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Contrasting Reduced Overshadowing and Blocking

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Abstract

Preexposure of a cue without an outcome (X-) prior to compound pairings with the outcome (XZ→O) can reduce overshadowing of a target cue (Z). Moreover, pairing a cue with an outcome (X→O) before compound training can enhance its ability to compete with another cue (i.e., blocking). Four experiments were conducted in a conditioned bar-press suppression preparation with rats to determine whether spacing of the X- or X→O trials would differentially affect reduced overshadowing and blocking. Experiment 1a showed that reduced overshadowing was larger with massed trials than with spaced trials. Experiment 1b found that blocking was larger with spaced trials than with massed trials. Experiments 2a and 2b indicated that these effects of trial spacing were both mediated by the associative status of the context at test. The results are interpreted in the framework of contemporary learning theories.

Keywords

reduced overshadowing; blocking; latent inhibition; trial spacing; extended comparator hypothesis

When a to-be-conditioned stimulus (CS) is paired with (i.e., precedes) an unconditioned stimulus (US), the CS comes to elicit a conditioned response, which is presumably mediated by a CS-US association. Since Pavlov's initial studies, the study of classical conditioning has been focused on factors that affect the acquisition, extinction, and expression of a CS-US association. One emphasis in the study of associative learning has been on cue-competition phenomena, which can occur when two cues are conjointly paired with a common outcome. Perhaps the most elementary example of cue competition is overshadowing. Overshadowing is often observed in Pavlovian conditioning when two CSs are paired with a US. This treatment results in weaker conditioned responding to either of the cues relative to a situation in which only the target CS is paired with the US (Pavlov, 1927, pp. 142-143, 269-270). Here we refer to the cue that is tested as the *target cue*, which is also sometimes called the *overshadowed cue*. The other cue is commonly called the *overshadowing cue*, although overshadowing can be reciprocal (e.g., Mackintosh, 1976). Most contemporary theories of associative learning can account for overshadowing, but they employ diverse mechanisms to do so.

The overshadowing effect can be reduced or augmented by different types of pretraining exposure to the overshadowing CS. For example, Kamin (1968) found that a light was more apt to overshadow a noise if the light received prior reinforcement in the absence of the noise. Although this effect can be referred to as *enhanced overshadowing*, Kamin referred to the effect as *blocking*. The latter term is probably more fitting because blocking is defined by the fact that the blocking stimulus (the noise in the preceding example) has a previously established relationship with the US before compound conditioning; overshadowing is more dependent on differences in salience between CSs (Mackintosh, 1976). The Kamin blocking effect captured

the attention of many learning theorists, and most contemporary theories of associative learning account for both effects.

In contrast to blocking, one often observes a reduction of overshadowing if the overshadowing cue is preexposed without reinforcement. For example, Carr (1974) found that nonreinforced exposure of a light stimulus effectively weakened its ability to subsequently overshadow a noise stimulus. This effect has since been dubbed *reduced overshadowing* (e.g., De Houwer, Beckers, & Glautier, 2002, p. 975). Procedurally, reduced overshadowing might be viewed as latent inhibition (e.g., Lubow & Moore, 1959) of the overshadowing CS. Applied to Carr's design, preexposure of the light stimulus should reduce the effect of subsequent reinforcement of the light, and consequently reduce the extent to which the light stimulus can overshadow the noise. Carr suggested that preexposure to the overshadowing stimulus might reduce its associability, which would impair its ability to compete with the noise for associative strength. The concept of reduced associability is a popular account of both latent inhibition and reduced overshadowing, but many alternative accounts of these effects have been developed, some of which emphasize the role of the context in latent inhibition, and consequently, reducing overshadowing.

Although blocking and reduced overshadowing are similar in design, the effectiveness of the two types of pretraining exposure to the competing cue (reinforced and nonreinforced) might be differentially sensitive to certain manipulations. Specifically, extended exposure to the context in which learning occurs might have a dissimilar influence on the effectiveness of the two manipulations. The effect of context exposure on reduced overshadowing and blocking may be better appreciated by considering the effect that the context can have on latent inhibition and simple acquisition, which seemingly are important for reduced overshadowing and blocking, respectively. Typically, if cue-outcome pairings (e.g., $X \rightarrow US$) are administered with relatively spaced trials, strong conditioned responding is observed. If the same number of cue-outcome pairings is administered in a shorter session with short trial spacing, weaker conditioned responding is observed (e.g., Barela, 1999; Jenkins, Barnes, & Barrera, 1981; Stout, Chang, & Miller, 2003). The response-degrading effect of trial massing can at least partially be accounted for as overshadowing of the target CS by the context (e.g., Stout et al., 2003). When trials are massed, the context undergoes little extinction between trials, which should enhance its association with both the CS and the US and subsequently produce more competition between the CS and the context. Trial massing has a similar effect on nonreinforced preexposures of a to-be-conditioned stimulus. Latent inhibition tends to be more profound if the nonreinforced CS exposures are temporally massed. As with the effect of trial massing on excitatory conditioning, context exposure appears to be integral to the effect of trial massing on latent inhibition (e.g., Escobar, Arcediano, & Miller, 2002). Thus, a large amount of context exposure due to the use of widely spaced trials is seen to enhance simple conditioning but attenuate the latent inhibition effect.

The effect of context exposure on blocking and reduced overshadowing may be observed with manipulations other than trial spacing. For example, posttraining context extinction can affect conditioning in a similar way as temporally spaced training. Chang, Stout, and Miller (2004) found that posttraining context extinction after relatively massed trials caused an increase in responding to a simple excitator. This result is not ubiquitous (e.g., Kehoe, Weidemann, & Dartnall, 2004; Poulos, Pakaprot, Mahdi, Kehoe, & Thompson, 2006), but it has been observed repeatedly in our laboratory as well as in others (e.g., Balsam, 1985; Grahame, Barnet, & Miller, 1992; Stout & Miller, 2004; Yin, Barnet, & Miller, 1994). Other studies have indicated that context exposure can attenuate latent inhibition if it is administered during preexposure (i.e., with spaced trials) or after preexposure (before conditioning), but not before preexposure (Escobar et al., 2002). Furthermore, posttraining context exposure can reduce latent inhibition even if exposure occurs after reinforcement (e.g., Grahame, Barnet, Gunther, & Miller,

1994). Thus, posttraining context exposure produces many of the same effects as context exposure during training because it extinguishes the association between the context and the target cue.

Considering the divergent influence that the context can have on a simple excitatory training (i.e., reinforcement) and latent inhibition treatment (i.e., nonreinforcement), it seems likely that the context could also interact divergently with blocking and reduced overshadowing. If the effectiveness of excitatory training of a CS is reduced by trial massing, it is logical to expect that relatively massed trials in the first phase of a blocking design ($X \rightarrow US$) should produce less blocking when X is later reinforced in compound with a novel stimulus ($XZ \rightarrow US$). If $X \rightarrow US$ training trials are widely spaced, the context extinction that occurs between trials reduces the context's association with X and with the US, thereby allowing for robust blocking. Likewise, context extinction after training could have a similar effect as widely spaced trials. In contrast, reduced overshadowing (X-followed by $XZ \rightarrow US$) should be differentially affected by trial massing during the X-treatment. Because trial massing produces more profound latent inhibition, one would expect it to cause a greater reduction in X's capability to overshadow Z. Consequently, it should enhance responding to Z because the context will have acquired a strong association to X. When the X- trials are spaced and possibly when the context is extinguished after overshadowing treatment, overshadowing should be more pronounced. Thus, contrary to what might be expected based simply on the design similarities between blocking and reduced overshadowing, the two effects might be differentially affected by the associative status of the context. Stated generally, extensive context exposure either during or after training of X should enhance cue competition in both situations (i.e., enhance blocking and attenuate reduced overshadowing).

The present series of experiments manipulated context exposure in two ways. Experiments 1a and 1b examined the basic prediction that massing trials would facilitate the reduced overshadowing effect but attenuate blocking. In Experiments 1a and 1b, the trial spacing was manipulated so that half of the subjects received relatively massed trials in Phase 1, whereas the other half received relatively spaced trials in Phase 1 (see Table 1). Experiments 2a and 2b investigated whether posttraining context exposure would eliminate the effects of trial massing. In Experiments 2a and 2b, Phase 1 training was massed for all subjects, and the context was extinguished for half of the subjects after training. All experiments were conducted in a conditioned bar-press suppression preparation with rats, in which auditory and visual stimuli served as CSs and footshock served as the US. Fear was assessed as the extent to which the presentation of the CSs disrupted performance on a previously trained lever-pressing task. Because the experiments were designed to manipulate the associative status of the training context, the physical context was varied between training and testing in all of the experiments. This was intended to minimize concerns that the context might directly elicit conditioned suppression at test, which might vary among groups based on overall context exposure.

One potential problem for Experiments 2a and 2b was that posttraining manipulations tend to be ineffective in reducing responding to a stimulus that has already attained biological significance (Denniston, Miller, & Matute, 1996; Miller & Matute, 1996).¹ Responding to a CS is largely immune to indirect manipulations intended to decrease conditioned responding unless the CS-US association is directly altered through CS extinction or US revaluation. Specifically, some retrospective revaluation effects that result in reduced responding to a previously trained stimulus are difficult to observe in first-order Pavlovian conditioning. For

¹Here *biological significance* refers to the potential of a stimulus to provoke a conditioned or unconditioned response. Although all perceived stimuli produce some covert or overt response in an animal, robust overt responding to a stimulus indicates that the stimulus has attained a high level of biological significance. Hence, biological significance is a continuum, but the phrase is used here specifically to refer to a stimulus that provokes a robust overt response such as freezing.

example, backward blocking (XZ→US trials followed by X→US trials, resulting in reduced responding to Z) has not been observed in first-order Pavlovian fear conditioning with nonhuman animals (e.g., Miller, Hallam, & Grahame, 1990; Schweitzer & Green, 1982). Although Experiments 2a and 2b did not investigate backward blocking, both experiments involved a posttraining manipulation (i.e., context exposure) that in principle could reduce responding to the target cue at test without directly extinguishing the target or altering the value of the outcome. Unpublished experiments from our laboratory have shown that responding to a biologically significant CS tends to be protected from reductions that could be caused by manipulations such as posttraining extinction or reinforcement of an associate of the CS (e.g., the context). In order to maximize the effectiveness of context extinction, we embedded all of the present experiments in a sensory-preconditioning design that has been shown to be more sensitive to retrospective revaluation effects such as backward blocking (e.g., Miller & Matute, 1996). In all of the experiments, subjects were trained by pairing the CSs with an initially innocuous outcome, which was reinforced with the US between training of the target cue and testing.

Experiment 1a

Experiment 1a was designed to test the effect of trial spacing on reduced overshadowing. The experiment was divided into shaping, three phases of training, and a test (see Table 1). All critical between-subjects manipulations took place in Phases 1 and 2. During Phase 1, subjects were exposed to eight nonreinforced presentations of either the overshadowing stimulus (X) or an irrelevant stimulus (Y). Subjects in the reduced overshadowing (reducedOV) condition received exposure to X, whereas subjects in the control and overshadowing (OV) conditions received exposure to Y. The relatively small number of Phase 1 exposures to X (or Y) was intended to produce a relatively small reducedOV effect, thereby increasing sensitivity to the context manipulations planned for Experiments 2a and 2b. Phase 1 occurred in two 2-hr sessions for subjects in the spaced condition, and in two 8-min sessions for subjects in the massed condition. In Phase 2, CS X and the target stimulus (Z) were compounded and paired together with the outcome (O) four times for the OV and reducedOV conditions, whereas Z alone was paired with O in the control condition. In Phase 3, O was reinforced with a footshock US, which allowed expression of the Z-O association based on the O-US association. Finally, the subjects experienced four test presentations of the Z stimulus in a single test session.

Method

Subjects—Subjects were 36 male (228–339 g) and 36 female (180–233 g) experimentally naive, Sprague-Dawley-descended rats obtained from our own breeding colony. Subjects were randomly assigned to one of six groups ($ns = 12$), counterbalanced within groups for sex. The animals were individually housed in standard hanging stainless steel wire-mesh cages in a vivarium maintained on a 16/8-hr light/dark cycle. Experimental manipulations occurred near the middle portion of the light phase. The animals were allowed free access to Purina Lab Chow, whereas water availability was limited to 30 min per day following a progressive deprivation schedule initiated 1 week 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 per week.

Apparatus—The apparatus consisted of 12 operant chambers each measuring $30.5 \times 27.5 \times 27.3$ cm ($l \times w \times h$). All chambers had clear Plexiglas ceilings and sidewalls and metal front and back walls. On one metal wall of each chamber there was an operant bar and, adjacent to it, a niche ($4.5 \times 4.0 \times 4.5$ cm) centered 3.3 cm above the floor through the top of which a solenoid could deliver 0.04 ml of water into a small cup at the bottom of the niche. Chamber floors were 4-mm grids spaced 1.7 cm apart center to center, connected with NE-2 neon bulbs, which allowed a 0.5-mA footshock to be delivered by means of a high voltage AC circuit in

series with a 1.0-M Ω resistor. All chambers were individually housed in sound- and light-attenuating enclosures. Three 45- Ω speakers mounted on three different interior walls of each environmental chest could deliver a complex tone (3000 and 3200 Hz) of 10 dB above background (C scale, sound-pressure level), a 6 per second click of 6 dB (C) above background, and a white noise of 8 dB (C) above the ambient background sound of 78 dB that was produced primarily by a ventilation fan. Additionally, a buzzer mounted on each environment chest was able to deliver a buzzing noise at 10 dB (C) above the background sound level. An overhead flashing (1/6 s on, 1/6 s off) light stimulus could be provided by a 60-W bulb (nominal at 120 volts of alternating current [VAC], but driven at 80 VAC). In this experiment, the buzzer and complex tone served as cues X and Y, counterbalanced within groups. The clicks served as the target cue Z. The flashing light served as the outcome O. The white noise was presented for 0.5 s simultaneously with each water delivery to facilitate acquisition of bar pressing for water. All stimuli were 30 s in duration with the exception of the 5-s flashing light, the 0.5-s white noise, and the 0.5-s footshock US.

The basic apparatus described in the preceding paragraph was manipulated to form two distinct contexts so that the subjects could be tested in a context other than the training context. In Context 1 (used for shaping, reshaping, and test), each chamber was dimly illuminated by a #1820 house light. In Context 2 (used for Phases 1-3), the house light was off. Furthermore, a distinct odor cue was present in Context 2 that was provided by two drops of methyl salicylate (wintergreen oil) placed on a wooden cube located outside of the operant chamber but inside of the sound-attenuating enclosure. Additionally, although the bars were present, no water was available in Context 2.

Procedure

Acclimation and shaping: Prior to Phase 1, a 5-day acclimation bar-press training regimen in Context 1 was administered. Each day, all subjects experienced a 60-min session. Subjects were shaped to bar press for water (0.04 ml) on a variable-interval 20-s schedule. To facilitate magazine training, the onset of the water delivery was accompanied by the 0.5-s white noise. On Days 1 and 2, a fixed-time 2-min schedule of noncontingent solenoid operation occurred concurrently with a continuous reinforcement schedule. On Day 3, noncontingent reinforcers were discontinued and subjects were trained on the continuous reinforcement schedule alone. Subjects that finished a session with less than 50 responses were hand-shaped later in the day with a successive approximation procedure. At the end of Day 3, all subjects had made at least 50 bar presses in a session. On Days 4 and 5, a variable interval 20-s schedule was imposed and maintained. This schedule of reinforcement prevailed in Context 1 throughout the remainder of the experiment, including testing.

Phase 1: On Days 6 and 7, all subjects experienced Phase 1 training in Context 2. For the subjects in the spaced condition, Phase 1 training occurred in daily 120-min sessions. In each session, subjects in the reducedOV-spaced group experienced four nonreinforced presentations of stimulus X with an average intertrial interval (ITI) of 30 min (presentations occurred 5, 45, 80, and 105 min into the session). Subjects in the OV-spaced and control-spaced groups received the same schedule of treatment, except Y was presented instead of X. For the subjects in the massed condition, Phase 1 training occurred in daily 8-min sessions. In each session, subjects in the reducedOV-massed group experienced presentations of stimulus X with a mean ITI of 2 min (presentations occurred 2, 4, 5.5, and 7 min into the session). Subjects in the OV-massed and control-massed groups received the same schedule of treatment, except Y was presented instead of X.

Phase 2: On Day 8, all subjects received a single 31-min session in Context 2. Subjects in the reducedOV and OV conditions experienced four XZ→O pairings with a mean ITI of 7.75 min

(presentations occurred 4, 12, 19.5, and 28 min into the session), which was the geometric mean of the ITIs of the Phase 1 trial spacing in the spaced condition (30 min) and the massed condition (2 min). The geometric means were used here based upon the finding that variation in time perception often follows Weber's law (e.g., Gibbon, 1977). The onset of the 5-s O stimulus occurred at the termination of the 30-s XZ compound. Subjects in the control condition received the same treatment, except that Z was paired with the outcome in the absence of X.

Phase 3: On Day 9, all subjects received four O-US pairings with a mean ITI of 7.75 min (presentations occurred 4, 12, 19.5, and 28 min into the session) in a 31-min session in Context 2. The 0.5-s footshock US coterminated with the 5-s O stimulus.

Reshaping and testing: On Days 10 and 11, all subjects received daily 60-min sessions of uninterrupted bar pressing in Context 1 that were intended to restabilize bar pressing. On Day 12, all subjects were tested on Z in a 30-min test session in Context 1. In each session, there were 4 nonreinforced presentations of Z (30 s in duration) separated by 4-min ITIs (onset to onset). The first test occurred 5 min following placement in the operant chamber. A suppression ratio was calculated for each subject by dividing the total number of bar presses made during the four CS presentations by the sum of that number plus half the total number of bar presses made during the four 60-s intervals that immediately preceded the 30-s CSs—that is, $BP_{CS} / (BP_{CS} + 0.5BP_{pre-CS})$.

Results

The suppression ratios from Experiment 1a are displayed in Figure 1. The subjects in the control condition showed strong fear of the target CS regardless of the trial spacing of Phase 1. Subjects in the overshadowing condition showed the weakest suppression regardless of whether Phase 1 trials were massed or spaced. Subjects in the reducedOV condition showed greater fear than that observed in the overshadowing condition, but the effectiveness of the Phase 1 preexposure to X varied based on trial spacing. Stronger fear was apparent when trials were temporally massed relative to when they were spaced. These observations were supported by the following statistical analyses.

An alpha level of .05 was adopted for all of the statistical analyses in this series of experiments. In order to determine whether there were any between-group differences in fear to the context before any CS test presentations, we analyzed the pre-CS lever presses before the first test trial with a 3 (treatment: reducedOV vs. OV vs. control) $\times$ 2 (trial spacing: spaced vs. massed) analysis of variance (ANOVA). For subjects in the spaced condition, the means were 21.67 ($SE = 3.75$), 21.08 ($SE = 1.86$), and 23.33 ($SE = 3.19$) for conditions reducedOV, OV, and control, respectively. For subjects in the massed condition, the means were 21.08 ($SE = 2.45$), 21.42 ($SE = 2.16$), and 22.17 ($SE = 3.47$) for conditions reducedOV, OV, and control, respectively. The ANOVA revealed no differences between any of the groups ($ps > .84$), which indicated that the groups did not appreciably differ in levels of baseline lever pressing before CS test presentations. A parallel ANOVA using the suppression ratios revealed an effect of treatment, $F(1, 66) = 99.90$, an effect of trial spacing, $F(1, 66) = 10.73$, and an interaction between the two variables, $F(1, 66) = 19.96$. Because the source of the interaction was somewhat ambiguous, the results of Experiment 1a were further analyzed with two 2×2 ANOVAs in order to determine whether Phase 1 trial spacing affected reducedOV. The first 2 (treatment: OV vs. control) $\times$ 2 (trial spacing: spaced vs. massed) ANOVA detected an overshadowing effect, $F(1, 44) = 211.32$, but no effect of Phase 1 trial spacing or any interaction between the two variables ($ps > .31$). Another 2 (treatment: reducedOV vs. OV) $\times$ 2 (trial spacing: spaced vs. massed) ANOVA was conducted to determine whether overshadowing was reduced by X-alone presentations prior to overshadowing treatment. This analysis revealed an effect of Phase 1 trial spacing, $F(1, 44) = 31.30$, an effect of treatment, $F(1, 44) = 125.75$,

and an interaction between the two variables, $F(1, 44) = 35.35$. Planned comparisons were conducted to determine whether the interaction suggested a more profound reduction of overshadowing when trials were temporally massed relative to when they were spaced. A comparison of groups ReducedOV-Spaced and OV-Spaced found that there was an increase in fear to CS Z when temporally spaced X- trials were administered in Phase 1, $F(1, 44) = 13.88$. This effect was also apparent in the massed condition, $F(1, 44) = 147.22$. Although reducedOV was apparent regardless of Phase 1 trial spacing, a comparison of groups ReducedOV-Massed and ReducedOV-Spaced indicated a greater increase in fear when Phase 1 X- trials were massed, $F(1, 44) = 66.59$.

Overall, these results conformed to the prediction that massed CS preexposure would be more effective than spaced CS preexposure. The effectiveness of an overshadowing stimulus was reduced by X preexposure in the reducedOV condition. In addition, overshadowing was reduced more in the situation in which X-preexposures were temporally massed.

Experiment 1b

Experiment 1b was conducted to examine the effect of Phase 1 trial spacing on blocking (see Table 1). The design was very similar to that of Experiment 1a, except there was no elemental control group for overshadowing. Instead, a group treated similarly to the OV group of Experiment 1a served as the control group for Experiment 1b. Also, the Phase 1 presentations of X or Y were immediately followed by the outcome (O). Wherever possible, the parameters were kept consistent with Experiment 1a. One necessary change involved altering the relative saliences of X, Y, and Z. In order to observe a significant effect of blocking, it was necessary to avoid a large overshadowing effect in the control subjects. Thus, the Z stimulus was more salient than X and Y.

Method

Experiment 1b was similar to Experiment 1a with the following exceptions. Only 24 male (263-330 g) and 24 female (186-232 g) subjects were used because there was no need for an elemental overshadowing control condition ($ns = 12$). Furthermore, X or Y presentations in Phase 1 were immediately followed by the 5-s O stimulus. Finally, the Z stimulus (clicks) was 10 dB above the background noise, whereas X and Y (buzzer and tone, counterbalanced within groups) were each 6 dB above the background noise.

Results

An equipment malfunction resulted in the elimination of 1 of the subjects from the Control-Massed group. The data from the remaining subjects are presented in Figure 2. Not surprisingly, subjects in the control condition displayed strong fear of the CS regardless of the trial spacing of Phase 1. In contrast, suppression in the blocking condition appeared to be dependent on the trial spacing in Phase 1. When trials were temporally massed, little blocking was observed in that subjects exhibited strong fear of Z. When Phase 1 trials were spaced, subjects in the blocking condition exhibited noticeably less fear than those in the control condition. The following statistical analyses verified these observations.

The mean number of lever presses during the pre-CS period before the first CS presentation was 20.08 ($SE = 2.82$), 18.58 ($SE = 2.20$), 18.58 ($SE = 1.66$), and 18.09 ($SE = 2.08$) in groups Blocking-Spaced, Control-Spaced, Blocking-Massed, and Control-Massed, respectively. A 2 (treatment: blocking vs. control) $\times$ 2 (trial spacing: massed vs. spaced) ANOVA of the pre-CS means revealed no significant effects or interaction ($ps > .65$). A parallel analysis of the suppression ratios revealed an effect of Phase 1 trial spacing, $F(1, 43) = 55.43$, an effect of treatment, $F(1, 43) = 82.30$, and an interaction between the two variables, $F(1, 43) = 49.38$. A

planned comparison of the blocking and control groups that received spaced trials in Phase 1 detected a reliable blocking effect, $F(1, 43) = 132.53$. A similar comparison of groups Blocking-Massed and Control-Massed showed no reliable difference between the groups, $F(1, 43) = 2.05$, $p = .16$. Furthermore, subjects in the Blocking-Spaced group expressed less fear relative to subjects in the Blocking-Massed group, $F(1, 43) = 107.10$.

Experiments 2a and 2b

In Experiments 2a and 2b (see Table 2), all subjects received massed trials in Phase 1, and the training context was extinguished after Phase 2 for half of the subjects. Like the spaced trials in Experiments 1a and 1b, this manipulation was intended to extinguish the association between the context and the competing stimulus. However, in this case, the context was extinguished extensively after training, rather than between the Phase 1 trials. If posttraining context extinction were effective, subjects that received this manipulation should have shown responding that was similar to that of subjects that received spaced trials in Experiments 1a and 1b. Following this assumption, posttraining extinction of the context should have reduced responding to Z, that is, increased overshadowing and blocking.

Method of Experiments 2a and 2b

Experiments 2a and 2b were similar to Experiments 1a and 1b, respectively, except all subjects received massed training trials in Phase 1. Furthermore, subjects in the Ext condition received massive exposure to the training context in an added phase of training that followed Phase 2. This massive exposure consisted of 2.5-hr daily sessions of context exposure across four consecutive days, which should have largely extinguished the associative influence of the context. Subjects in the NoExt condition received only 5-min daily sessions of context exposure across four consecutive days, thereby controlling for exposure to handling cues. Therefore, the associative value of the context should have remained relatively unchanged for subjects in the NoExt condition. Experiment 2a used 36 male (280-404 g) and 36 female (198-278 g) rats, and Experiment 2b used 24 male (311-393 g) and 24 female (195-273 g) rats.

Results of Experiment 2a

One rat from group Control-NoExt was eliminated because of a mechanical malfunction that occurred during Phase 3. The results of Experiment 2a are depicted in Figure 3. Suppression was greatest in subjects in the control condition, with the most fear exhibited by subjects in the Control-Ext group. Subjects in the overshadowing condition expressed little fear of Z regardless of whether they experienced 20 min or 10 hr of context extinction following overshadowing treatment. The effectiveness of preexposing X before overshadowing treatment varied depending on the duration of context exposure during Phase 3. Subjects that received little context exposure exhibited strong fear of Z, which replicated the observation in Experiment 1a of a robust reduction of overshadowing when the X preexposures were temporally massed. When the context was extinguished for 10 hr after overshadowing treatment in group ReducedOV-Ext, suppression was weakened. Context extinction following overshadowing treatment appeared to be inversely related to the effectiveness of X preexposure.

The number of pre-CS lever presses before the first test trial was analyzed with a 3 (treatment: reducedOV vs. OV vs. control) $\times$ 2 (posttraining extinction: Ext vs. NoExt) between-subjects ANOVA. For subjects in the Ext condition, the means were 21.33 ($SE = 1.88$), 26.00 ($SE = 2.09$), and 24.17 ($SE = 2.83$) for conditions reducedOV, OV, and control, respectively. For subjects in the NoExt condition, the means were 19.42 ($SE = 2.07$), 18.50 ($SE = 2.53$), and 23.82 ($SE = 2.50$) for conditions reducedOV, OV, and control, respectively. The ANOVA revealed no differences between any of the groups ($ps > .09$). A parallel ANOVA using the

suppression ratios revealed an effect of treatment, $F(1, 66) = 75.44$, and an interaction, $F(1, 66) = 20.73$, but no main effect of posttraining extinction, $F(1, 66) = 2.26$. In order to elucidate the source of this interaction, we further analyzed the suppression ratios with two 2×2 between-subjects ANOVAs. A 2 (treatment: OV vs. control) $\times$ 2 (posttraining extinction: Ext vs. NoExt) ANOVA detected an effect of treatment, $F(1, 43) = 161.39$, an effect of posttraining extinction, $F(1, 43) = 7.95$, but no reliable interaction ($p > .23$). Less suppression was observed in both of the overshadowing groups regardless of the amount of posttraining context exposure. The effect of treatment suggests that suppression was more apparent in subjects that received a large amount of posttraining context extinction, which was not initially expected. Because this difference was not anticipated, a Fisher's least significant difference post hoc analysis was performed that revealed greater suppression in group Control-Ext than in group Control-OV ($p < .05$) but no reliable difference between groups OV-Ext and OV-NoExt ($ps > .25$). The difference between the two control groups reflected an increase in response potential as a result of context extinction, which has been observed elsewhere (e.g., Balsam, 1985; Chang et al., 2004; Stout & Miller, 2004). This increase was not strongly anticipated here, but it does serve to show that context extinction did not produce a universal decrease in responding through a mechanism such as secondary extinction.

Another 2 (treatment: reducedOV vs. OV) $\times$ 2 (posttraining extinction: Ext vs. NoExt) ANOVA revealed an effect of treatment, $F(1, 44) = 41.64$, an effect of posttraining context exposure, $F(1, 44) = 14.02$, and an interaction between the two variables, $F(1, 44) = 28.72$. Planned comparisons were conducted to determine whether the effectiveness of X preexposures to reduce overshadowing depended on the amount of posttraining context exposure. A comparison of groups ReducedOV-NoExt and OV-NoExt indicated that overshadowing was much more robust when massed X-alone exposures were not administered before overshadowing treatment, $F(1, 44) = 69.76$. This replicated the result of Experiment 1a. In contrast, group ReducedOV-Ext did not exhibit significantly less fear relative to group OV-Ext, $F(1, 44) = 0.60$, $p > .44$. Taken together with the significant interaction, these comparisons suggested that posttraining extinction of the context produced a reemergence of the overshadowing effect. Further supporting this conclusion, an additional planned comparison revealed that group ReducedOV-NoExt showed greater suppression than group ReducedOV-Ext, $F(1, 44) = 41.43$.

Results of Experiment 2b

During Phase 2 training, a mechanical malfunction caused the elimination of 1 rat from the Blocking-NoExt group. Figure 4 displays the data from the remaining animals. The results of Experiment 2b partially replicated Experiment 1b and further showed that posttraining extinction of the training context reduced the effect of trial massing. When Phase 1 trials were massed and posttraining context exposure was minimal (i.e., 20 min), no blocking effect was observed. In contrast, blocking was robust when the context was massively extinguished after training (i.e., 10 hr). This result suggests that the associative status of the training context can influence responding to the target stimulus after blocking training.

The mean number of lever presses during the pre-CS period before the first test was 25.58 ($SE = 2.83$), 24.08 ($SE = 2.42$), 23.46 ($SE = 2.76$), and 21.58 ($SE = 1.08$) in groups Blocking-Ext, Control-Ext, Blocking-NoExt, and Control-NoExt, respectively. A 2 (treatment: blocking vs. control) $\times$ 2 (posttraining extinction: Ext vs. NoExt) ANOVA of the pre-CS means revealed no significant effects or interaction ($ps > .33$). The suppression ratios were analyzed with a parallel ANOVA. This analysis revealed an effect of treatment, $F(1, 43) = 25.37$, an effect of posttraining context exposure, $F(1, 43) = 20.98$, and an interaction between the two variables, $F(1, 43) = 16.40$. The interaction suggested that posttraining context extinction altered the strength of the blocking effect, and planned comparisons were conducted to test this possibility.

A planned comparison of groups Blocking-NoExt and Control-NoExt detected no reliable difference, which replicated the failure of Experiment 1b to find blocking when Phase 1 trials were massed, $F(1, 43) = 0.14$, $p = .71$. In contrast, a comparison of groups Blocking-Ext and Control-Ext revealed a reliable blocking effect, $F(1, 43) = 38.08$. In addition, a direct comparison of the two blocking groups showed that suppression to Z was weaker when the context was extinguished for 10 hr after blocking training relative to when the context was extinguished for only 20 min, $F(1, 43) = 40.38$. Therefore, posttraining context extinction appeared to have caused a reemergence of blocking.

General Discussion

The present experiments delineate the effects of context exposure on reducedOV and blocking. Experiment 1a indicates that overshadowing is greatly reduced when the overshadowing stimulus is preexposed in a relatively short training session, and it is less affected when the training session is longer. In contrast, Experiment 1b shows that the magnitude of blocking is directly related to the trial spacing of the Phase 1 training trials. Massed Phase 1 trials produce poor blocking relative to spaced Phase 1 trials. In Experiment 2a, posttraining extinction of the training context following target training enhanced the potential of the overshadowing stimulus to compete with the target cue. Suppression to the target was still influenced by the associative status of the context, even though the target had already been trained at the time of context extinction. Experiment 2b revealed a similar result in blocking. Although blocking was reduced when Phase 1 trials were massed in Experiment 1b, blocking was recovered when the context was extinguished after blocking training in Experiment 2b. In both cases, responding to the target cue appears to be directly related to the associative status of the context at test.

Before entertaining the larger theoretical implications of the present research, it is important to consider its limitations. For reasons discussed previously, the results of Experiments 2a and 2b probably would not be replicable in a first-order conditioned suppression preparation with rat subjects. If this is true, then the generality of the results is obviously restricted. But before this research is dismissed as unimportant, it should be noted that many learning situations involve stimuli of low biological significance. There is no question that learning can occur in the absence of a biologically significant US. Learning can involve symbolic stimuli (such as words) that are far removed from the biologically significant stimuli that they represent. Therefore, even if the results of Experiments 2a and 2b do not generalize to first-order conditioning situations, they are still important for many learning situations.

Several models of associative learning readily explain the results of Experiments 1a and 1b, but Experiments 2a and 2b are more challenging. Theories that describe overshadowing and blocking as failures to acquire an association do not readily account for the outcome of the second pair of experiments. In contrast, models that emphasize the response variables that might be involved in overshadowing and blocking are more adept at accounting for the results of Experiments 2a and 2b. These two sorts of models can be roughly classified as acquisition- and performance-focused accounts of cue competition. Acquisition-focused accounts state that cue competition is a consequence of competition between two or more cues in acquiring associative strength with an outcome. Performance-focused accounts state that cue competition occurs when subjects fail to express an acquired cue-outcome association. In order to clarify the distinction between these two families of models as they apply to the present results, we present here two different specific accounts of blocking and reducedOV: Wagner's (1981) standard operating procedures (SOP) and Denniston, Savastano, and Miller's (2001) extended comparator hypothesis (ECH).

Wagner's (1981) SOP model provides a popular acquisition-focused account of blocking and reducedOV. For Experiment 1a, SOP appeals to the influence that the training context has on

conditioning. When X is exposed without reinforcement, it forms an association with the context because representations of X and the context are simultaneously activated into A1. If the context-X association is strong, the context will activate a large portion of the X elements into the A2 state (this mechanism also explains latent inhibition). When the context activates X elements into the A2 state during XZ→O presentations, a smaller portion of X elements will be available to be activated into A1 relative to a stimulus that was not preexposed. Because a smaller portion of X elements is present in A1, more Z elements are eligible for activation into the limited-capacity A1 state. Also, because the X stimulus fails to acquire a strong association with O, X activates fewer O elements into A2 across successive XZ→O trials. This allows more O elements to enter the A1 state and form a stronger association with the Z stimulus. Therefore, SOP predicts that the reducedOV effect occurs because Z is allowed to form a stronger association with O than if X had not been preexposed. This effect is ultimately directly related to the strength of the context-X association, which accounts for the fact that massed preexposure to X was more effective than spaced preexposure in Experiment 1a.

In order to explain blocking in Experiment 1b, SOP assumes that a strong X-O association can result from spaced X-O pairings and impair subsequent learning of the Z-O association. According to SOP, initial pairings of a blocking stimulus (X) alone with O (i.e., X→O) cause an excitatory association to be formed between X and O because the representational elements of X and O are simultaneously activated in the highly active A1 state. After repeated X-O pairings, the presentation of X causes a large portion of O elements to be activated into the relatively less active A2 state. When X and the blocked stimulus (Z) are later conjointly paired with O (i.e., XZ→O), the presentation of X again activates a large portion of O elements into A2. Because there are a large number of O elements in the A2 state, and they are consequently unavailable to be primed into the A1 state, the Z stimulus elements do not form a strong excitatory association with the O elements. However, if the X-O pairings are temporally massed as in Experiment 1b, the context forms a strong association with X and O. Trial massing reduces the effectiveness of X as a blocking cue because the context overshadows X during Phase 1 and primes X into A2 in Phase 2, both of which reduce X's ability to block Z.

Unlike SOP, Denniston et al.'s (2001) ECH explains reducedOV and blocking as performance effects rather than effects that take place during acquisition (see Figure 5 for a depiction of the ECH). According to the ECH, cue competition affects the expression of a CS-US association without affecting the acquisition of that CS-US association. When a target CS is tested (i.e., presented alone without reinforcement), the model posits that the CS activates a representation of the US through a CS-US association that directly contributes to conditioned responding (Link 1 in Figure 5). The target CS also activates representations of all comparator stimuli with which the CS is associated (Link 2). An effective comparator stimulus includes any stimulus that is associated with both the target CS and the US when the CS is tested. The activation of the representation of a comparator stimulus by a target CS in turn activates its own representation of the US (Link 3). The product of the strengths of Links 2 and 3 determines the strength of the indirectly activated US representation, which contributes negatively to conditioned responding. Thus, responding to the target is facilitated by the strength of Link 1, but it is reduced by the multiplicative strengths of Links 2 and 3.

Similar to SOP, the ECH appeals to the context when explaining the reducedOV observed in Experiment 1a, but through a very different mechanism. In order to account for the role of the context in this situation, the model assumes that comparator stimuli have their own comparator stimuli. Just as Links 2 and 3 reduce the expression of Link 1, the effectiveness of Link 2 and of Link 3 each can be reduced through similar comparator processes. The comparator stimuli that directly affect responding to a target cue are referred to as *first-order comparator stimuli*, whereas the comparator stimuli that modulate first-order comparator stimuli are referred to as *second-order comparator stimuli*. In the OV and reducedOV conditions in

Experiment 1a, the X stimulus serves as the first-order comparator stimulus for Z. According to the ECH, nonreinforced preexposure of X in the reducedOV condition should build a strong association between X and the context (Link 2.3 and Link 3.2), particularly if that preexposure is temporally massed. After compound training, when Z is tested, it should activate a representation of X, which in turn should activate its own representation of O (the basic comparator process). However, the expression of Link 2 is modulated by a secondary comparator process that involves the training context. Z activates a representation of the context (Link 2.2) as well as a representation of X (Link 2.1). The context representation activates its own X representation through Link 2.3, which has been strengthened by the X-alone presentations within the training context. The product of Links 2.2 and 2.3 down-modulates Link 2.1, generally decreasing the effective strength of Link 2. Similarly, Link 3.2 (X-context) is strengthened by the X-alone presentations, which in conjunction with Link 3.3 enhances its ability to down-modulate Link 3.1. Ultimately, this reduces the product of Links 2 and 3, which reduces the effectiveness of X in serving as a comparator for Z. Thus, the ECH posits that overshadowing occurs because X impairs responding to Z at test, and reducedOV occurs because the context interferes with X's ability to serve as an effective comparator stimulus. This differs from the SOP account because the formation of the Z-O association is unaffected according to the ECH.

Applied to the blocking effect observed in Experiment 1b, the ECH predicts that initial $X \rightarrow O$ pairings will strengthen Link 3. When X is later paired with O in compound with Z, all three links (i.e., Z-O, Z-X, and X-O) are strengthened, but provided that compound training is not extensive, Link 3 (X-O) remains stronger than the others. Thus, when Z is tested, responding will be reduced by the product of the strengths of Links 2 and 3, which will be large because Link 3 is exceptionally strong relative to conventional control subjects. Unlike SOP, the ECH posits that the Z-O association is latent during testing but was acquired during training. In other words, even though the formation of the Z-O association is not blocked, the expression of that association is blocked. However, X's ability to act as an effective comparator stimulus is reduced if it forms an exceptionally strong association with the context. In the massed condition of Experiment 1b, the context should act as a second-order comparator stimulus for Z at test, resulting in relatively little blocking.

Both SOP and the ECH predict the results of Experiments 1a and 1b, but they do so in different ways. One distinction between SOP and the ECH lies in their predictions concerning the relationship between responding to X and Z. In a situation in which X is trained alone, both models state that responding should be stronger if trials are spaced rather than massed, but the presence of Z in Phase 2 causes their predictions to diverge. According to SOP, the relationship between responding to X and Z should be inverse. The conditions that produce reducedOV of Z (i.e., produce stronger conditioned responding to Z) should also produce weak responding to X, and the parameters that produce blocking of Z should also produce strong responding to X because X and Z compete for associative strength. The ECH does not make such an unambiguous prediction regarding responding to X because, in a compound-training situation, the ECH can under certain conditions make counterintuitive predictions that diverge from those of SOP. According to the ECH, the potential of X to act as a first-order comparator stimulus for Z is compromised by the context in the groups that received massed exposure to X in Phase 1. But responding to X under these circumstances can still be robust because X should be affected by a comparator process different than the process that affects responding to Z. Although the context would act as a first-order comparator stimulus for X, Z would act as a potentially effective second-order comparator stimulus for X, which could attenuate the effectiveness of the context as a first-order comparator stimulus. This second-order impact of Z on X is parameter dependent, such that the less salient Z stimulus should have a limited effect on X in Experiment 1a, but the more salient Z stimulus should have a more profound effect in Experiment 1b. The fact that X was not tested in the present studies precludes a comparison

of the models based on these divergent predictions, but past studies from our laboratory have shown an advantage of compound over elemental training when trials are massed (Stout et al., 2003) or when the compound training trials follow nonreinforced preexposure to the target cue alone (Blaisdell, Bristol, Gunther, & Miller, 1998).

Experiments 2a and 2b provide a more informative test of the predictions made by SOP and the ECH. SOP fails to predict the results of Experiments 2a and 2b because there is no mechanism by which posttraining extinction of the context can decrease responding to Z. SOP anticipates that massed Phase 1 trials will reduce overshadowing in Experiment 1a and reduce blocking in Experiment 1b. This is based on the assumption that a strong association will develop between the context and X, which in turn reduces the effectiveness of X to compete with Z during Phase 2 compound training. In this way, the training context affects the acquisition of the Z-outcome association, not the expression of that association. Therefore, extinguishing the training context after training with Z should have had no retroactive influence on responding to Z according to SOP, but a retroactive influence was in fact observed in Experiments 2a and 2b.

Since the introduction of Wagner's (1981) SOP, others have suggested modifications that can explain some retroactive effects. Dickinson and Burke (1996; also see Aitken & Dickinson, 2005) modified SOP (MSOP) to account for changes in the associative value of a cue based on posttraining manipulations of one of the cue's associates. They suggested that excitatory associations are formed between elements of a cue that are in the A2 state and elements of an outcome that are in the A2 state. Furthermore, they posited that inhibitory associations would form between elements of a cue that are in the A2 state and elements of an outcome that are in the A1 state. Applied to the results of Experiments 2a and 2b, MSOP would suggest that posttraining exposure to the context activates context elements into A1, which would in turn activate elements of X, Z, and the outcome into the A2 state. As a result, excitatory associations would form between X and the outcome and between Z and the outcome, which should augment responding to both cues. Therefore, MSOP does have a mechanism to account for an increase in the X-outcome association due to context extinction, but there is no mechanism for that change in the associative status of X to alter the associative status of Z. In fact, extinction of the context should, if anything, augment the Z-outcome association, which was observed in the control condition of Experiment 2a but was unapparent in any groups that received compound training (i.e., XZ-O).

According to the ECH, responding to Z at test in Experiments 2a and 2b was facilitated by the strength of the association between Z and the outcome (Link 1), but it was reduced by the multiplicative strengths of the within-compound association between Z and X (Link 2.1) and the association between X and the outcome (Link 3.1). Furthermore, the effectiveness of X in reducing responding to Z is modulated by the context (the second-order comparator for Z). When Phase 1 trials are massed, the context should have a strong association with the X stimulus (Links 2.3 and 3.2), which should down-modulate Links 2.1 and 3.1. The down-modulation of Links 2 and 3 should cause greater responding to the target stimulus Z relative to a situation in which Phase 1 trials are spaced. Thus, when the context is extinguished after training, the associations between Z and the context (Link 2.2), between the context and X (Links 2.3 and 3.2), and between the context and the outcome (Link 3.3) should be extinguished. This should attenuate the role of the context in the comparator mechanism. If the influence of the context is eliminated before test, X will be a more effective comparator for Z, resulting in less reducedOV (i.e., greater overshadowing) in Experiment 2a and greater blocking in Experiment 2b.

In conclusion, the general theoretical implications of Experiments 2a and 2b illuminate whether cue-competition effects occur primarily when associations are formed or when associations

are expressed. Wagner's (1981) SOP falls under a broad umbrella of what can be referred to as *acquisition-focused accounts* of cue competition. In contrast, performance-focused accounts, such as Denniston et al.'s (2001) ECH, state that cue competition occurs when a stimulus is tested. In Experiments 2a and 2b, posttraining extinction of the context appeared to cause a change in responding to Z, even though subjects received no further training with Z. SOP struggles with these results because the change in the associative status of the context occurred after training and, therefore, presumably after any effect of the context on the acquisition of associative strength by Z. The performance-focused account of Experiments 1a and 1b also predicts the results of Experiments 2a and 2b because the posttraining context manipulation necessarily affects responding to the Z stimulus by altering the associative status of the context when Z is tested. This prediction is more easily obtained from a performance-focused account of cue competition because the associative status of the competing cue is critical at test, rather than at acquisition.

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Figure 1.

Experiment 1a: The bars depict the suppression ratio in response to Z across four test trials. Lower ratios indicate less bar pressing, thus better conditioned suppression to the fear-invoking stimulus. Therefore, higher scores are indicative of overshadowing (OV). Error brackets denote the standard error of the mean for each group. See Table 1 for procedural details.

Figure 2.

Experiment 1b: The bars depict the suppression ratio in response to Z across four test trials. Lower ratios indicate less bar pressing, thus better conditioned suppression to the fear-invoking stimulus. Therefore, higher scores are indicative of blocking. Error brackets denote the standard error of the mean for each group. See Table 1 for procedural details.

Figure 3.

Experiment 2a: The bars depict the suppression ratio in response to Z across four test trials. Lower ratios indicate less bar pressing, thus better conditioned suppression to the fear-invoking stimulus. Therefore, higher scores are indicative of overshadowing (OV). Error brackets denote the standard error of the mean for each group. See Table 2 for procedural details.

Figure 4.

Experiment 2b: The bars depict the suppression ratio in response to Z across four test trials. Lower ratios indicate less bar pressing, thus better conditioned suppression to the fear-invoking stimulus. Therefore, higher scores are indicative of blocking. Error brackets denote the standard error of the mean for each group. See Table 2 for procedural details.

The Extended Comparator Hypothesis

Figure 5.

The extended comparator hypothesis. Boxes represent observable events (i.e., stimulus and response). Ovals represent mental representations of stimuli. Diamonds represent comparator processes. CS = conditioned stimulus; US = unconditioned stimulus.

Table 1

Designs for Experiments 1a and 1b

Treatment	Phase 1	Phase 2	Phase 3	Test
Experiment 1a				
ReducedOV	8X-	4XZ→O	4O→US	4Z-
OV	8Y-	4XZ→O	4O→US	4Z-
Control	8Y-	4Z→O	4O→US	4Z-
Experiment 1b				
Blocking	8X→O	4XZ→O	4O→US	4Z-
Control	8Y→O	4XZ→O	4O→US	4Z-

Note. X and Y were a 30-s tone and a 30-s buzzer, respectively, and counterbalanced. Z was a 30-s click. O was a 5-s flashing light stimulus that served as the outcome and the unconditioned stimulus (US) was a footshock. Half of the subjects in each condition in Phase 1 experienced two 2-hr sessions (spaced), whereas the other half experienced two 8-min sessions (massed). OV = overshadowing.

Table 2

Designs for Experiments 2a and 2b

Treatment	Phase 1	Phase 2	Phase 3	Phase 4	Test
ReducedOV	8X- 8Y- 8Y-	4XZ→O 4XZ→O 4Z→O	20 min or 10 hr 20 min or 10 hr 20 min or 10 hr	4O→US 4O→US 4O→US	4Z- 4Z- 4Z-
OV					
Control					
Blocking	8X→O 8Y→O	4XZ→O 4XZ→O	20 min or 10 hr 20 min or 10 hr	4O→US 4O→US	4Z- 4Z-
Control					

Note. X and Y were a 30-s tone and a 30-s buzzer, respectively, and counterbalanced. Z was a 30-s click. O was a 5-s flashing light stimulus that served as the outcome and the unconditioned stimulus (US) was a footshock. All subjects received massed trial presentations in Phase 1. In Phase 3, half of the subjects received massive exposure to the context (10 hr over 4 days), whereas the other half experienced only 20 min of context exposure over 4 days. OV = overshadowing.