Published in final edited form as:

Q J Exp Psychol (Hove). 2008 September ; 61(9): 1340–1355.

Associative Interference in Pavlovian Conditioning: A Function of Similarity Between the Interfering and Target Associative Structures

Jeffrey C. Amundson and Ralph R. Miller
State University of New York at Binghamton

Abstract

Three lever-press suppression studies were conducted with water-deprived rats to investigate the role of similarity in proactive interference within first-order Pavlovian conditioning. Experiments 1a and 1b assessed the influence of stimulus complexity in proactive interference. Both experiments found greater interference when the interfering cue and target cue were composed of the same number of elements. Experiment 2 assessed the influence of context similarity in proactive interference and demonstrated that stronger proactive interference occurred when the interfering cue and the target cue were trained in the same context. The results in conjunction with other reports indicate that various types of cue interaction (e.g., interference and competition) are influenced by similarity of the interacting training events.

“One of these things is not like the others. One of these things is kind of the same.” The lyrics to this song for the kids’ discrimination game popularized by the television show *Sesame Street* is familiar to anyone who spends time with American children. The object of the game is to decide which one of four objects is not like the others. The game, like many decisions, requires the ability to discriminate objects based on the level of similarity of the attributes shared by the objects. In general, one must discriminate by identifying the attributes of events that are similar and those that are different. The topic of similarity is also of interest for researchers who study basic associative processes. One area of investigation in which the role of similarity has been extensively examined is interference between memory representations.

Traditionally, interference effects have been studied in the paradigms of proactive interference and retroactive interference (for reviews, see Britt, 1935; Postman & Underwood, 1973). In proactive interference the information acquired during Phase 1 interferes with the retrieval (or acquisition) of the target information trained during Phase 2, and in retroactive interference the associations acquired during Phase 2 interfere with the retrieval of the target associations acquired during Phase 1. The concepts of proactive interference and retroactive interference developed primarily within the early studies of verbal behavior, especially those using paired-associate stimuli (for reviews, see Slamecka & Ceraso, 1960; Swenson, 1941) and list learning. For example, in one type of retroactive cue interference study using verbal paired-associate learning, human participants were first presented with a list of independent paired-associates (e.g., words, nonsense syllables, or

Correspondence to: Ralph R. Miller.

Mailing Address: Ralph R. Miller Department of Psychology State University of New York Binghamton Binghamton, NY 13902-6000, USA TEL: (607) 777-2291 FAX: (607) 777-4890 E-mail: rmiller@binghamton.edu.

Support for this research was provided by NIMH Grant 33881. We thank David Guez, Alyssa Orinstein, Gonzalo Urcelay, Kouji Urushihara, Daniel Wheeler, and James Witnauer for their comments on a preliminary version of this manuscript.

trigrams) including a pair of associates of the form A-B (e.g., cat-tree) and then a second list of the form C-B (e.g., horse-tree) which included a pair of associates. At test, participants were presented with the common associate (B) and asked to recall all stimuli that were paired with it. Although participants tended to learn the pairs of items over several trials, the probability that they could recall the target stimulus (A, in this example, cat) decreased if they had also been exposed to the C-B pairings (e.g., Johnston, 1968). That is, presumably the C-B association retroactively interfered with retrieval based on the A-B association, thereby attenuating the recall of stimulus A compared to a condition in which the C-B list was not presented.

The general requirement for the observation of interference in paired associate learning is that a shared element must exist in the two associations (tree in the previous example). In other words, some degree of similarity must exist between the target association and the interfering association in order for interference to occur. For example, an early study by Wickens, Born, and Allen (1963), using a paired associate task with humans, demonstrated that a decrease in the similarity between the interfering material and target material decreased proactive interference. Specifically, Wickens et al. presented participants with trigrams formed either by consonants or numbers on the first three training trials and then on the fourth trial switched the participants who were first exposed to the consonant trigrams to number trigrams and the participants who were first exposed to the number trigrams to the consonant trigrams. The control condition did not experience a switch on the fourth trial. The results showed that the performance in the switch condition was better (i.e., reduced proactive interference as evidenced by better recall of the trigram experienced second) than in the control condition, regardless of the type of switch (consonants to numbers or numbers to consonants). The importance of similarity in interference was recognized early by Skaggs (1925) and Robinson (1927). They proposed an inverted U-shaped function in which interference was greatest when an intermediate level of similarity existed between the target association and the interfering association, weaker when the two associations were completely dissimilar, and no interference (in fact facilitation) when the two associations were identical. The last of these three conditions of course arises because, if the target association is identical to the interfering association, then presentation of the interfering association is simply additional trials of the target association.

The importance of the study of similarity in paired associate interference to the current report is that it has much in common with phasic Pavlovian conditioning with different cues (e.g., Escobar, Matute, & Miller, 2001). Moreover, there appear to be some illuminating commonalities between interference effects and cue competition in Pavlovian conditioning (Miller & Escobar, 2002). Here cue competition refers to situations in which the presence of a nontarget stimulus during reinforced training of a target cue attenuates conditioned responding to the target cue at the time of test relative to reinforcement of the target cue alone (e.g., overshadowing or forward blocking). In contrast, cue interference refers to situations in which a target cue is paired with a reinforcer before or after a nontarget cue is paired with the same reinforcer, such that the nontarget cue trials impair the behavioral control of the target cue that would otherwise result. Alternatively stated, cue competition refers to a deleterious interaction between cues trained together, whereas cue interference refers to a deleterious interaction between cues trained apart. More generally the term cue interaction can be used to conjointly refer to cue interference and cue competition. The contemporary associative analysis of cue interaction in Pavlovian conditioning has focused almost exclusively on the examination of cues that are presented in compound at some point during training (e.g., blocking, overshadowing, and the relative stimulus validity effect).

Recent studies of cue interaction in Pavlovian conditioning have suggested that the similarity between an interfering or competing association and a target association plays an

important role in both cue interference and cue competition. Let us first consider cue interference. Escobar and Miller (2003) examined the role of temporal variables in retroactive cue interference using rats in a Pavlovian preparation. Specifically, they manipulated (a) the similarity of the intervals between cue termination and outcome onset for the target and interfering training phases, (b) the similarity of the durations of the target and interfering cues, and (c) the similarity of the durations of the outcome used in the target and interfering training phases. Their results indicated that greater interaction occurred when the interfering and target associations shared a high degree of similarity in their temporal structure. For example, more interaction was observed when the interfering cue and the target cue were both ten seconds in duration, than when the interfering cue was three seconds in duration and the target cue was ten seconds in duration. A similar effect of the influence of temporal similarity was demonstrated in interaction between cues trained together with a common outcome (Barnet, Grahame, & Miller, 1993; Blaisdell, Denniston, & Miller, 1998; Blaisdell, Denniston, & Miller, 1999). Barnet et al., (1993), using rats as subjects, manipulated the temporal relationship between the blocking cue and the outcome (forward or simultaneous) relative to the temporal relationship between the blocked cue and the outcome (forward or simultaneous) and observed the strongest blocking effects when the two temporal relationships were the same compared to when they were different. More recently, Amundson and Miller (2006) demonstrated, using rats as subjects in a trace conditioning procedure, that blocking is attenuated when the blocking cue-US and the blocked cue-US trace intervals are different. Importantly, there is recent evidence of parallel temporal effects of similarity on interference between cues trained apart in Pavlovian analogues with humans (e.g., Matute & Pineño, 1998).

Cue interference in Pavlovian conditioning preparations are difficult for most contemporary learning models (e.g., Gallistel & Gibbon, 2000; Mackintosh, 1975; McLaren & Mackintosh, 2000; Miller & Matzel, 1988; Pearce, 1987; Pearce & Hall, 1980; Rescorla & Wagner, 1972) to explain because these models were designed to account for competition between cues trained together that predict a single outcome, not interference between cues trained independently with the same outcome. However, of import to the current report is that Pearce's (1987) model does account for the impact of similarity on cue interaction by assuming that responding transfers between a previously trained stimulus and subsequently trained stimulus as a function of the number of shared elements between the two stimuli. Moreover, Bouton (1993) proposed a retrieval-focused model that, in situations in which a cue is associated with multiple outcomes, assumes that subjects use contextual or punctate stimuli present at the time of testing to determine which association will control behavior and which association will be behaviorally silent. However, Bouton's model was designed to address situations in which a single cue is trained separately with multiple outcomes. Thus, it cannot explain the interaction effects seen when two cues are trained independently with the same outcome. Consequently, understanding additional factors that contribute to cue interaction, such as similarity, would be helpful in developing a model that can account for cue interaction effects observed both when cues are trained together and when cues are trained apart.

The influence of similarity on cue interaction effects in Pavlovian conditioning suggests that any decrease in the similarity between the interfering association (elements or connecting relationship) and the target association might attenuate interference in Pavlovian conditioning. (Here we ignore instances in which the two associations are so similar as to constitute a common association). Specifically, one might expect a decrease in proactive interference when elements are added to the interfering or target cue to make the two cues more dissimilar. Additionally, one might expect a similar decrease in interference when training of the interfering association and training of the target association occur in different contexts, an issue not previously examined in first-order conditioning with a biologically

significant outcome (but see Escobar et al., 2001; Matute & Pineño, 1998, for such a decrease in retroactive interference without a biologically significant outcome). The current experiments investigated these possibilities in a proactive interference design originally used by Amundson, Escobar, and Miller (2003). All experiments incorporated the same parameters used in Amundson et al.'s experiments in order to observe proactive interference in first-order Pavlovian conditioning with nonhumans.

Experiment 1a

Experiment 1a tested the role of similarity between the interfering association and the target association in proactive interference by varying the complexity of the interfering cue (one or three elements) while keeping the target cue simple (one element). Specifically, we expected that a more complex interfering cue (ABC) would be less similar to the simple target cue (X), thereby attenuating proactive interference. Importantly, to obtain interference rather than cue competition, there must be no nominal cues in common between the interfering event and the target event. If we had manipulated the number of overt elements in common, we would have confounded interference with varying degrees of cue competition.

Method

Subjects—The subjects were 24 male (295 - 345 g) and 24 female (188 - 247 g) adult, experimentally naïve, Sprague-Dawley rats, bred in our colony. They were individually housed in wire-mesh hanging cages in a vivarium maintained on 16-hr light / 8 hr-dark cycle. Experimental manipulations occurred approximately midway through the light portion of the cycle. A progressive water deprivation schedule was imposed over the week prior to the beginning of the experiment until water availability was limited to 30 min per day. All subjects were handled for 30 s three times per week from weaning until the initiation of the study.

Apparatus—The apparatus consisted of twelve operant chambers, each measuring 30 × 30 × 27 cm (l × w × h). The side walls of the chamber were made of stainless steel sheet metal, and the front wall, back wall, and ceiling of the chamber were made of clear Plexiglas. On one metal wall of each chamber, there was an operant lever and adjacent to it a niche (4.5 × 4.0 × 4.5 cm) centered 3.3 cm above the floor through the top of which a solenoid-driven valve could deliver 0.04 ml of water into a cup at the bottom of the niche. Chamber floors were stainless steel cylindrical rods, 4 mm in diameter, spaced 1.7 cm apart center-to-center, connected with NE-2 neon bulbs which allowed constant-current 0.6-mA footshock US to be delivered by means of a high voltage AC circuit in series with a 1.0-MΩ resistor. All chambers were housed in sound and light attenuating environmental chests. A SonAlert mounted on the front wall of the chambers was used to deliver a high frequency (1900 Hz) tone 8 dB above background. Each chamber was also equipped with three 45-Ω speakers widely separated on the inside walls of the environmental chest. Each speaker could deliver a different auditory stimulus. One speaker mounted on the right sidewall was used to deliver a low tone stimulus (500 Hz), 8 dB above background. A second speaker mounted on the back sidewall of the experimental chamber was used to deliver a click stimulus (6/s), 8 dB above background. The click, tone, and SonAlert served as Stimuli A, B, and C, counterbalanced within groups. The third speaker, mounted on the left sidewall of the chamber, was used to deliver a white noise 6 dB above background which served as Stimulus X. All CSs were 30 s in duration. A 0.5-s visual stimulus consisted of a 100-W light nominal at 120 VAC but driven at 100 VAC, mounted on the interior back side of each environmental chest approximately 30 cm from the center of the experimental chamber, served as the signal for water delivery. Ventilation fans in each enclosure provided a

constant 74-dB background noise. Background illumination was provided by a #1820 bulb positioned on the ceiling of the chambers.

Procedure (see Table 1)

Acclimation and shaping: On Days 1-5, all subjects were trained to lever press for water (0.04 ml) on a variable-interval 20-s schedule during daily 60-min sessions. To facilitate magazine training and lever pressing, the onset of the water delivery was accompanied by the onset of the 0.5-s white light. On Days 1 and 2, a fixed-time 2-min schedule of noncontingent water delivery occurred concurrently with a continuous reinforcement schedule. On Day 3, noncontingent water was discontinued, and subjects were trained on the continuous reinforcement schedule alone. Subjects that did not make more than 50 responses in this session were hand-shaped through successive approximation. On Days 4 and 5, a variable interval 20-s (VI-20) schedule was imposed. This schedule of reinforcement prevailed throughout the remainder of the experiment including reshaping and testing.

Preexposure: On Day 6, all subjects received two nonreinforced presentations of Stimuli A, B, and C 9, 18, 27, 36, 45, and 54 min into a 60-min session, with stimulus order counterbalanced within groups. These exposures were intended to minimize configuring of the cues during Phase 1 training.

Phase 1. Interfering association training: On Days 7-9, subjects in groups Elemental-PI and Compound-PI received 4 daily presentations of A-US or ABC-US, respectively, with a mean intertrial interval of 35 ($\pm$ 15) min in a 120-min session. Two different schedules (1 and 2) were used on alternate days. In Schedule 1, the CS presentations occurred 10, 30, 80, and 115 min into the session. In Schedule 2, the CS presentations occurred 21, 54, 89, and 109 min into the session. Schedule 1 was used on Days 7 and 9 and Schedule 2 was used on Day 8. During Phase 1, groups Elemental-NoPI and Compound-NoPI received uncorrelated presentations of Stimulus A or Stimulus ABC, respectively, as well as presentations of the US, all with a mean intertrial interval of 16 ($\pm$ 10) min. US presentations were administered at the same as the other groups. The CS presentations occurred 3, 40, 60, and 95 min into the session for Schedule 1 and occurred 10, 36, 69, and 116 min into the session for Schedule 2. Onset of the US coincided with the CS termination in groups Elemental-PI and Compound-PI. The US presentation lasted 0.5 s. The duration of the sessions in this phase (and Phase 2) was 120 min in order to decrease the likelihood of obtaining a US-preexposure effect in groups Elemental-NoPI and Compound-NoPI. That is, the length all sessions was long in order to spread the unsignaled US trials over a longer period so as to extinguish the context during the intertrial intervals, thereby minimizing blocking by the context (Randich & LoLordo, 1979).

Phase 2. Target training: On Day 10, all subjects in all groups received two X-US pairings. Stimulus X onset occurred at 30 min and 90 min into the 120 min session, with the US being presented immediately after termination of X.

Reacclimation: On Days 11-13, to restabilize lever pressing which might have been disrupted by footshock, the animals from all groups experienced daily 60-min sessions, which allowed uninterrupted lever pressing (i.e., no nominal stimuli were presented). The animals that registered less than 50 responses on Day 11 were given an extra 30-min session on that day.

Test: On Day 14, subjects were tested on CS X in a 30-min test session. During this session, there were four 30-s presentations of X. Presentations of X occurred 6, 10, 14, and 20 min into the session. To minimize any possible effect of differences in base rate lever pressing,

Kamin suppression ratios were used. A single Kamin suppression ratio for each animal was calculated across all four test trials to determine conditioned suppression to the CS. The numbers of lever presses emitted during the 60 s immediately prior to the onset of each test trial CS and during the presence of each test trial CS were recorded. A 60-s baseline measure of lever presses was used instead of a 30-s measure because it reduced within-subject variability. The suppression ratio for each subject consisted of the total number of lever presses made during all presentations of the CS divided by the sum of that number plus half the total number of lever presses made during all the 60-s intervals that immediately preceded the 30-s CS (i.e., $\text{lever-press}_{\text{CS}} / [\text{lever-press}_{\text{CS}} + 0.5 \text{ lever-press}_{\text{pre-CS}}]$). On Day 15, subjects in groups Elemental-PI and Elemental-NoPI were tested on CS A and subjects in groups Compound-PI and Compound-NoPI were tested on the ABC compound in a 30-min test session. During the session, there were four 30-s presentations of CS A or ABC alone. Presentations of CS A or ABC were timed identically to X on Day 14. A single Kamin suppression ratio for each animal was calculated across all four test trials to determine conditioned responding to CS A in the same manner as the ratio was calculated for CS X. The data from two subjects (one from group Elemental-PI and one from group Compound-PI) were eliminated from the analysis due to experimenter error.

Results and Discussion

The results revealed that, when the interfering stimulus was complex and the target stimulus was elemental, proactive interference was attenuated relative to when both cues were elemental (see Figure 1). This conclusion was confirmed by the following analyses. A 2 (PI vs. No PI) $\times$ 2 (Elemental vs. Compound) analysis of variance (ANOVA) was used to assess conditioned suppression during the test presentations of CS X. This analysis revealed a main effect of proactive interference treatment, $F(1, 42) = 8.43$, $MSE = 0.02$, $p < .01$, a main effect of stimulus complexity, $F(1, 42) = 11.34$, $MSE = 0.02$, $p < .002$, and an interaction, $F(1, 42) = 6.88$, $MSE = 0.02$, $p < .02$. In order to determine the source of the interaction, pairwise comparisons were conducted. These comparisons revealed that group Elemental-PI suppressed less to X than did group Compound-PI, $F(1, 42) = 17.94$, $p < .001$, thereby suggesting that making the interfering cue relatively dissimilar to the target cue decreased proactive interference to X. An additional comparison of the difference between groups Elemental-PI and Elemental-NoPI revealed that proactive interference occurred in the condition in which the interfering cue was composed of only one stimulus element, $F(1, 42) = 15.27$, $p < .001$. In contrast, the difference between groups Compound-PI and Compound-NoPI was not significant, $F(1, 42) = .04$, $p > .85$.

A 2 (PI vs. No PI) $\times$ 2 (Elemental vs. Compound) ANOVA was used to assess conditioned suppression during the test presentations of CS A or ABC. Of interest was whether the subjects learned an association between CS A or ABC and the US when the two events were paired (groups Elemental-PI and Compound-PI) compared to when the two events were unpaired (groups Elemental-NoPI and Compound-NoPI). As expected, this analysis revealed a main effect of PI treatment, $F(1, 42) = 18.49$, $MSE = 0.03$, $p < .001$, but no main effect of stimulus complexity, $F(1, 42) = 0.76$, $MSE = 0.03$, $p > .38$, or an interaction, $F(1, 42) = 1.70$, $MSE = 0.03$, $p > .19$. Planned comparisons detected differences in suppression to CS A between groups Elemental-PI ($M = .20$, $SD = .03$) and Elemental-NoPI ($M = .34$, $SD = .04$), $F(1, 42) = 4.49$, $p < .05$, and in suppression to ABC between groups Compound-PI ($M = .18$, $SD = .03$) and Compound-NoPI ($M = .45$, $SD = .07$), $F(1, 42) = 15.70$, $p < .001$, indicating that an association was formed between A or ABC and the footshock when these two events were paired in Phase 1 but not when these events were unpaired (groups Elemental-NoPI and Compound-NoPI).

Experiment 1b

Experiment 1a used an elemental target cue and found that prior training of an elemental interfering cue produced greater interference than training of a complex (i.e., compound) interfering cue. However, this observation leaves unclear whether the lack of interference by the complex interfering cue resulted from the relative dissimilarity between the interfering and target cues or simply from the compound interfering cue possibly being less salient than the elemental interfering cue. To differentiate between these two possibilities, we conducted Experiment 1b in which we varied the complexity of the target cue rather than that of the interfering cue. Specifically, in Phase 1 all subjects were trained with an elemental interfering cue (A) that was either paired or unpaired with the US, and in Phase 2 half of the subjects (orthogonal to Phase 1) were trained with an elemental target cue (X), whereas the remaining subjects were trained with a complex target cue (XYZ). Subjects were then tested on the cue with which they were trained in Phase 2. It was expected that greater similarity between the interfering and target cues would result in greater interference. Thus, the interference group trained and tested with a complex target cue (three elements) was expected to exhibit less interference, that is, more conditioned suppression.

Method

Subjects and Apparatus—The subjects were 24 male (301 - 380 g) and 24 female (199 - 245 g) rats otherwise identical to those in Experiment 1a. The apparatus was identical to that used in Experiment 1a except that the white noise, tone, and SonAlert served as the added Cues X, Y, and Z, counterbalanced within groups. The clicks served as Cue A.

Procedure (see Table 2)—All training was the same as in Experiment 1a except that in Phase 1 CS A was never compounded, and in Phase 2 CS X was compounded with Y and Z for two of the groups (i.e., groups Compound-PI and Compound-NoPI). Specifically, during Phase 2 target training (Day 10) subjects in the elemental condition received two presentations of X-US and subjects in the compound condition received two presentations of XYZ-US. Testing occurred as in Experiment 1a except that during testing (Day 14) groups Compound-PI and Compound-NoPI were presented with the compound XYZ. In order to assess responding to the target cue (X or XYZ) and CS A during testing, a single Kamin suppression ratio for each animal on each test stimulus was calculated in the same manner as in Experiment 1a. The data from five subjects (four from group Elemental-NoPI and one from group Compound-NoPI) were eliminated from the analysis because they did not make any responses during the pre-CS periods. An additional subject was eliminated from group Compound-PI due to an equipment failure.

Results and Discussion

The results of Experiment 1b revealed that, when the interfering cue was elemental and the target cue was complex, proactive interference was attenuated (see Figure 2). This conclusion was confirmed by the following analyses. A 2 (PI vs. No PI) $\times$ 2 (Elemental vs. Compound) ANOVA was used to assess conditioned suppression during the test presentations of CS X or XYZ. This analysis revealed a main effect of stimulus complexity, $F(1, 38) = 12.03$, $MSE = 0.02$, $p < .002$, and an interaction, $F(1, 38) = 5.81$, $MSE = 0.02$, $p < .03$, but no main effect of proactive interference treatment, $F(1, 38) = .30$, $p > .59$. In order to determine the source of the interaction pairwise comparisons were conducted. These comparisons revealed that group Elemental-PI suppressed less to X than group Compound-PI suppressed to XYZ, $F(1, 38) = 19.34$, $p < .001$, thereby suggesting that making the target cue relatively dissimilar to the interfering cue decreased proactive interference to the target cue. An additional comparison of the difference between group Elemental-PI and group Elemental-NoPI revealed that proactive interference did occur in the condition in which the

target cue was composed of only one stimulus element, $F(1, 38) = 4.09, p < .05$, but not when the target cue was complex (group Compound-PI vs. Compound-NoPI), $F(1, 38) = 1.87, p > .18$.

A 2 (PI vs. No PI) $\times$ 2 (Elemental vs. Compound) ANOVA was used to assess conditioned suppression during the test presentations of Cue A. Not surprisingly, this analysis revealed a main effect of PI treatment, $F(1, 38) = 27.32, MSE = 0.02, p < .001$, but not stimulus complexity $F(1, 38) = 1.29, MSE = 0.02, p > .26$, or an interaction, $F(1, 38) = 0.02, MSE = 0.02, p > .91$. Pairwise comparisons detected differences between group Elemental-PI ($M = .11, SD = .03$) and group Elemental-NoPI ($M = .34, SD = .05$), $F(1, 38) = 13.36, p < .001$ and between group Compound-PI ($M = .16, SD = .05$) and group Compound-NoPI ($M = .38, SD = .04$), $F(1, 38) = 14.02, p < .001$, indicating that an association was formed between cue A and the footshock when these two events were paired in Phase 1 but not when these events were unpaired (groups Elemental-NoPI and Compound-NoPI).

The results of Experiment 1b alone could be viewed as suggesting either of two accounts. First, greater similarity between target training and interference training could foster interference. Second, a simpler (and presumably less salient) target event could be more prone to interference. But if Experiment 1a and 1b are considered together, the only unified account is that interference increased when target training and interference training were not too dissimilar.

Experiment 2

The goal of this series was to examine the role of similarity between the target cue and interfering cue on proactive interference in first-order Pavlovian conditioning. However, to preclude cue competition so as to focus on stimulus interference, we had to minimize the occurrence of cue elements in common between the target and interfering stimuli. Thus, in Experiments 1a and 1b we varied similarity in terms of the abstract quality stimulus complexity. Another way to assess the influence of similarity in cue interaction is to vary the contextual associates of the interacting cues. That is, a very different type of similarity between the interacting events in an interference situation is potentially provided by the context in which the two types of training occur. If, as we have suggested, interference decreases when the interacting memories are more dissimilar, then one might expect that cue interference would be reduced when the interfering and target associations are trained in dissimilar contexts. Experiment 2 assessed this prediction by using four groups of rats that experienced proactive interference treatment or a control treatment either in the same or different context as target training.

Method

Subjects and Apparatus—The subjects were 24 male (283 - 391 g) and 24 female (192 - 247 g) rats otherwise identical to those used in Experiments 1a and 1b. The click train served as Stimulus A. The white noise served as Stimulus X. All CSs were 30 s in duration. The 500-Hz tone stimulus, 8 dB above background, served as the signal for water. In order to create two distinct contexts, a lemon odor was added and the houselight was on in Context 1, and a wintergreen odor was added and the houselight was turned off in Context 2. Additionally, different instances of the enclosure were used for Contexts 1 and 2. The two versions of the context were counterbalanced within groups. The lever and water reinforcement were available in both contexts.

Procedure (see Table 3)

Acclimation and shaping: The acclimation and shaping procedures (Days 1-5) were the same as Experiments 1a and 1b except subjects were acclimated and shaped during two daily 30-min sessions (one session in Context 1 and a second session in Context 2). This change served to equate overall exposure to the contexts.

Phase 1. Interfering association training: CS A-US training occurred over Days 6-11. Subjects in groups SameCTX-PI and DiffCTX-PI received four daily presentations of A-US on three of these six days (Days 6, 8, and 10, or 7, 9, and 11, counterbalanced within groups), with a mean intertrial interval of 35 ($\pm$ 15) min in a 120-min session. Onset of the US coincided with the CS termination in groups SameCTX-PI and DiffCTX-PI. Groups SameCTX-NoPI and DiffCTX-NoPI received uncorrelated presentations of Stimulus A and the US, respectively, with a mean ITI of 16 ($\pm$ 10) min. The US presentations occurred at the same times as the other groups with CS presentations interspersed. In condition Same this occurred in Context 1 and in condition Diff it occurred in Context 2. On the other three days of Days 6-11 on which treatment with A did not occur, subjects were simply placed in the alternative context for 120-min (condition Same in Context 2 and condition Diff in Context 1). This equated groups for total exposure to the two contexts.

Phase 2. Target training: On Day 10, subjects in all four groups received two daily presentations of X-US in Context 1. The Stimulus X onset occurred at 30 min and 90 min into the 120-min session, with the US being presented immediately after termination of X. Note, because there was only one day of treatment with X and all subjects received training with X in one context, subjects were not exposed to the alternate context during training of X.

Reacclimation: On Days 13, 14, and 15, in order to restabilize lever pressing, the animals from all groups experienced daily 60-min sessions in the test contexts, that is, both Context 1 and Context 2. No nominal stimuli were presented. This served to restore baseline lever pressing in each context. Animals that registered less than 50 responses on Day 13 in each context were given an extra 30-min session on that day in the context in which responding was deficient.

Test: On Day 16, subjects were tested for suppression to CS X in Context 1 in a 30-min test session. During each daily session, there were four presentations of X alone, 30 s in duration. The presentations of X occurred 6, 10, 14, and 20 min into the session. A single Kamin suppression ratio for each animal was calculated in the same manner as in Experiments 1a and 1b. On Day 17, subjects were tested on CS A in A's training context, that is, either in Context 1 (groups SameCTX-PI and SameCTX-NoPI) or Context 2 (groups DiffCTX-PI and DiffCTX-NoPI) in a 30-min test session. During the session, there were four presentations of A alone, 30 s in duration, with the same temporal distribution as on Day 16. A single Kamin suppression ratio for each animal was calculated across all four test trials to determine conditioned suppression to CS A in the same manner as the ratio was calculated for CS X. Due to an equipment failure, the data from three subjects in groups SameCTX-PI and SameCTX-NoPI, four in group DiffCTX-PI, and two in group DiffCTX-NoPI were eliminated from the study.

Results and Discussion

The results of Experiment 2 revealed that, when the interfering cue was trained in a different context than the target cue, proactive interference was reduced (see Figure 3). This conclusion was confirmed by the following analyses. A 2 (PI vs. No PI) $\times$ 2 (Elemental vs. Compound) ANOVA was used to assess conditioned suppression during the test

presentations of CS X. This analysis revealed a main effect of proactive interference treatment, $F(1, 32) = 6.38$, $MSE = 0.02$, $p < .02$, a main effect of context change, $F(1, 32) = 10.18$, $MSE = 0.02$, $p = .01$, and a significant interaction, $F(1, 32) = 13.23$, $MSE = 0.02$, $p = .001$. In order to determine the source of the interaction, pairwise comparisons were conducted. A comparison of group SameCTX-PI and group SameCTX-NoPI revealed that proactive interference occurred in the condition in which the interfering cue and target cue were trained in the same context, $F(1, 32) = 19.11$, $p < .001$. In contrast, the difference between groups DiffCTX-PI and DiffCTX-NoPI, was not significant, $F(1, 32) = .61$, $p > .44$. Most important, group SameCTX-PI suppressed less to X than did group DiffCTX-PI, $F(1, 32) = 22.07$, $p < .001$, thereby suggesting that a change in context between the interference training and target training attenuated proactive interference to X.

A 2 (PI vs. No PI) $\times 2$ (Elemental vs. Compound) ANOVA was used to assess conditioned suppression during the test presentations of Cue A. This analysis revealed a main effect of PI treatment, $F(1, 32) = 24.39$, $MSE = 0.02$, $p < .001$, but no main effect of a change of context, $F(1, 32) = 1.32$, $MSE = 0.02$, $p > .25$, or an interaction, $F(1, 32) = .14$, $MSE = 0.02$, $p > .71$. Planned comparisons detected differences between group SameCTX-PI ($M = .05$, $SD = .02$) and group SameCTX-NoPI ($M = .23$, $SD = .04$), $F(1, 32) = 14.19$, $p < .001$, and between group DiffCTX-PI ($M = .02$, $SD = .01$) and group DiffCTX-NoPI ($M = .18$, $SD = .05$), $F(1, 32) = 10.36$, $p < .01$, indicating that an association was formed between Cue A and the footshock when these two events were paired in Phase 1 but not when these events were unpaired (groups SameCTX-NoPI and DiffCTX-NoPI).

Overall, the results of Experiment 2 indicate that proactive interference was attenuated in the condition in which the interference training and target training occurred in different contexts. Conversely, in the condition in which the interference training and target training occurred in the same context robust proactive interference was observed. Thus, a greater similarity in the training contexts used for the interfering and target associations appears to augment proactive interference.

General Discussion

Experiments 1a and 1b demonstrated that proactive interference was attenuated when the interfering cue was made more complex than the target cue (Experiment 1a) and when the target cue was made more complex than the interfering cue (Experiment 1b) compared to a condition in which the interfering cue and the target cue were both composed of elemental cues. Notably, there were only a limited number of stimuli available in the apparatus used, which is why the manipulation of stimulus complexity was not completely counterbalanced (i.e., no 3-element interfering stimuli potentially acting on 3-element target stimuli). However, the results and intuition suggest that interference would be observed when the interfering association and target association were both composed of three elements. Experiment 2 revealed a decrease in proactive interference when the interfering cue was trained in a different context than the target cue relative to a condition in which both cues were trained in the same context. These observations are similar to the findings of Matute and Pineño (1998). They used an anticipatory suppression preparation analogous to Pavlovian conditioning to investigate retroactive interference in humans. In their Experiment 3, they assessed the impact of the similarity between the training and test contexts on retroactive interference. Following training of the target cue in one context and the interfering cue in a different context, retroactive interference was not observed (unless testing occurred in the context in which the interfering association was trained). Collectively with the present data it appears that the use of a similar context for training the target and interfering associations enhances both retroactive and proactive interference. Thus, the

current results indicate that similarity in stimulus complexity (or salience) and in training context favors the observation of proactive interference in Pavlovian conditioning.

Before considering the theoretical relevance of the current findings, it is appropriate to address potential concerns about the suppression observed during the test of Stimulus A or ABC in the control groups for each experiment. The reason we tested on Stimulus A or ABC was to assess whether or not an association was formed between the interfering cue and the US in the experimental groups relative to the control groups. This was necessary in order to make the argument that proactive interference depends upon this association. Ideally, one would expect complete suppression to Stimulus A or ABC (i.e., a Kamin ratio equating to zero) in the experimental groups (in which A or ABC were paired with the US) and no suppression (i.e., a Kamin ratio equating to 0.50) in the control groups (in which A or ABC were not paired with the US). However, conditioning is rarely complete and some suppression to even an unpaired stimulus would be expected based on CS-nonspecific fear that is enhanced by any sort of US delivery, particularly unsignaled USs. Moreover, in the current experiments testing of A or ABC occurred after testing of X. As testing used a flooding procedure, extinction of X surely occurred during testing of X, which, due to acquired equivalence, may have resulted in some extinction of Stimulus X or Stimulus XYZ generalizing to Stimulus A and Stimulus ABC in the experimental groups. Thus, all one might realistically expect of the tests of A (or ABC) in these studies is that suppression would be greater in the experimental groups than the control groups, a criterion that was met in each of the studies.

The theoretical importance of the current findings is twofold. First, they lend support to the possibility that a common mechanism underlies the two types of cue interaction mentioned in this report: competition between cues trained together and interference between cues trained apart. This conclusion is based on cue interference being found to increase with similarity in other than primary stimulus dimensions (e.g., complexity and context) between the interacting cues, just as has been reported for cue competition. For example, Bonardi, Honey, and Hall (1990, Experiment 3) found blocking (a form of cue competition) to be reduced if Phases 1 and 2 occurred in different contexts. Our results concerning similarity encouraging cue interaction also converge with prior research that examined other dimensions of similarity. For instance, greater similarity in temporal variables between the interacting cues, such as interstimulus intervals, yields increased cue interference (e.g., Escobar & Miller, 2003) and cue competition (e.g., Amundson & Miller, 2006; Schreurs & Westbrook, 1982).

The second point of theoretical importance is that the results suggest a different role for the context than that previously surmised from studies of renewal from extinction (a form of retroactive outcome interference). A review of investigations of extinction suggests that context changes between acquisition and interference training (i.e., extinction) do not ordinarily produce differences in the amount of interference observed (but see Bonardi et al., 1990, Experiment 2). However, renewal represents a situation in which a single cue is paired with two outcomes, each in a different context, and the test context serves to facilitate the discrimination (or prime the memory) of those outcomes associated with the CS (Bouton, 1993). That is, previous findings suggest that the context acts like an occasion setter (for a review on the special role of the context see Pearce & Bouton, 2001). But the results of Experiment 2 indicate that the role of the context might be more than just to serve as an occasion setter. An additional role for the context is perhaps defined by how the findings of Experiment 2 relate to the findings of Experiments 1a and 1b. The similar contexts used for interfering and target training may have constituted a stimulus element in common between the interfering cue and target cue. This would require thinking of each cue as a configurational unit that includes its context. That is, for group SameCTX-PI of Experiment

2 the interfering cue could be viewed as composed of Stimulus A and Context 1 and the target cue as composed of Stimulus X and Context 1, whereas for group DiffCTX-PI the interfering cue could be viewed as composed of Stimulus A and Context 2 and the target cue could be viewed as composed of Stimulus X and Context 1. This distinction in group DiffCTX-PI may have reduced interference in much the same way as altering the complexity of the stimuli in Experiments 1a and 1b reduced interference. This approach would favor a configural theory such as Pearce's (1987), but, as mentioned in the Introduction, models like Pearce's were designed to explain effects when cues are trained together, as opposed to apart which is the case in interference designs. If the cue were a configurational unit comprising the context and the nominal CS, then one needs to explain why the current procedure led to a context-cue configuration that does not seem to appear in other experiments addressing context-switch effects (e.g., Bonardi et al., 1990, Experiment 1). One might simply suggest that the role of the context varies depending on whether one is examining cue interference or outcome interference. That is, previous studies of the effect of context shifting typically involved one cue and two outcomes (e.g., the occurrence of the US and the absence of the US). In contrast, in the current work there were two cues and only one outcome. The distinction might serve to alter the role of the context. Therefore, it might be important for future work to determine if cue interaction and outcome interaction differ in the way that they depend on the context.

An alternative account of the present data is that in Phase 2 the presence of more novel attributes in the elements of the target association could have resulted in that association being better attended to and hence better learned. That is, differences of the target cue from the interfering cue in Experiments 1a and 1b could have resulted in more attention being focused on the novel attributes of the target cue rather than the common attributes. Likewise the change of context between the training of the interfering cue and the target cue in Experiment 2 could have resulted in extra attention being given to events occurring in the new context. This approach emphasizes better learning in the control (different) subjects rather than impaired learning in the interference subjects. However, in order to advance this argument, one would need to test its basic assumption. Notably, MacLeod (1975) demonstrated in humans that, when attention to the target items was reduced, a decrease in proactive interference did not occur. Nevertheless, more work will be necessary to discriminate between these accounts. What is clear about the current findings, in conjunction with previous findings, is that avoiding high dissimilarity appears to enhance cue interaction whether it arises from cues trained together (i.e., cue competition; e.g., Amundson & Miller, 2006) or cues trained apart (i.e., cue interference; e.g., Matute & Pineño, 1998; and the present studies).

References

- Amundson JC, Escobar M, Miller RR. Proactive interference between cues trained with a common outcome in first-order Pavlovian conditioning. *Journal of Experimental Psychology: Animal Behavior Processes*. 2003; 29:311–322. [PubMed: 14570518]
- Amundson JC, Miller RR. CS-US temporal relations in blocking. 2006 Manuscript submitted for publication.
- Barnet RC, Grahame NJ, Miller RR. Temporal encoding as a determinant of blocking. *Journal of Experimental Psychology: Animal Behavior Processes*. 1993; 19:327–341. [PubMed: 8228832]
- Blaisdell AP, Denniston JC, Miller RR. Temporal encoding as a determinant of overshadowing. *Journal of Experimental Psychology: Animal Behavior Processes*. 1998; 24:72–83. [PubMed: 9438967]
- Blaisdell AP, Denniston JC, Miller RR. Posttraining shifts in the overshadowing stimulus-unconditioned stimulus interval alleviates the overshadowing deficit. *Journal of Experimental Psychology: Animal Behavior Processes*. 1999; 25:18–27. [PubMed: 9987855]

- Britt SH. Retroactive inhibition: A review of the literature. *Psychological Bulletin*. 1935; 32:381–440.
- Bonardi C, Honey RC, Hall G. Context specificity of conditioning in flavor-aversion learning: Extinction and blocking tests. *Animal Learning & Behavior*. 1990; 18:229–237.
- Bouton ME. Context, time, and memory retrieval in the interference paradigms of Pavlovian learning. *Psychological Bulletin*. 1993; 114:80–99. [PubMed: 8346330]
- Escobar M, Matute H, Miller RR. Cues trained apart compete for behavioral control in rats: Convergence with the associative interference literature. *Journal of Experimental Psychology: General*. 2001; 130:97–115. [PubMed: 11293462]
- Escobar M, Miller RR. Timing in retroactive interference. *Learning & Behavior*. 2003; 31:257–272. [PubMed: 14577549]
- Gallistel CR, Gibbon J. Time, rate, and conditioning. *Psychological Review*. 2000; 107:289–344. [PubMed: 10789198]
- Kamin, LJ. 'Attention-like' processes in classical conditioning. In: Jones, MR., editor. Miami symposium on the prediction of behavior: Aversive stimulation. University of Miami Press; Miami, FL: 1968. p. 9-33.
- Johnston WA. Bidirectional interference in an A-B, C-B paradigm. *Journal of Verbal Learning and Verbal Behavior*. 1968; 7:305–311.
- Lashley KS. An examination of the continuity theory as applied to discriminative learning. *Journal of General Psychology*. 1942; 26:241–265.
- MacLeod CM. Release from proactive interference: Insufficiency of an attentional account. *American Journal of Psychology*. 1975; 88:458–465.
- Mackintosh NJ. A theory of attention: Variations in the associability of stimuli with reinforcement. *Psychological Review*. 1975; 82:276–298.
- Matute H, Pineño O. Stimulus competition in the absence of compound conditioning. *Animal Learning & Behavior*. 1998; 26:3–14.
- McLaren IPL, Mackintosh NJ. An elemental model of associative learning: I. latent inhibition and perceptual learning. *Animal Learning & Behavior*. 2000; 28:211–246.
- Miller, RR.; Matzel, LD. The comparator hypothesis: A response rule for the expression of associations. In: Bower, GH., editor. *The psychology of learning and motivation*. Vol. 22. Academic Press; San Diego, CA: 1988. p. 51-92.
- Miller RR, Escobar M. Associative interference between cues and between outcomes presented together and presented apart: An integration. *Behavioural Processes*. 2002; 57:163–185. [PubMed: 11947996]
- Pearce JM. A model for stimulus generalization in Pavlovian conditioning. *Psychological Review*. 1987; 94:61–73. [PubMed: 3823305]
- Pearce JM, Bouton ME. Theories of associative learning in animals. *Annual Review of Psychology*. 2001; 52:111–139.
- Pearce JM, Hall G. A model for Pavlovian learning: Variations in the effectiveness of conditioned but not of unconditioned stimuli. *Psychological Review*. 1980; 87:532–552. [PubMed: 7443916]
- Postman L, Underwood BJ. Critical issues in interference theory. *Memory and Cognition*. 1973; 1:19–40.
- Randich A, LoLordo VM. Preconditioning exposure to the unconditioned stimulus affects the acquisition of a conditioned emotional response. *Learning and Motivation*. 1979; 10:245–277.
- Rescorla, RA.; Wagner, AR. A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and nonreinforcement. In: Black, AH.; Prokasy, WF., editors. *Classical conditioning II: Current research and theory*. Appleton-Century-Crofts; New York: 1972. p. 64-99.
- Robinson ES. The similarity factor in retroaction. *American Journal of Psychology*. 1927; 39:297–312.
- Schreurs BG, Westbrook RF. The effect of changes in the CS-US interval during compound conditioning upon an otherwise blocked element. *Quarterly Journal of Experimental Psychology*. 1982; 34B:19–30. [PubMed: 6890222]
- Skaggs, EB. Further studies in retroactive inhibition. In: Frantz, SI.; Warren, HC.; Watson, JB.; Bently, M.; Ferneberger, SW., editors. *Psychological Monographs*. Vol. 34. Psychological Review Company; Princeton, NJ: 1925.

- Slamecka NJ, Ceraso J. Retroactive and proactive inhibition of verbal learning. *Psychological Bulletin*. 1960; 57:449–475.
- Swenson, EJ. *University of Minnesota Studies in Education*. Vol. 1. University of Minnesota Press; Minneapolis: 1941. Retroactive inhibition: A review of the literature; p. 7–41.
- Underwood BJ. Interference and forgetting. *Psychological Review*. 1957; 64:49–60. [PubMed: 13408394]
- Wickens DD, Born DG, Allen CK. Proactive inhibition and item similarity on short-term memory. *Journal of Verbal Learning and Verbal Behavior*. 1963; 2:440–445.

Figure 1.

Group means of the CS X test in Experiment 1a. The PI groups were those in which proactive interference was expected due to prior training of an interfering cue in Phase 1. The NoPI groups served as basic acquisition controls. Stronger proactive interference is evident in the lower suppression to CS X of group Elemental-PI relative to group Compound-PI and the control groups.

Figure 2.

Group means of the CS X test in Experiment 1b. The PI groups were those in which proactive interference was expected due to prior training of an interfering cue in Phase 1. The NoPI groups served as basic acquisition controls. Stronger proactive interference is evident in the lower suppression to CS X of group Elemental-PI relative to group Compound-PI and the control groups.

Figure 3.

Group means of the CS X test in Experiment 2. The PI groups were those in which proactive interference was expected due to prior training of an interfering cue in Phase 1. The NoPI groups served as basic acquisition controls. Stronger proactive interference is evident in the lower suppression to CS X of group SameCTX-PI relative to group DiffCTX-PI and the control groups.

Table 1

Design of Experiment 1a

Group	Phase 1	Phase 2	Test X	Test A or ABC
Elemental-PI	12 A → US	2 X→US	cr	(A) CR
Elemental-NoPI	12 A / US	2 X→US	CR	(A) cr
Compound-PI	12 ABC→US	2 X→US	CR	(ABC) CR
Compound-NoPI	12 ABC / US	2 X→US	CR	(ABC) cr

Note: The numbers preceding the letters indicate the total number of presentations of the stimuli in that phase. Slashes separate unpaired presentations of CSs and USs. → indicates “followed by.” The letters in parenthesis in the Test of A or ABC column indicate whether subjects were tested on the element or the compound. CR and cr denote expected strong and weak responding, respectively.

Table 2

Design of Experiment 1b

Group	Phase 1	Phase 2	Test X or XYZ	Test A
Elemental-PI	12 A→US	2 X→US	(X)	cr CR
Elemental-NoPI	12 A / US	2 X→US	(X)	CR cr
Compound-PI	12 A→US	2 XYZ→US	(XYZ)	CR CR
Compound-NoPI	12 A / US	2 XYZ→US	(XYZ)	CR cr

Note: The numbers preceding the letters indicate the total number of presentations of the stimuli in that phase. Slashes separate unpaired presentations of CSs and USs. → indicates “followed by.” The letters in parenthesis in the Test of X or XYZ column indicate whether subjects were tested on the element or the compound. CR and cr denote expected strong and weak responding, respectively.

Table 3

Design of Experiment 2

Group	Phase 1 (CTX)	Phase 2 (CTX)	Test X (CTX)	Test A (CTX)
SameCTX-PI	12 A→US (1)	2 X→US (1)	cr (1)	CR (1)
SameCTX-NoPI	12 A / US (1)	2 X→US (1)	CR (1)	cr (1)
DiffCTX-PI	12 A→US (2)	2 X→US (1)	CR (1)	CR (2)
DiffCTX-NoPI	12 A / US (2)	2 X→US (1)	CR (1)	cr (2)

Note: The numbers preceding the letters indicate the total number of presentations of the stimuli in that phase. Slashes separate unpaired presentations of CSs and USs. → indicates “followed by.” The numbers in parenthesis indicate whether subjects were trained or tested in Context 1 or 2. In Phase 1 subjects were trained in both contexts. CR and cr denote expected strong and weak responding, respectively.