, Fs < 1. Subsequent Bonferroni corrected pairwise comparisons revealed that there was a significant difference between the durations of responding to the reinforced element and nonreinforced element and between the durations of responding to the reinforced compound and nonreinforced element. As in Experiment 2, there was also a significant difference between responding to the reinforced compound and reinforced element.

The mean durations of magazine activity for the groups during presentations of the stimuli in Stage 3 are presented in the right-hand panels of Figure 7. From these panels it appears that this training was effective in reversing the significance of both A and B in all groups. A two-way ANOVA conducted on the mean individual durations of magazine activity during presentations of A on the final two sessions, with the factors of group (blocking or control) and number of tests (1 or 2), revealed a significant effect of group, $F(1, 60) = 44.77$, but no effect of number of tests, or Group $\times$ Number of tests interaction, Fs < 1. This analysis therefore confirmed that both control groups spent significantly longer in the magazine during presentations of A than the blocking groups, and that the durations of responding to this stimulus were comparable whether subjects received two tests with X or just one.

The same analysis was conducted on responding during B on the final two sessions. This analysis also revealed a significant effect of group, $F(1, 60) = 51.66$, but no effect of number of tests, or Group $\times$ Number of tests interaction, Fs < 1. Thus both blocking groups spent significantly longer in the magazine during presentations of B than the control groups. Taken together, the results from both ANOVAs confirmed that in all groups Stage 3 training successfully reversed the significance of both stimuli involved in Stage 1.

During Test 1, the Blocking-2 and Control-2 groups received three test trials with X. The mean duration of magazine activity during these trials is shown in the left-hand panel of Figure 8. From this figure it is evident that during presentations of X, group Control-2 spent longer in the magazine than group Blocking-2. A *t* test conducted on the mean individual durations of magazine activity during presentations of X revealed a significant effect of group, $t(30) = 2.37$.

The mean durations of magazine activity for all four groups during presentations of X on Test 2 are presented in the right-hand panel of Figure 8. From this figure it is evident that groups Control-1 and Control-2 spent comparable durations in the magazine, which were considerably longer than the similar durations that groups Blocking-1 and Blocking-2 spent in the magazine. Accordingly, a two-way ANOVA with the factors of group (blocking or control) and number of tests (1 or 2) revealed a significant effect of group, $F(1, 60) = 9.32$, but no significant effect of number of tests and no Group × Number of Tests interaction, $F\text{s} < 1$.

The results of Experiment 3 replicate those of Experiments 1 and 2, suggesting that the failure for revaluation of the competing cue to influence blocking in this paradigm is a robust effect. The lack of a difference between the control groups and between the blocking groups during Test 2 indicates that an initial test of X prior to revaluation with the competing cue does not influence subsequent responding to X.

In all three experiments, a reduction in responding in both the blocking and control groups from Test 1 to Test 2 was observed. In Experiment 3, a comparably low level of responding during Test 2 was observed in groups that received either one or two tests with X, which suggests that the reduction in responding to X observed on Test 2 was due to the passage of time, rather than to the extinction trials with X in Test 1.

General Discussion

In three experiments a blocking group of rats received reinforcement with A that either preceded conditioning with AX, or preceded and accompanied conditioning with AX. Subsequent testing with X in each experiment revealed weaker responding than in a control group that received similar treatment, but A by itself was not reinforced. The more important finding from the experiments is that these demonstrations of blocking were unaffected by subsequent training in which A was paired with food in the control group but presented without food in the blocking group. In other words, the final treatment with A did not result in retrospective revaluation of responding to X. The results are entirely consistent with the explanation for blocking put forward by for example, the Rescorla–Wagner model (Rescorla & Wagner, 1972).

The principal purpose of the experiments was to use a new methodology to test predictions made by the comparator hypothesis (e.g., Miller & Schachtman, 1985) concerning the influence of retrospective revaluation on blocking. According to this hypothesis, the strength of the response to X during the test trials in each experiment will be inversely related to the associative strength of A at the time of testing. In each experiment, responding to A was more vigorous before Test 2 in the control than the blocking group, which, according to the comparator hypothesis, should have resulted in stronger responding during X on this test by the blocking than the control group. In each experiment, however, the opposite outcome was recorded. The results from the three experiments thus pose a problem for the explanation of blocking provided by the comparator hypothesis. Blaisdell et al. (1999) argued that to observe retrospective revaluation following blocking it is necessary to give many hundreds of extinction trials with the blocking cue after compound conditioning. Although this may be true, it should be emphasized that this conclusion is not in keeping with the spirit or the detail of the comparator hypothesis, especially as far as the present experiments are concerned. Once the extinction trials with A during Stage 3 in the blocking group have resulted in a weaker response than that resulting from the reinforced trials with A in the

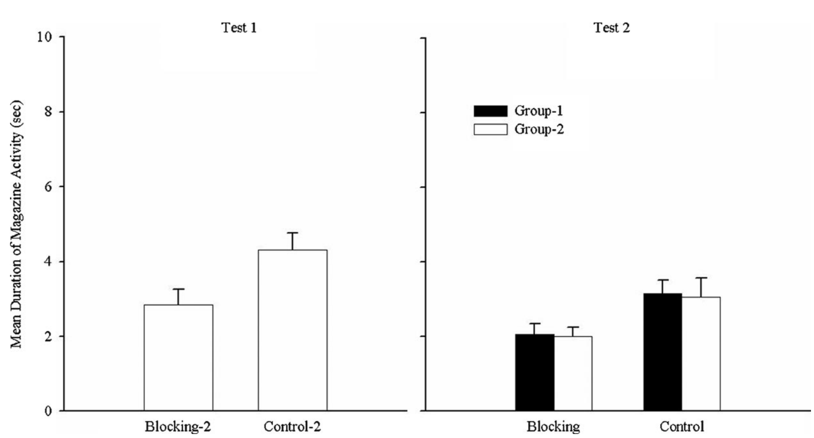

Figure 8. Mean duration of magazine activity (plus *SEM*) for groups Blocking-2 and Control-2 during presentations of X on Test 1 (left-hand panel), and for all four groups during presentations of X on Test 2 (right-hand panel) of Experiment 3. Group-1 refers to the Blocking-1 and Control-1 groups, and Group-2 refers to the Blocking-2 and Control-2 groups.

control group, the hypothesis unequivocally predicts that the outcome of Test 2 will be the opposite to that of Test 1.

Thus far we have examined the present results from the perspective of the comparator hypothesis put forward by Miller and Matzel (1988), but this hypothesis has since been developed into the extended comparator hypothesis (Denniston, Savastano, & Miller, 2001), and there is also a sometimes competing retrieval version of the hypothesis (Stout & Miller, 2007). The principal difference between the newer versions of this model and the original one is that Links 2 and 3 in Figure 1 can be influenced by second-order and third-order comparator processes. As far as second-order processes are concerned, the effectiveness of the X–A association in Link 2 of Figure 1 will be reduced by a function of the product of the strength of an X-context and a context-A association. Similarly, the effectiveness of the A–US association in Link 3 will be reduced by a function of the product of an A-context and a context-US association. The strength of each of these four second-order associations should not differ between the two groups. As a consequence, second-order comparator processes should not alter qualitatively the predictions that were derived from the original comparator hypothesis concerning the test trials with X. Second-order processes will, however, reduce the magnitude of the predicted influence of first-order comparator processes on responding to X.[1]

Turning now to third-order comparator processes, these will exert an influence on the role played by the context-US association in second-order comparator processes. The strength of this association will be reduced by a function of the product of the context-B and the B–US associations. Consider the second test with X in the blocking group. At the time of this test, the first-order A–US association in Link 3 of Figure 1 will be close to zero because of the extinction trials in Stage 3. The second-order comparator process for this link will weaken further the effectiveness of the A–US association. However, because B will have high associative strength its role in the third-order comparator process will be to weaken the second-order process. In other words, once account is taken of third-order comparator processes, the prediction concerning the outcome of the second test with the blocking group is much the same as that made by the original comparator hypothesis: The response to X will be strong. In contrast, because the strength of the B–US association can be assumed to be close to zero at the time of the second test in the control group, the third-order comparator process can be ignored in this group, which means performance during X will be weakened by the second-order comparator process. Thus the A–US association, which will be close to asymptotic strength because of the Stage 3 training, will be diminished to some extent by the second-order comparator process, but this effect will be slight because the context-US association on which it is based will be weak. Accordingly, despite the influence of third-order comparator processes, the comparator hypothesis predicts that the effectiveness of the A–US association will be greater in the control than the blocking group, and that responding during X will be weaker in the former than the latter. The fact that the opposite outcome was observed indicates that even the most complex version of the comparator hypothesis is unable to explain our results.

In addition to the comparator hypothesis, it was shown in the introduction that the theories of Van Hamme and Wasserman (1994) and Dickinson and Burke (1996) can also explain retrospective revaluation effects. According to these theories, the revaluation treatment with A during Stage 3 of each experiment will provide the opportunity for the associative strength of X to be changed, but in the opposite direction to that of A. Although the Stage 3 treatment should result in X gaining associative strength in the blocking group, and losing it in the control group, it is not clear the theories predict, as the comparator hypothesis does, that the second test will necessarily reveal a stronger response to X in the blocking than the control group. Conceivably, the negative learning rate parameter for absent stimuli is relatively low, in which case the difference between the two groups on the first test should be diminished, but not reversed for the second test. Thus the failure to find a stronger response in the blocking than the control group during the second test with X need not be taken as evidence against these theories. A further reason why the present results may not pose a serious challenge to these theories can be based on the claim by Dickinson and Burke that effective retrospective revaluation depends upon the existence of strong within-compound associations. There are two reasons why these associations may not have been particularly strong in the present experiments. On the one hand, Freberg (1979, as cited in Rescorla, 1981) demonstrated that preexposure to one element of a compound can disrupt the development of within-compound associations, which makes it possible that in each experiment the initial conditioning with A resulted in the subsequent formation of a weak A–X association (but see Balleine, Espinet, & González, 2005). On the other hand, the independent presentations of A in Stage 3 of each experiment, and in Stage 2 of Experiments 2 and 3, may have weakened the A–X association formed during compound conditioning (e.g., Rescorla & Freberg, 1978; but see Esber, Pearce, & Haselgrove, in press).

If the A–X association does not form, the theories of Van Hamme and Wasserman (1994) and Dickinson and Burke (1996) predict that retrospective revaluation will not occur, as A will not activate a representation of X when it is presented in extinction during Stage 3. In support of this proposal, Dickinson and Burke demonstrated with humans that retrospective revaluation effects are not obtained in the absence of within-compound associations (see also Melchers, Lachnit, & Shanks, 2006). If, however, the A–X association is formed but weakened by presentations of A alone, then on at least the initial extinction trials with A, a representation of X will be activated, allowing an increment in the associative strength of this stimulus. Hence, in this case a retrospective revaluation effect would be expected on test. The comparator hypothesis cannot explain the results of Experiments 1 to 3 by appealing to either the prevention of the X–A association or the weakening of this association. If the X–A association is prevented by the initial conditioning with A, blocking will not occur. However, if the X–A association forms and is then weakened by subsequent extinction trials with A, the combined influence of this

[1] In addition to A, the context might also be conceived as being a first-order comparator for X, with A acting as a second-order comparator. However, Savastano et al. (2003) argued that the salience of the context will be relatively low and because there are protracted periods when the context is presented in the absence of the US, its associative strength will be low relative to A, B, or X. As a consequence, the influence of the context as a first-order comparator stimulus will be modest and not affect qualitatively the predictions that have already been derived.

weak association and the weak A–US association should result in a particularly strong recovery from blocking effect being observed on test.

The failure to observe retrospective revaluation following blocking is consistent with the results reported by Holland (1999); Rauhut et al., (2000) and by Miller, Schachtman, and Matzel (1988, as cited in Blaisdell et al., 1999). These results were all obtained with rats, but a similar failure to find a reversal of blocking by retrospective revaluation has also been reported using pigeons by Rescorla and Durlach (1981, pp. 91–93). In contrast to these findings, and those reported in the present article, Blaisdell et al. were able to observe a recovery from blocking after nonreinforced exposure to the blocking stimulus. There are a number of differences between the method adopted by Blaisdell at al. and that adopted for the present studies, which makes it difficult to explain why we failed to replicate their findings. First, Blaisdell et al. used aversive conditioning with 12 A+ trials and 4 AX+ trials whereas we used appetitive conditioning and at least 120 A+ trials and at least 32 AX+ trials. Second, in the experiments by Blaisdell et al., conditioning took place in a different context to the one in which the extinction trials with A, and the test with X took place. We used the same apparatus for all phases of each experiment. It is conceivable that if the design of our experiment had more closely matched that of Blaisdell et al. then we might have found an effect of retrospective revaluation on blocking. However, the principal purpose of the experiments was not to identify the circumstances under which retrospective revaluation on blocking can be found. Rather, it was to test a specific prediction of the comparator hypothesis by examining whether the effects on X of two different types of training, A+ then AX+ or A– then AX+, can be reversed by reversing the significance of A. Our failure to replicate the results of Blaisdell et al. does not affect at all the conclusions we wish to draw from our experiments, namely, that responding during X was unaffected by the reversal training with A.

Matzel, Shuster, and Miller (1987) reported that after conditioning with AX+, responding to X was enhanced by subsequent A– trials, but not affected by A+ trials. The implication of this finding for the present experiments is that the reinforced trials with A during Stage 3 in the control group may not have been ideal for revealing retrospective revaluation effects with blocking. Whether this is the case, the treatments in Stage 3 were effective in producing stronger responding to A in the control than the blocking group. As just noted, such an outcome according to the comparator hypothesis should have revealed a complementary pattern of results with X during the final test, yet the opposite was observed.

The retrospective revaluation effect brought about by the A– trials in the above study by Matzel et al. (1987) has been reported on a number of occasions in overshadowing studies with animals (Balleine et al., 2005; Kaufman & Bolles, 1981; Liljeholm & Balleine, 2006; Matzel, Schachtman, & Miller, 1985; Miller, Barnet, & Grahame, 1992). If retrospective revaluation is effective in these circumstances, the question is then raised as to why it is less successful with blocking. Perhaps, as noted above, the necessity of presenting the blocking cue separately from the blocked cue makes it difficult for associations to develop between the stimuli. In the absence of these associations, Dickinson and Burke (1996) argued that retrospective revaluation is unlikely to take place.

Previous studies that have looked for evidence of retrospective revaluation have relied on extinction training with the blocking cue to test for retrospective revaluation following blocking. In the novel design reported here, whereas the blocking group initially received reinforced presentations of the blocking cue, A, the control group received nonreinforced presentations of this cue. The reversal of this training following blocking meant that as well as giving extinction training with A in the blocking group, reinforced presentations of this cue were given in the control group. Revaluing A in both groups allowed the predictions of the comparator hypothesis to be tested, but avoided the difficult question of how many extinction trials to give. Therefore although further research will be required to determine the precise conditions that give rise to retrospective revaluation in blocking, the present results show clearly that blocking does not depend upon the associative strength of A being high at the time when X is tested. On this basis, it must be concluded that at least in certain circumstances, blocking is a consequence of a failure by a stimulus to acquire associative strength.

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