CUE COMPETITION IN THE ABSENCE OF COMPOUND TRAINING
Its Relation to Paradigms of Interference between Outcomes

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I. Introduction

Cue competition is an established phenomenon in many different learning situations such as Pavlovian conditioning, causal learning, categorization, and many others. Research with both humans and animals has shown that organisms tend to discount the potential predictive role of a cue, X, in predicting an outcome, O, if they know that another cue, A, which occurs in compound with X, is a better predictor of the outcome. In general, whenever two cues occur together, they interact with one another, so that responding to each of them is not only a function of its own pairings with the outcome, but also a function of the degree to which the other cues that occur in compound with it are paired with the same outcome. Instances of these *cue competition* effects can also be frequently observed in real life. As an example, if we have developed an allergic reaction (outcome) after having taken two different medicines together, A and X, we would probably attribute the allergic reaction to A rather than to X, if we had also taken A alone and developed the reaction as well.

One of the best well-known experimental designs on cue competition is Kamin's (1968, 1969) forward blocking, in which the A → O pairings occur before the AX → O pairings, and this prior knowledge that A predicts O.

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reduces the ability of X to predict that the outcome will occur, as compared to a control group which has not received the A → O pairings. Similar results can be observed in backward blocking experiments (e.g., Shanks, 1985), in which it is the subsequent (rather than previous) knowledge that A predicts O that causes impaired responding to X (i.e., AX → O pairings followed by A → O pairings). There are many other designs in which cue competition effects have been observed (e.g., the effect of relative stimulus validity, described by Wagner, Logan, Haberlandt, & Price, 1968), but, to the best of our knowledge, all of them have included compound training of the target cue, X, and the competing cue, A. In consequence, current theories of learning generally assume that compound training is necessary for cue competition to occur. In other words, they predict that competition would not occur if A and X were not trained in compound.

In this chapter we will describe a series of recent experiments in which we have tested this assumption. These experiments are problematic for all theories of learning of which we are aware because they show that cue competition can occur, under some circumstances, even when A and X are trained separately. Our basic design consisted of a simplification of the forward and backward blocking designs so that X was never trained in compound with A (Matute & Pineño, 1998). In our forward condition, subjects received A → O pairings followed by X → O pairings, instead of the typical forward blocking training consisting on A → O followed by AX → O. In the backward condition, subjects received X → O followed by A → O, instead of the typical backward blocking training consisting of AX → O followed by A → O. At test, we observed weak responding to X in the backward condition, as compared to an appropriate control group, but not in the forward condition. That is, the acquisition of a second cue → outcome association (A → O) disrupted responding to a previously acquired association between a different cue and the same outcome (X → O), even though the two cues had never received compound training.

Because this effect was new and quite surprising, we have conducted a number of experiments in trying to make sense of the observed data. This chapter will summarize what we so far have learned about this effect. We will first briefly describe the findings reported in Matute and Pineño (1998) and will argue that none of the theories that explain cue competition effects can explain those results. We will then describe several unpublished experiments that we have conducted while trying to seek an explanation for this effect. Perhaps the most interesting finding is that, by borrowing a few ideas from the literature of interference between outcomes (e.g., extinction and counterconditioning, see Bouton, 1993), we were able to make sense of the initial results on competition between elementally trained cues, and to make accurate predictions for the newer experiments. Interestingly, competition between cues seems to be subject to the same manipulations that have been used in the study of interference between outcomes. This finding is important because, although the study of competition between outcomes is currently being integrated within the larger field of interference paradigms, a rather fragmented picture emerges when our textbooks, still today, have to make use of different theories to explain, for example, extinction and cue competition effects (e.g., Matute, in press). The present results suggest that models that explain competition between outcomes can be extended to account for competition between cues. This, we will argue, has the advantage of allowing for integration of two areas of research that are being developed quite independently of each other.

II. Cue Competition in the Absence of Compound Training: The Basic Effect

The dominant explanation of cue competition effects during many years has been provided by traditional associative theories (e.g., Mackintosh, 1975; Pearce & Hall, 1980; Rescorla & Wagner, 1972). The Rescorla-Wagner model, for example, assumes that learning occurs only as long as the outcome is surprising. In this way, this theory explains traditional (i.e., compounded) forward blocking by assuming that because A is fully predicting the outcome by the time that the AX → O pairings occur, the outcome will not be surprising when X is first presented, and for this reason, the X → O association is not acquired. However, this theory has found problems in explaining several other well-known phenomena (for a review of successes and failures of the Rescorla-Wagner model see Miller, Barnet, & Grahame, 1995). Quite possibly, one of the greatest problems for traditional associative theories has been the observation of backward blocking, which was first observed with human subjects by Shanks (1985), and has also been recently observed in rats (Miller & Matute, 1996). To recap, in backward blocking, the AX → O pairings are given before the A → O pairings. Traditional associative theories cannot explain why responding to X should be impaired by the exposure to subsequent A → O trials. The problem is that those theories predict that the X → O association should be acquired during Stage 1 of backward blocking, and that the further A → O pairings given during Stage 2 cannot affect the already acquired X → O association. If X is not present during Stage 2, no learning about X can take place.

With regard to the experiments that we will describe here, in which the A → O and X → O pairings occur in different stages of the experiments, rather than in compound, the Rescorla-Wagner model predicts an absence of cue competition between A and X: If A and X are not trained in compound, the outcome will be surprising when paired with X, regardless of whether or not it has previously or subsequently been paired with A. Nevertheless, according to these theories, the context in which X and A are trained could be regarded as a compounded cue that could produce, if it acquired enough associative strength during Stage 1, forward blocking of X by context in the forward condition (but not in the backward one, which is analogous to backward blocking). Thus, if we were to observe competition only in the forward condition, the experiments could be interpretable in terms of forward blocking by context.

A blocking by context effect would also be predicted in the present experiments, although through a very different mechanism, by comparator theories (e.g., Miller & Matzel, 1988; Shanks & Dickinson, 1987). In this case, equal forward and backward blocking by context should be observed. For example, according to Miller and Matzel, traditional forward and backward blocking effects do not represent a failure to acquire the X → O association, as postulated by Rescorla and Wagner (1972), but a failure to express it. According to Miller and Matzel (1988), the two cues in a traditional (i.e., compounded) forward or backward blocking experiment acquire an association to the outcome. Later, when X is presented during testing, it activates a representation of the outcome as well as a representation of A (through the X-A within-compound association that is formed during compound training). The two cues then activate their own representation of the outcome. At this point, blocking will be observed if the representation of the outcome that is activated by A is stronger than the representation of the outcome that is activated by X, which is the cue that is actually present. Thus, although this theory predicts an absence of competition between cues that have been elementally trained (because there is no association between them), this theory predicts that, if the context acquires enough associative strength, both forward and backward blocking by context should occur. If this were correct, blocking by context should be observed both in our forward condition and in our backward condition, with no differences between them being predicted by these theories.

Several nonassociative (rule-based) models would also predict impaired responding to X in the two groups, regardless of trial order, not because of associative interference, but because of the identical statistical contingency to which the two groups were exposed (e.g., Allan, 1980; Busemeyer, Myung, & McDaniel, 1993; Cheng & Novick, 1992; Rescorla, 1968). Moreover, some recent revisions of rule-based theories (e.g., Cheng, 1997) make the explicit prediction that competition between elementally trained cues should not be observed (see, e.g., Cheng, Park, Yarlas, & Holyoak, 1996, p. 345).

The first experiments that we will describe were aimed to test the prediction of all of these traditional theories that competition between elementally trained cues should not be observed.

A. Methodological Aspects Common to All Experiments

In all of the experiments to be described in this chapter, our subjects were volunteer college students and the experiments were run in a large computer room that allowed for simultaneous running of all subjects in each experiment.

In all of the experiments, except for those in Section V, the preparation that we used was a behavioral task for use with humans that was recently developed by Arcediano, Ortega, & Matute (1996). In this preparation, the experiments are superimposed on a video game in which the task of the subjects is to shoot a laser gun (the space bar) at Martians that are trying to invade the Earth. Martians appear, one at a time, every 0.2 seconds, which gives a behavioral baseline of about 5 responses per second. But subjects are told that, from time to time, the Martians may connect an anti-laser shield that is evidenced through a white flashing of the screen and that, if they shoot while the shield is connected, many Martians will suddenly invade. Therefore, the subjects suppress their bar-pressing behavior when the shield is connected. On this baseline game, we superimpose the experiments: Changes in the background color of the screen are used as cues that sometimes signal that the shield (outcome) is about to be connected, and sometimes signal nothing. For example, a change from black (the default color of the screen during the intertrial intervals) to blue may signal that the shield is about to be connected, whereas a change to yellow may signal nothing. During the intertrial intervals and during the presentation of the cues, bar-presses are reinforced with Martians exploding. However, bar-presses that occur while the shield is connected are punished with an invasion. The experiments are conducted with no breaks or interruptions between stages (i.e., the last trial of each stage and the first trial of the following stage are separated by a regular intertrial interval in which the subjects are shooting at Martians).

The learning curves obtained with this preparation by Arcediano et al. (1996) show that the subjects learn to suppress bar-pressing when the screen color changes to that of the cue that signals the outcome and not otherwise. This suppression of ongoing bar-pressing is our dependent variable and is used as an index of whether the subject is expecting the outcome to occur immediately after the target cue. The suppression ratio is computed as $a/(a + b)$ where a is the number of bar-presses during the presentation of the target cue (e.g., color blue) and b is the number of bar-presses during a period of time identical to that of the presentation of the cue and that immediately precedes its presentation. This preparation has also shown to be reliable in the study of traditional (i.e., compounded) blocking effects with humans (Arcediano, Matute, & Miller, 1997).

In the preparation described by Arcediano et al. (1996), Martians appear, one at a time, in horizontal rows. In the experiments reported here, we use this horizontal format when only one context is needed. However, some of the experiments to be described here use two different contexts. In those cases, a vertical presentation of Martians, with Martians appearing one at a time in vertical columns, is used as the second context (Matute & Pineño, 1998).

B. Experiment 1: Backward, but Not Forward, Competition Between Elementally Trained Cues

In this experiment we (Matute & Pineño, 1998) modified the typical forward and backward blocking designs to test which of them, if any, produced the strongest cue competition effect in the absence of compound training. The design is summarized in Table 1. Our forward-competition group received A → O training during Stage 1, and X → O training, instead of the AX → O training typical of more traditional blocking studies, during Stage 2. The test phase consisted of one presentation of X. The forward-control group received identical training and testing on X, but was simply exposed to the experimental context (i.e., shooting at Martians in the video game) during Stage 1, with no cues or outcomes being presented during that stage. The backward-competition and -control group received the equivalent training but the order of the two training phases was reversed. That is, for the backward-competition group the A → O pairings occurred during Stage

TABLE I

Design Summary of Experiment 1

Group	Treatment		Test
	Stage 1	Stage 2	
Forward-Competition	A → O/B → no O	X → O/C → no O	X
Forward-Control	—	X → O/C → no O	X
Backward-Competition	X → O/C → no O	A → O/B → no O	X
Backward-Control	X → O/C → no O	—	X

Note. A and X were the critical CSs and were yellow and blue, counterbalanced; B and C were two distractor stimuli that were included to prevent strong stimulus generalization (see text). These stimuli were red and brown, counterbalanced. Presentations of A and X were always followed by the outcome whereas presentations B and C were never followed by the outcome.

2, as in traditional backward blocking experiments, but Stage 1 consisted of X → O pairings rather than the typical AX → O pairings. Finally, the backward-control group was exposed to X → O pairings during Stage 1, and to the experimental context (shooting at Martians) during Stage 2, receiving no exposure to any cues or outcomes during this stage. The other cues that are shown in Table 1, cues B and C, are distractor stimuli, which were never paired with the outcome, and which are generally needed in this type of simple computerized human preparations in order to prevent subject from just responding to anything that appears in the screen. A and X were yellow and blue background colors of the screen, counterbalanced; B and C were red and brown, counterbalanced.

The results of this experiment are shown in Fig. 1. There was no tendency towards competition in the forward condition. The forward-competition group showed good suppression of responding to X, which means that these subjects were expecting the outcome to occur after X when this stimulus was presented at test. If anything, a (nonsignificant) tendency in the opposite direction was observed, in that suppression to X in the forward-competition group tended to be better than that in the forward-control group. Most importantly, a reliable cue competition effect was observed in the backward condition. Backward-control subjects showed good suppression of responding when *X* was presented at test, but suppression to X was "blocked" in the backward-competition group. That is, subjects in the backward-competition group responded at test as if they were not expecting the outcome to occur when X was presented. This result is similar to backward blocking except that the competing cue, A, was not presented in

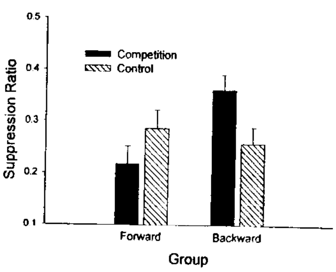

Fig. 1. Conditioned responding to the target cue, X, during the test stage of Experiment 1. The dependent variable was mean suppression ratio. Thus, a lower value indicates stronger conditioning. Error bars represent standard errors of means. After Matute and Pineño (1998).

compound with X during Stage 1. Thus, this suggests the existence of competition between cues that were elementally trained in the backward condition. Moreover, these results suggest that acquisition of a second cue → outcome association (A → O) can disrupt responding to a previously acquired association between the same outcome and another cue (X → O).

The present results are problematic for traditional theories of learning because they predict an absence of competition between elementally trained cues. As previously mentioned, traditional associative theories predicted blocking by context in the forward, rather than backward condition (e.g., Rescorla & Wagner, 1972). Comparator theories predicted equal forward and backward blocking by context (e.g., Miller & Matzel, 1988). And rule-based theories predicted an absence of cue competition and similar degrees of responding in both forward- and backward-competition groups (e.g., Cheng, 1997). Instead, the present results suggest that (a) the effect is not due to blocking by context or contingency effects because it only occurred in the backward condition, and (b) the effect seems to be due to competition between the two elementally trained cues, A and X. But before going any further, some less interesting but plausible alternative interpretations need to be discarded. This was the purpose of the next experiment.

C. Experiment 2: The Effect Is Not Due to Memory Overload

The effect observed in Experiment 1 cannot be attributed to differences in retention intervals because the backward-control group was exposed to the same retention interval as the backward-competition group. Nor can it be attributed to blocking by context because the effect was only observed in the backward condition. Nevertheless, it might well be that instead of cue competition in the absence of compound training, some simpler explanations could still account for the results of Experiment 1. For example, the presentation of any stimulus during Stage 2 may produce a memory overload that might interfere with what was learned during Stage 1. Would A → no O trials given during Stage 2 produce the same effect? How about giving the A → O trials in a different context? If our effect were due to memory overload, giving A → no O trials, or giving A → O trials in a second context should produce a detrimental effect similar to that observed in Experiment 1. A related possibility is that our presenting two novel cues during Stage 2 (A plus the distractor cue C) might have also produced some form of memory overload. In this case, eliminating the presentation of novel cues during Stage 2 should attenuate the effect. Experiment 2 was designed to control for these possibilities.

Thus, in this experiment we tested whether the effect of backward competition between individually trained cues observed in Experiment 1 could be due to novelty of cues or to memory overload rather than associative interference. For this reason, we now used two new groups of subjects in addition to the critical backward-competition group that replicated (with the changes mentioned above) that of Experiment 1. The design is summarized in Table 2. One of the new groups (group A → no O) received A → no O training during Stage 2; the other group received A → O trials, as our critical group, although these trials were given in a second context. This group was called group 1-2-1 because Stage 1 and testing took place in Context 1, and Stage 2 took place in Context 2. The critical group, which replicated the backward-competition group of Experiment 1, is here called group 1-1-1 because all phases of the experiment took place in Context 1. The other substantial difference with respect to Experiment 1 was that now, all three groups were exposed to only two cues (A and X) instead of four. This was done in order to reduce the number of stimuli involved, and thus, the possibility of memory overload or of novelty of the cues influencing the results. Thus, in this experiment, all three groups received discrimination training with X → O and A → no O during Stage 1, but received no distractors during Stage 2 (only cue A was presented at that stage). The horizontal and vertical contexts described in Section II.A, counterbalanced, served as Contexts 1 and 2 in this experiment. A and X were blue and yellow background colors, counterbalanced.

The results of this experiment are shown in Fig. 2. As can be seen in this figure, our critical group, group 1-1-1, replicated the findings of the backward-competition group in Experiment 1. This occurred despite our having reduced the number of stimuli involved, as well as the novelty of the stimuli presented during Stage 2. Moreover, the results also show that this effect did not occur in the group exposed to A → no O trials during Stage 2 or in the group receiving the A → O pairings in a second context. Thus, this experiment replicates our findings that the acquisition of a new

TABLE II

Design Summary of Experiment 2

Group	Treatment		Test
	Stage 1	Stage 2	
1-1-1	$(X \rightarrow O/A \rightarrow no\ O)_1$	$(A \rightarrow O)_1$	$(X)_1$
A → no O	$(X \rightarrow O/A \rightarrow no\ O)_1$	$(A \rightarrow no\ O)_1$	$(X)_1$
1-2-1	$(X \rightarrow O/A \rightarrow no\ O)_1$	$(A \rightarrow O)_2$	$(X)_1$

Note. A and X were the critical CSs and were yellow and blue, counterbalanced; 1 and 2 refer to Contexts 1 and 2, respectively.

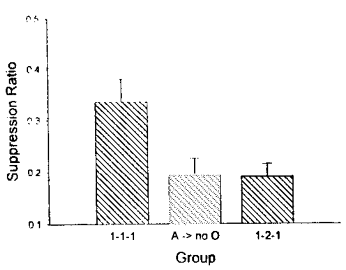

Fig. 2. Conditioned responding to the target cue, X, during the test stage of Experiment 2. The dependent variable was mean suppression ratio. Thus, a lower value indicates stronger conditioning. Error bars represent standard errors of means. After Matute and Pineño (1998).

cue → outcome association can disrupt responding to a previously acquired association between another cue and the same outcome, and shows that this effect is not an artifact produced by memory overload, nor novelty of the cues presented during Stage 2. Moreover, these results also suggest that the effect is context specific.

We are not aware of previous studies that have tested the possibility of associative competition between elementally trained cues. However, there are some results in the "miscuing effect" literature that are consistent with our observations (Lipp, Siddle, & Dall, 1993; Packer & Siddle, 1989; Siddle, 1985; Siddle, Broekhuizen, & Packer, 1990). For example, Lipp et al. showed that giving just one miscued trial in which the outcome was signaled by a cue that previously had signalled its absence (i.e., one A → O trial given after an X → O, A → no O discrimination) reduced electrodermal responding to the outcome in a subsequent test stage in which the outcome was preceded by the excitatory cue, X. In those studies, reduced responding at test was observed when the outcome was presented, but not when X was presented. Nevertheless, according to Lipp et al., their observing the effect only in response to the outcome could be due to their use of electrodermal responding as the dependent variable. The present experiment can be regarded as an extension of the experiment by Lipp et al. because it shows that the miscuing effect (a) can also be observed in response to X, (b) can be obtained with a very different preparation (although, unlike Lipp et al., we used more than one miscued trial), and (c) is context-specific. Other experiments in our laboratory have demonstrated a miscuing effect with just one trial in Stage 2 using the behavioral preparation used in the present

experiments, and have shown that the miscuing effect is not due to blocking by context (Ortega & Matute, 1997). That is, giving the outcome alone during Stage 2 does not produce the miscuing effect. This last observation is also consistent with the results of Experiment 1, as well as with experiments to be described below, which also show that blocking by context cannot account for the results of competition between elementally trained cues reported herein.

Although the present experiment can be regarded as an extention of the miscuing effect, Experiment 1 (as well as the experiments to be reported next) did not use miscued trials but used a different design in which a novel cue, rather than an inhibitory cue, was paired with the outcome during Stage 2. Thus, the effect observed in the present series appears to be more general than that produced by miscued trials. However, the similarities between our findings and the miscuing effect suggest convergent evidence of stimulus competition effects in the absence of compound training. As previously stated, this is contrary to traditional theories of learning. In the next section we investigate the possibility that the X → O association was unlearned during the A → O trials of Stage 2.

III. The Unlearning Explanation

There are some recent revisions of the Rescorla-Wagner model that could potentially explain the results of Experiments 1 and 2 (Dickinson & Burke, 1996; Markman, 1989; Tassoni, 1995; Van Hamme & Wasserman, 1994). These revised versions of the Rescorla-Wagner model were developed to account for backward blocking effects and other related effects that suggested retrospective revaluation of cues after their training had been complete (e.g., weak responding to X observed if AX → O training is followed by A → O training). According to these models, if a cue is omitted in a trial in which it was expected, the representation of that cue becomes negatively activated. If the outcome occurs, this negative activation produces a loss of associative strength. That is, according to this view, each of the A → O trials of Stage 2 in a traditional backward blocking design produces unlearning of X. Therefore, if we interpret X as an absent cue that was expected during the A → O pairings in our backward (but not forward) condition, these models would explain our effect through unlearning of X during the A → O pairings of Stage 2 in the backward condition.

According to Van Hamme and Wasserman (1994), any cue that has acquired some degree of associative strength in a given context (or that has been mentioned in the instructions of the experiment) should be regarded as a "relevant" cue that will be reevaluated in trials that occur in the same context in which the cue itself is absent (p. 132). This could explain our observation of impaired responding to X when the A → O pairings occurred in the same context as the X → O pairings, as well as the absence of this effect when the A → O pairings occurred in a second context. According to Dickinson and Burke, however, only those cues that have a within-compound association to cues that are present in a given trial are expected, and thus, reevaluated in trials in which they are absent. Therefore a literal interpretation of Dickinson and Burke's version of the modified Rescorla-Wagner model would predict no unlearning of the X → O association in our experiments, whereas Van Hamme and Wasserman's version does predict unlearning. Alternatively, we could probably integrate the predictions of these two versions by assuming that the two of them could rest on the association formed between X and the context during Stage 1, rather than between X and A. In this case, both versions would predict unlearning of the X → O association in our experiments, as long as the A → O pairings occur in the same context as the X → O pairings. In our next experiment we decided to provide a more direct test for this prediction.

A. Experiment 3: Competition Occurs When the Target Cue Is Tested in a Context in Which the Competing Cue Is More Strongly Activated Than the Target Cue

The revised Rescorla-Wagner model (e.g., Dickinson & Burke, 1996; Van Hamme & Wasserman, 1994) could perhaps explain the results of Experiments 1 and 2 through unlearning of the X → O association during the A → O trials of Stage 2. Another potential interpretation of our Experiments 1 and 2 is that each of the associations (i.e., X → O and A → O) was acquired independently of each other and neither of them was unlearned. Instead, because the A → O association was presumably more strongly activated by the test context (because the test trial was presented immediately after the last Stage 2 trial, in which A → O, but not X → O was activated). A competed with X in the activation of the outcome representation during the test stage. The observation of no impairment in responding to X when the A → O pairings occurred prior to the X → O pairings (forward-competition group), as well as when the context was shifted between Stage 2 and testing (Group 1-2-1), or when A → no O, rather than A → O pairings occurred during Stage 2 (Group A → no O) gives some support to this hypothesis. In Group 1-2-1, the test context no longer resembled the context in which A → O had been trained, and the return to the experimental context of Stage 1 for testing could have produced a reactivation of the X → O association. Alternatively, the context shift that occurred between Stages 1 and 2 in that group, rather than the context

shift occurring between Stage 2 and testing, might have been the critical factor, as predicted by the negative activation models (e.g., Dickinson & Burke, 1996; Van Hamme & Wasserman, 1994). Thus, in this experiment, we tested whether the critical factor was training A → O in the context in which the X → O pairings had occurred, as predicted by the negative activation models, or whether it was testing X in the context in which the A → O pairings occurred.

A design summary for this experiment is presented in Table 3. Four groups of subjects were exposed to the same contingencies (X → O/C → no O in Stage 1, followed by A → O in Stage 2, and test on X), and we manipulated the context in which each stage took place for each group. Stage 1 was conducted in Context 1 for all four groups. Stage 2 was conducted in Context 1 for two of the groups (groups 1-1-1 and 1-1-2) and in Context 2 for the other two groups (groups 1-2-1 and 1-2-2). Orthogonally, the test stage took place in either Context 1 (groups 1-1-1- and 1-2-1) or Context 2 (groups 1-1-2 and 1-2-2). The horizontal and vertical contexts, counterbalanced, served as Contexts 1 and 2. A and X were blue and yellow, counterbalanced; C was red. If our effect were due to unlearning of X during Stage 2, it should only be observed if the A → O pairings occurred in the context in which X was trained (i.e., it should occur in groups 1-1-1 and 1-1-2, but not in groups 1-2-1 and 1-2-2). Alternatively, if the effect were due to A being more strongly activated than X during testing, the effect should be observed if X were tested in the context in which the A → O pairings occurred, regardless of whether A and X were trained in the same or in different contexts (it should occur in groups 1-1-1 and 1-2-2 but not in groups 1-1-2 and 1-2-1).

TABLE III

Design Summary for Experiment 3

Group	Treatment		Test
	Stage 1	Stage 2	
1-1-1	$(X \rightarrow O/C \rightarrow \text{no } O)_1$	$(A \rightarrow O)_1$	$(X)_1$
1-1-2	$(X \rightarrow O/C \rightarrow \text{no } O)_1$	$(A \rightarrow O)_1$	$(X)_2$
1-2-1	$(X \rightarrow O/C \rightarrow \text{no } O)_1$	$(A \rightarrow O)_2$	$(X)_1$
1-2-2	$(X \rightarrow O/C \rightarrow \text{no } O)_1$	$(A \rightarrow O)_2$	$(X)_2$

Note. The four groups received the identical treatment and testing but we manipulated the contexts (1 and 2) in which the different stages occurred. Group names refer to the context in which each of the three stages took place for that group. A and X were yellow and blue, counterbalanced; C was red.

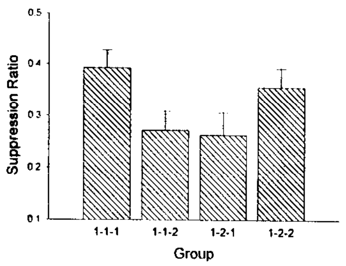

Fig. 3. Conditioned responding to the target cue, X, during the test stage of Experiment 3. The dependent variable was mean suppression ratio. Thus, a lower value indicates stronger conditioning. Error bars represent standard errors of means. After Matute and Pineño (1998).

The results of this experiment can be seen in Fig. 3. Neither the context of Stage 2, nor the test context appeared critical in producing the effect. Instead, the interaction of these two contexts was significant: The effect was observed only in those groups that were tested in the context in which the competing A → O association had been trained (i.e., groups 1-1-1 and 1-2-2).

Thus, contrary to the predictions of the negative activation models, the A → O pairings given during Stage 2 did not produce unlearning of the X → O association that had been acquired during Stage 1. Instead, good responding to X was observed after the A → O pairings as long as these occurred in a context different from that in which X was tested (groups 1-2-1 and 1-1-2).

Other results that also speak against the unlearning explanation commonly used by associative theories to explain weak responding are spontaneous recovery from extinction (Pavlov, 1927), as well as the observation that good responding after extinction can be obtained through the use of several contextual (or other) manipulations (see e.g., Bouton, 1993). Indeed, it is well known today that extinction does not result, as predicted by traditional associative theories, in the destruction of the X → O association (see, e.g., Rescorla, 1996a; Rosas & Bouton, 1996). This "catastrophic interference" prediction, as it is sometimes called, is also known to be a problem of many neural network models (see McCloskey & Cohen, 1989).

Thus, how should we interpret these data? It seems clear that competition occurred during retrieval and that the X → O association was not unlearned because impaired suppression to X was observed only when the test context and that in which A had been trained, were the same one. A theory such as Miller and Matzel's (1988), which assumes that cue competition effects occur after, rather than during acquisition, might, at least in principle, be able to explain these results. However, this theory, like most any other theories, has no means by which two elementally trained cues can interact with one another. This theory would in principle explain the results of our Experiments 1 and 2 by assuming that backward blocking by context, rather than competition between A and X, had occurred. However, by the same reasoning, this theory would predict forward blocking by context, which is inconsistent with the trial order effects that we observed in Experiment 1. Moreover, Miller and Matzel's hypothesis actually predicts backward blocking by context in Group 1-1-2 in the present experiment, rather than in our critical group throughout the three experiments (e.g., Group 1-1-1), because in Group 1-1-1 both the training context and X are physically present during testing, and thus, no competition between them should be expected (if anything, some summation should be expected in Group 1-1-1). However, the role played by context in the present research appears to be a modulatory one rather than a competitive one.

We know of no one theory of cue competition that can currently explain these effects. In the three experiments described so far, the acquisition of a new cue → outcome association impaired responding to a previously acquired association between that outcome and another cue. The only principle that appears clear is that competition occurred whenever the target cue was tested in the context in which the competing cue had been trained. Quite possibly, this occurred because the competing association was more strongly activated than the target one in that context. In the next section we look at the possibility that theories that have been developed to account for extinction and other interference effects that could not be explained by cue competition theories could perhaps be extended to account for the present results.

IV. Theories of Interference between Outcomes

Our eliminating compound training from the backward blocking design has resulted in a design surprisingly similar to those generally used in the study of interference between outcomes, such as counterconditioning and extinction (e.g., Bouton, 1993; Bouton & Ricker, 1994; Rescorla, 1996a, 1996b). For example, counterconditioning is another form of retroactive interference in which the acquisition of a second cue → outcome association (X → O2) also interferes with (but does not destroy) the retrieval of a previously acquired association (X → O1). Similarly, extinction is yet another instance of retroactive interference in which what is learned during Stage 2 (i.e., X → no O) interferes, but does not destroy, what was learned during Stage 1 (i.e., X → O). Moreover, weak responding to X after extinction has taken place is often observed if X is tested in the context used for Stage 2, but responding to X can be *renewed* if X is tested in the context used for Stage 1 or in a new context (i.e., renewal effect, see, e.g., Bouton & Bolles, 1979; Rosas & Bouton, 1997). Thus, quite amazingly, extinction (as well as counterconditioning) do not only show that, like in the present experiments, the acquisition of the second cue → outcome association can interfere with a previously acquired one, without destroying it, but also appear to be subject to contextual manipulations very similar to those used in Experiment 3.

Both counterconditioning and extinction are generally regarded as something that has very little to do with cue competition. However, the similarities between those studies, that could be regarded as showing competition between outcomes, and the cue competition effect that we have been observing, suggest that similar processes may be involved. The only difference between those studies and our effect is that, in our experiments, the event that changes from one stage to another is the first event in the association (i.e., the cue) whereas in the studies of competition between outcomes, it is the second event in the association (i.e., the outcome) the one that changes from one stage to the other one. How critical is this difference?

It could be argued that this difference is critical because competition between cues has generally been reported in compounded conditions (e.g., blocking) whereas competition between outcomes has generally been reported in noncompounded conditions in which the two outcomes were trained separately (e.g., counterconditioning). However, the present experiments show that compound training is not necessary for the occurrence of competition between cues, just as it is not necessary for the occurrence of competition between outcomes. Moreover, several animal experiments have shown that outcomes may also compete with one another if they are trained in compound, in a way similar to that observed between compounded cues (e.g., blocking of compounded outcomes in animals, see Esmorís-Arranz, Miller, & Matute, 1997; Miller & Matute, in press; Rescorla, 1980). Similarly, several human causal judgment studies have shown competition between multiple compounded effects of one cause (e.g., Matute, Arcediano, & Miller, 1996; Price & Yates, 1993, 1995; Shanks, 1991; Shanks & López, 1996). Thus, the compound versus elemental training dimension does not seem to be a critical one in differentiating between competition between outcomes and competition between cues. Moreover, if both cues and outcomes can compete regardless of whether they are trained in an elemental or compounded manner, we find no a priori reason to assume that they are governed by different mechanisms, as postulated by current theories. In contrast, we will argue that models of competition between outcomes can be extended to account for competition between cues.

It could also be argued that in Pavlovian research with animals, cues (conditioned stimuli, or CSs, such as lights and tones) are known to be processed differently than outcomes (unconditioned stimuli, or USs, such as food or footshock). However, it has been shown that differences in the processing of CSs and USs are not dependent on whether they are cues or outcomes in the associative pair. Instead, as Pavlov (1927) had suggested long ago, differences in biological significance is what appears to differentiate a CS from a US (Gunther, Miller, & Matute, 1997).

One more line of research that calls for integration of studies of competition between cues and between outcomes is the old paired associate literature. Indeed, the two paradigms that we have been discussing so far, competition between cues and between outcomes, were extensively studied in the paired associate literature (e.g., Underwood, 1966) and were known as the A–B C–B paradigm (analogous to the effect of competition between individually trained cues described in this chapter) and A–B A–C paradigm (analogous to counterconditioning experiments in which the training with a second outcome interferes with retrieval of a previously acquired association between the same cue and a different outcome). Both the A–B C–B and the A–B A–C paradigms are known to produce interference (see Underwood), and once again, there appear to be no a priori reasons to assume that separate explanations should be developed to account for those two effects.

In his review of several interference paradigms in the animal Pavlovian conditioning literature, Bouton (1993; see also Bouton, 1994) noted that the effects that produce either proactive or retroactive interference through pairing of multiple outcomes to a common cue in separate stages (e.g., extinction, counterconditioning, latent inhibition), are generally explained by different mechanisms in the associative learning literature. For example, the unlearning explanation is often used to account for extinction, but other interference effects such as, for example, latent inhibition, are generally explained in a very different way (e.g., Mackintosh, 1975; Pearce & Hall, 1980). He suggested that, by accepting four basic assumptions, many of those interference paradigms in Pavlovian conditioning that involve training with multiple outcomes can be explained in an integrative manner. These assumptions are (a) contextual stimuli guide retrieval, (b) time is context, (c) different memories are differentially dependent on context (i.e., excitatory associations are more readily generalized to new contexts than inhibitory associations), and (d) interference occurs at performance output.

In Bouton's view, if a cue becomes associated to two different outcomes in different stages, none of those associations is unlearned, but the cue is not able to retrieve both outcomes simultaneously. In those cases, the cue will predict one or the other outcomes as a function of the context in which retrieval occurs (with the context for each stage being either a physically distinct context or the temporal context in which it occurred). If retrieval occurs in the temporal and/or physical context of Stage 1, the cue predicts Outcome 1; if it occurs in the context of Stage 2, the cue predicts Outcome 2. This would explain, for example, why renewal of responding after extinction is observed if the target association is tested in the context used for acquisition, or in a new one, rather than in that used for extinction. Similarly, spontaneous recovery can be explained using the same principle if we assume that the passage of time removes the subject from the temporal context of cue → no outcome pairings that are controlling extinction performance (Bouton, 1991). Other phenomena, such as reinstatement (Rescorla & Heth, 1975) showing that a mere reexposure to the outcome before testing also produces good responding to an extinguished cue, can also be interpreted in similar terms. In this case, according to Bouton, the cue is returned to a feature of the conditioning context when the outcome is presented before testing. Spontaneous recovery, reinstatement, and renewal effects after extinction has taken place have also been reported in human causal learning situations (Vila, Miranda, Rentería, & Romero, 1997) as well as in other paradigms showing interference between outcomes in animals, such as, for example, counterconditioning and latent inhibition (Bouton & Peck, 1992; Brooks, Hale, Nelson, & Bouton, 1995; Kraemer, Randall, & Carbary, 1991; Peck & Bouton, 1990).

Bouton's (1993) theory predicts competition between independent outcomes during retrieval, but does not predict competition between independent cues. However, we suggest that these assumptions can be extended so as to account, not only for interference effects involving competition between outcomes, but also for those involving competition between cues, such as those described in this chapter. This has the advantage of allowing for a more integrative account of all of the interference paradigms, including cue competition, which, in this way, would no longer need to be regarded as an exception to other interference paradigms.

From the above argument, it follows that traditional cue competition studies, such as traditional blocking effects, should be subject to the same manipulations that have been used in the study of competition between outcomes. That is, cue competition should occur during retrieval, and should be sensitive to manipulations of physical and temporal contexts (e.g., spontaneous recovery from cue competition should be observed if the test stage occurs in a temporal test context that is different from that in which competition took place). This is contrary to the dominant explanations of cue competition, which have generally assumed that cue competition effects are due to a failure to acquire the target association (e.g., Rescorla & Wagner, 1972). However, it is consistent with the results of Experiments 1–3 as well as with many other experiments that have shown that traditional (i.e., compounded) cue competition is subject to spontaneous recovery (Cole, Gunther, & Miller, 1997; Kraemer, Lariviere, & Spear, 1988), reinstatement by presentation of the outcome or the cue before testing (Balaz, Gutsin, Cacheiro, & Miller, 1982; Cole, Denniston, & Miller, 1996), and several other postacquisition phenomena that strongly suggest that cue competition takes place during retrieval rather than during acquisition (see Miller & Matzel, 1988, for a review). Moreover, studies on backward blocking also suggest that a failure to acquire the target X → O association is not the cause of the observed weak responding to X at test (e.g., Denniston, Miller, & Matute, 1996; Miller & Matute, 1996; Shanks, 1985). Although there are currently several theories of cue competition that can explain the backward blocking effect (e.g., Dickinson & Burke, 1996; Miller & Matzel, 1988), none of those theories can explain spontaneous recovery or reinstatement in cue competition, extinction, and counterconditioning studies. In the next experiments, we tested whether Bouton's theory, which can explain those effects in situations of interference between outcomes, could be extended to account for competition between elementally trained cues. If this were the case, similar manipulations should yield similar effects in the two paradigms.

A. Experiment 4: The Role of Temporal Contexts

The results of Experiments 2 and 3, taken together, suggest that competition in the absence of compound training occurred when X was tested in a physical context in which the A → O association was more strongly activated than the X → O association. Additionally, these experiments can also be interpreted as demonstrating a "renewal" effect when X was tested in its original (physical) context (group 1-2-1) or in a new context (group 1-1-2) after it had been subject to cue competition training. If this is true, our findings are not too dissimilar to those observed in the literature of interference between outcomes. This suggests that similar theories should be able to explain them. In Experiment 1, however, we did not manipulate the physical context. At first glance, this might suggest that Experiment 1 should be explained through a different mechanism. But using a different mechanism to explain each of the possible ways in which the effect can be obtained does not seem to be the most parsimonious option. Instead, Bouton's (1993) notion of temporal contexts appears to provide a unified explanation of what occurred in the three experiments. In Experiment 1, the test of X consisted of one trial that was given immediately after the last A → O trial. Therefore, in Experiment 1 the effect was observed when the test of X occurred in the *temporal* context in which A had been trained, just like in Experiments 2 and 3 the effect was observed when X was tested in the physical context of A.

But why did subjects create different temporal contexts for each of the training stages in Experiment 1? Quite possibly, the presentation of two stimuli, X and C, during Stage 1, and of two different stimuli, A and B, during Stage 2, allowed subjects to discriminate between the two training stages. In Stage 2, the stimuli that were presented had changed, and this may have allowed for the discrimination between the two temporal contexts even though the physical context did not change in that experiment. If this were the case, the same principle that explains Experiments 2 and 3 could explain Experiment 1 as well. Namely, competition occurs when the competing cue is more strongly activated than the target cue in the (physical or temporal) context in which retrieval takes place. Now, if this is true, we should be able to manipulate the conditions under which temporal contexts can be created and can affect competition.

In the present experiment, our competition group received X → O/C → no O discrimination training during Stage 1, and A → O training during Stage 2. This manipulation should create, like in Experiment 1, two different temporal contexts coincident with the two stages of the experiment. Group random, by contrast, received random presentations of X → O, C → no O, and A → O trials, both during Stage 1 and during Stage 2. The number of times that each cue → outcome (or cue → no outcome) pair was presented was identical in the two groups. The only manipulation was whether the different types of trials were presented in random or sequential order. In the random group, no differential temporal contexts could be created for each stage because the trial types of each stage did not differ from the trial types of the other stage. Thus, in this group, both A and X should be equally activated in the test temporal context. The competition group, however, should replicate the conditions of Experiment 1 in which two different temporal contexts were presumably created. Because A is presumably more strongly activated than X in the temporal context in which the test of X takes place in this group, responding to X in this group should be impaired, as compared to group random. Therefore, if our hypothesis is correct, competition should only be observed in the competition group.

The results of this experiment were as expected. Weak suppression to X at test was observed in group competition, in which different temporal contexts for A and X could be created ($M = 0.23$; $SE = 0.2$) as compared to group random ($M = 0.16$; $SE = 0.2$), which could not create two different temporal contexts for A and X. This replicates and extends the results of the previous experiments by showing that in this experiment, like in the previous ones, competition occurred only when X was tested in a (temporal or physical) context in which another cue, A, was more strongly activated. Moreover, although the results of Experiment 2 could be interpreted in terms of backward blocking by context, the present results, as well as those of Experiment 1 and 3, show that blocking by context cannot account for this effect. In the event that blocking by context had occurred, it should have also taken place in group random. Instead, the present results suggest that competition between A and X does occur only if they are trained in different (temporal or physical) contexts and X is tested in the context used for the training of A.

B. Experiment 5: A Retrieval Cue for the Acquisition Stage Attenuates the Effect

One manipulation that Bouton and his colleagues have sometimes used to show the influence of temporal contexts on extinction is the use of a retrieval cue to retrieve one or the other stage of the study just before testing (Brooks & Bouton, 1993). Presumably, if subjects retrieve the information acquired during the Stage 1, they should show behavior appropriate for that stage, whereas if they retrieve the information acquired during the second stage, their behavior should be quite different. For example, Brooks and Bouton (1993) have shown that a retrieval cue for extinction can attenuate spontaneous recovery. Similar manipulations have also been shown to attenuate cue competition in traditional (i.e., compounded) situations by Miller and his colleagues (e.g., Miller & Matzel, 1988).

The purpose of this experiment was to test whether a similar manipulation to that used by Brooks and Bouton (1993) could be used to retrieve responding to X in our paradigm. If this were the case, good responding to X should be expected even after exposure to cue competition training with A. Thus, in this experiment our competition group was used as the control group against which to assess retrieval of the X → O association in the retrieval group. Our purpose was to test the prediction that a retrieval cue for the temporal context in which X had been trained could renew responding to X. Thus, the two groups were exposed to X → O, C → no O in Stage 1, followed by A → O, B → no O in Stage 2, and tested on X. According to what we have seen so far, impaired responding should be observed. However, just before testing took place in group retrieval, we presented C, which was the nonreinforced cue that had been trained in the same temporal context as X. Thus, presumably, the retrieval, just before testing of the temporal context in which X was trained, should produce a renewed responding to X. The control (competition) group, however, received a control cue instead (i.e., this group simply received one more trial with cue B at the end of Stage 2, just before testing). The results showed renewal of suppression to X in the retrieval group ($M = 0.20$; $SE = 0.3$) as compared to the competition group ($M = 0.33$; $SE = 0.5$). Thus, this result adds to the growing evidence reported above that suggests the effect of competition between elementally trained cues only occurs when the target association is tested in a (physical or temporal) context in which the competing association is more strongly activated. Moreover, the similarities between this experiment and that of Brooks and Bouton (1993) suggest that similar processes may be operating here.

V. Competition between Elementally Trained Cues in Judgmental Tasks

All of the experiments that we have reported so far had been conducted using the behavioral (Martians) preparation described in Section II.A, in which learning is assessed through a behavioral index (suppression ratio). However, most of the studies that are currently being conducted on human associative learning make use of judgmental tasks that assess learning through the subjective judgment of the degree to which the cue predicts the outcome. Therefore, in order to assess the generality of our effect, we next explored whether the effect could be obtained using a judgmental preparation.

The most commonly used judgmental task to study associative learning in humans is the "allergy task" (Wasserman, 1990). In this task, the subjects play the role of allergists who are studying the medical files of fictitious patients. The fictitious patients have taken some foods or medicines (cues) and some of them have developed an allergic reaction (outcome). Each of the fictitious patients represents one trial, and after having observed the records of a number of patients, the subjects are asked to rate the degree to which they think that each of the potential cues is the cause of the outcome. Several variations of this task have been successfully used in many demonstrations of traditional (i.e., compounded) cue competition effects in humans, both in our laboratory and in many others (e.g., Dickinson & Burke, 1996; Matute et al., 1996; Shanks & López, 1996; Van Hamme & Wasserman, 1994). Thus, we adapted our design of competition between elementally trained cues to this preparation. Surprisingly, however, we run into failure after failure to replicate the effect. Below we describe some of the hypothesis that we have entertained while trying to explain these failures, as well as some of the experiments that we have conducted,

some of them showing the effect and some of them not showing the effect. We found it important to report those hypothesis as well as the two types of studies because, taken together, these studies show, on the one hand, that the effect is not specific to the Martians preparation, but on the other hand, that specific conditions need to be met in order to obtain the effect in a judgmental task.

One difference between the Martians task and the judgment preparation is the reaction time. In a judgment preparation, subjects can take all the time they need before they give their judgments at test. However, in the Martians task, X is presented for a very short time (generally 1 second during training and 3 seconds during testing). Thus, the judgmental response might represent a more elaborated reasoning process in which subjects may take into account all of what they learned during the two training stages, whereas, perhaps in the Martians task, there is no time for elaborated processing. This is a difference that might be important. However, it cannot fully account for all of the data. For example, Escobar and Matute (1998) happened to observe this effect of competition in the absence of compound training in a very different series of experiments, which was looking at differences between differential (i.e., elemental) and Pavlovian (i.e., compounded) inhibition, using a judgmental task quite different from the allergy task but in which the subjects could respond at their own pace (Escobar & Matute, 1998). We will not describe the details of those experiments in this chapter because they were primarily dealing with inhibition rather than cue competition but the important point, for our present purposes, was that they suggested that the effect could be obtained in a judgmental preparation different from the allergy task. The question was why.

There were at least two differences between the judgmental task used by Escobar and Matute (1998) and the allergy task that we had been using in our attempts to obtain this effect. First, in the allergy task we were assessing subjects' judgments at the end of the experiment whereas in Escobar and Matute's task, the judgments had been assessed in a trial-by-trial basis. This could be important because judgmental preparations have been shown to be sensitive to frequency of judgment manipulations (Catena, Maldonado, & Cándido, in press). Thus, we conducted yet one more experiment with the allergy task using a trial-by-trial assessment of causal judgments. Again, the results showed an absence of competition between elementally trained cues. Thus, at least with our parameters, this variable did not seem to be critical in obtaining competition between elementally trained cues.

The other apparent difference between the allergy task and the one used by Escobar and Matute was that the new task involved predictive judgments rather than causal judgments. That is, in each trial, instead of observing medical records, subjects had to predict whether an outcome was to appear on the screen based on the information provided by several lights that could be turned on and off. It could well be that predictive, but not causal judgments, were subject to the effect of competition between elementally trained cues. Indeed, the behavioral responses assessed during the Martians task quite probably reflected predictive rather than causal knowledge. To this end we decided to develop yet one more judgmental task designed to focus on predictive rather than causal judgments. Experiments 6 and 7 describe our results with that new judgmental task.

A. Experiments 6 and 7: Role of Contexts in Judgmental Tasks

For these two experiments we used a new judgmental preparation, in which the computer screen presented in each trial one of two colored folders (cues). In each trial, the subjects had to open the folder that was present and see whether it contained a piece of paper (outcome). The design of Experiment 6 was X → O, A → no O in Stage 1, followed by A → O in Stage 2. A and X were blue and yellow folders, counterbalanced. At test, subjects were shown folder X and were asked to respond, in a 0 to 9 scale, to which degree they expected the paper to be in that folder. This should have been a direct replication of Experiment 2 with a predictive judgment task. However, the results showed no tendency toward any impairment in the ratings of X at test. That is, subjects were perfectly aware that folder X should contain the piece of paper. They had seen many trials in which that was the case during Stage 1 and they seemed to be unaffected by the A → O trials given during Stage 2.

Thus, contrary to what we had observed in the experiments reported above, which used the behavioral (Martians) task, and in the experiments reported by Escobar and Matute (1998), which used the lights-outcome judgmental task, the subjects in this experiment were apparently taking into account both the temporal context of Stage 1 and the temporal context of Stage 2 when they gave their ratings of X at test. If our hypothesis that the effect of competition in the absence of compound training could only occur when X was tested in the context of A were correct, perhaps we were failing to obtain the effect in this experiment because we were actually testing X in a whole new context. That is, in the behavioral Martians task (as well as in the judgmental light task used by Escobar & Matute, 1998) the test of X was actually one more trial given at the end of Stage 2, and thus, the test of X occurred in the temporal context of Stage 2. However, in the folders judgmental preparation used in this experiment (as well as in the allergy task that we had used in previous attempts) the test trial had taken place in a whole new context in which the relative attractive graphics

mode used during training was substituted for a bland text screen showing instructions and questions. If this were true, the use of differential physical contexts should produce the effect in this task. Thus, in the next experiment, we decided to explicitly manipulate the contexts in which each phase of the folders study took place.

In Experiment 7, we again used the judgmental folders task used in Experiment 6, but we introduced two different physical contexts, which were defined by whether the folder belonged to a man or to a woman. If the folder in a particular trial belonged to a man, a picture of a businessman appeared on the screen, next to the folder. If the folder belonged to a woman, a picture of a businesswoman appeared next to the folder. These contexts were counterbalanced. Subjects were warned by the instructions that the folders could contain the paper or not, as a function, not only of their color, but also of whether the owner was the man or the woman.

The design of this experiment replicated that of Experiment 6, by using the same cues and trial types, except that we now manipulated the contexts in which each stage took place: Both groups performed Stage 1 in Context 1, and Stage 2 in Context 2. However, group 1-2-1 performed the test stage in Context 1, while group 1-2-2 performed the test stage in Context 2. We expected to obtain a lower judgment to X in group 1-2-2 because the A → O association should presumably be more strongly activated than the X → O association in the test context for this group, and a greater judgment for X in group 1-2-1, because in this group the X → O association should be more strongly activated than the A → O association in the test context. As expected, the results showed that the judgment in group 1-2-2 (M = 2.57; SE = 1.44) was significantly lower than that in group 1-2-1 (M = 9; SE = 0). Thus, this showed that competition between elementally trained cues could also be obtained in judgmental situations as long as physical contexts are explicitly manipulated so that it is made explicit that the test of X is taking place in the context in which A, rather than X, was trained.

It could be argued that the weak responding observed in group 1-2-2 was due to a generalization decrement because X was tested in a context in which it had never been presented before. This explanation is discarded in the next experiment. Moreover, in order to further explore the generality of the effect, the next experiment makes use of the more traditional allergy task, and of an explicit manipulation of temporal (rather than physical) contexts.

B. Experiment 8: Making Temporal Contexts Explicit in the Allergy Task

The experiments that we have reported so far suggest that competition can be observed whenever the target cue is tested in a (temporal or physical) context in which the competing cue is more strongly activated. Moreover, Experiments 6 and 7 strongly suggest that subjects might not as readily create temporal contexts in judgmental tasks as compared to behavioral tasks, and that, in judgmental tasks, an explicit contextual manipulation might be necessary to obtain this effect.

In this experiment we explicitly manipulated the temporal contexts in the allergy task. Given that everything is fictitious in this task, and that it apparently works well with other cue competition designs (e.g., Dickinson & Burke, 1996; Matute et al., 1996; Shanks & López, 1996; Van Hamme & Wasserman, 1994), we anticipated that fictitious manipulations of time should also be possible in such a setting. To this end, we developed a "time machine" to be used in conjunction with the allergy task.

The preparation worked as in our previous attempts, with the subjects seeing the records of fictitious patients, one at a time, on the computer screen, and their judgments of the degree to which each of the medicines were causing the allergic reaction being assessed after all of the training trials had been presented. The main difference with respect to our previous attempts to obtain the effect using this preparation was the explicit manipulation of temporal contexts. Subjects were told that, from time to time, they would be traveling in a time machine, and that, when this occurred, they could either return to the same century or appear in a different one. Thus, they should pay attention, not only to the medicines and allergies that were presented in each trial, but also to the messages in the time machine, which indicated the century they were at. Between Stages 1 and 2, and between Stage 2 and testing, the screen was cleared and the message "Time machine activated . . . Traveling through time" was displayed. Moreover, a message stating "You are in the [Nth] century" was always displayed at the top of the screen.

In this way, we manipulated three different explicit temporal contexts: 15th, 16th, and 17th centuries, counterbalanced. The design for this experiment is shown in Table 4. Three groups of subjects were exposed to the identical contingencies: Intermixed X → O, C → no O trials during Stage 1, followed by A → O during Stage 2, and test on X. Also, the three groups were identical in the explicit temporal contexts used for Stage 1 and Stage 2 (i.e., all groups were exposed to Context 1 in Stage 1 and to Context 2 in Stage 2). The critical difference between them was the temporal context in which the test took place: It was Context 1 for Group 1-2-1, Context 2 for Group 1-2-2, and Context 3 for Group 1-2-3. Like in the other allergy task experiments we had conducted, the physical contexts used for training and testing were very different from each other. Training was conducted with a relatively attractive graphic mode using large style fonts showing, in colored screens, the medical files of each patient, their patient number,

TABLE IV

DESIGN SUMMARY OF EXPERIMENT 8

Group	Treatment		Test
	Stage 1	Stage 2	
1-2-1	$(X \rightarrow O/C \rightarrow \text{no } O)_1$	$(A \rightarrow O)_2$	$(X)_1$
1-2-2	$(X \rightarrow O/C \rightarrow \text{no } O)_1$	$(A \rightarrow O)_2$	$(X)_2$
1-2-3	$(X \rightarrow O/C \rightarrow \text{no } O)_1$	$(A \rightarrow O)_2$	$(X)_3$

Note. Experiment 8 used a causal judgment preparation. A, X, and C were potential causes of an effect (O). Presentations of X and A were always followed by the effect, whereas presentations of C were never followed by the effect. Numbers 1, 2, and 3 symbolize the contexts that we manipulated.

as well as the time machine messages, and several other decorative stimuli (colored borders and so on). By contrast, testing was conducted in black-and-white regular font text screens showing just the instructions on how to respond and the actual test questions. The instructions explained that they should respond by typing a number between 0 (definitely not) and 8 (definitely) to indicate the degree to which they believed that each of the medicines was the cause of the allergic reaction. The test questions used in this study took the form of "You are in the [Nth] century. To which degree is [medicine X] the cause of the allergic reaction? (Please, type a number between 0 and 8 according to the instructions above.)"

We expected to obtain a weaker judgmental response to X in Group 1-2-2 when compared to Group 1-2-1, because of the strong activation of the A → O association in the temporal context in which the test of X was performed in Group 1-2-2. Group 1-2-3 served to assess the judgment to X in a novel temporal context, in order to know whether the impaired judgment in Group 1-2-2 was due to generalization decrement produced by presenting X in a temporal context in which it had not received training (in which case judgment in Groups 1-2-2 and 1-2-3 should be similar) or whether it was due to genuine cue competition (in which case judgment in Group 1-2-2 should be lower than in Group 1-2-3). Thus, we expected to find higher judgments in Groups 1-2-1 and 1-2-3 when compared to Group 1-2-2. As can be seen in Fig. 4, we obtained exactly those results. This means that competition between individually trained stimuli can occur using a judgmental preparation, not only by manipulating physical contexts but also by manipulating the conditions under which temporal contexts may be formed. This discards the possibility that the effect was due to an artifact of our behavioral task. However, the results of the judgmental studies

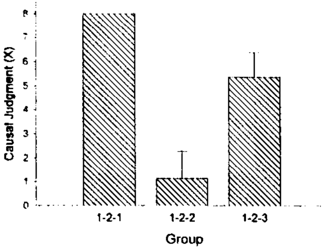

Fig. 4. Mean causal judgment to the target cause, X, during the test stage of Experiment 8. Error bars represent standard errors of means. The lack of an error bar in group 1-2-1 is due to $SE = 0$ in that group.

described herein also suggest that, in judgmental situations, subjects do not appear to create different temporal contexts for each stage and, thus, the explicit manipulation of temporal or physical contexts seems to be a factor modulating this effect.

A more traditional explanation of this experiment can also be constructed for those probably many readers, who might be skeptical about our use of a time machine to manipulate temporal contexts. The sentence "You are in the [Nth] century" inserted in the test question can be regarded as a retrieval cue for a given stage of the experiment. In this case, Groups 1-2-2 and 1-2-1 are similar to groups competition and retrieval, respectively, of Experiment 5, although in this case, the retrieval cue used during testing was physically different from that used during training. Thus, like in Experiment 5, the presentation of a retrieval cue for Stage 1 during testing in Group 1-2-1 effectively retrieved the context in which the X → O association had been trained, and in this way, good responding to X was observed. Note that in this interpretation it is also necessary to assume that temporal contexts (in this case implicit ones) have been created. As previously mentioned, the physical contexts used during training and testing were very different from each other. Thus, it seems that the retrieval of temporal contexts, either through the time machine, or perhaps more conservatively, through the use of a retrieval cue, favored the retrieval of the X → O association after it had been subject to cue competition training. This result is similar to those observed in the literature of interference between outcomes (e.g., Brooks & Bouton, 1993).

The results of Group 1-2-3 are also interesting. On the one hand, the comparison between Group 1-2-3 and Group 1-2-1 shows that the judgment

was weaker in Group 1-2-3. This can probably be attributed to some generalization decrement that occurs when X is tested in a new context. The comparison between Group 1-2-3 and Group 1-2-2, shows, on the other hand, that impaired responding to X was greater in Group 1-2-2. This suggests that the effect observed in Group 1-2-2 cannot be attributed to a simple generalization decrement effect. In other words, competition was not observed when the test context was new (and thus, neither A nor X were presumably activated in that context). This confirms the results of previous experiments that suggested that competition only took place when X was tested in the context in which A had been trained. Additionally, this is, once again, quite similar to results in the literature of interference between outcomes, which also suggest that extinction and counterconditioning are observed if the test stage occurs in the test context used for Stage 2, but not if it occurs in the context of Stage 1 or in a new context (e.g., Bouton, 1993). According to Bouton, different memories are differentially dependent on context, with excitatory associations generally predominating over inhibitory ones unless the test context is that in which the inhibitory association was trained. That is, in a new context, the excitatory association should predominate over the inhibitory one. This opens the possibility that an inhibitory association might be formed during Stage 2 in the present experiments. This potential explanation, as well as the relative activation hypothesis that we have been assuming through this chapter, are discussed in the next section.

VI. Extending Models of Competition between Outcomes to Account for Competition between Cues

In the previous sections we have summarized what we so far have learned about the effect of cue competition in the absence of compound training. Because these results were new and hard to explain, our primary efforts have focused on obtaining data that could suggest possible avenues to explain this effect. At this point, we know that cue competition is much more similar than we had thought to several effects observed in the literature of interference between outcomes. This calls for integration of the two areas. Given the results reported in this chapter, as well as many other results in the literature (see above), it appears easier to extend theories of interference between outcomes to account for competition between cues than vice versa. However, we are still uncertain as to the best way in which theories that could account for both phenomena should be constructed. Thus, in this section we will only speculate about some possible ways in which models of interference between outcomes could be extended to account for cue competition effects.

One possibility is that an inhibitory association was formed during Stage 2 of the present experiments, and this prevented responding to X when the test trial was performed in the context used for Stage 2. This inhibitory association might have formed, for example, between A and X (because when A is present, X is absent, see Espinet, Iraola, Bennett, & Mackintosh, 1995). This inhibitory association, if it really exists, appears to be specific to the context in which it is acquired. This is consistent with the contextual-specificity of inhibitory associations observed in the literature of interference between outcomes (e.g., Bouton, 1993, 1994).

A related possibility is that the potential inhibitory association might alternatively have formed between X and O (or between X and the response, R). However, this possibility requires some additional assumptions. In extinction experiments, an inhibitory association between, say, X and O, can be formed when we present X and it is not followed by O (e.g., Rescorla, 1993). However, in order to extend this idea to the present experiments, we would need to assume that the inhibitory association between X and O is formed when we present O and X does not precede it. Dickinson and Burke (1996) had proposed a revision of Wagner's (1981) SOP model that makes this prediction. According to Dickinson and Burke, if the representation of an absent cue is activated (in this case by the within-compound association between X and the context) and the outcome occurs, an inhibitory association is formed between the absent cue, X, and the outcome. Although this view alone would not explain several of the results presented in this chapter (e.g., the observation of an interaction between the test context and the context used for Stage 2; see e.g., Experiment 3), if we add to this Bouton's assumption that inhibitory associations are specific to the context in which they are learned, a plausible explanation emerges: An inhibitory association is formed between X and O during Stage 2 but it does not generalize to other contexts. We currently have no data to favor this veiw over the alternative ones that we are speculating about, but this is one more possibility that should certainly be considered.

An alternative interpretation of how such inhibitory association between X and O might have formed assumes the existence of bidirectional associations, an idea that is quite foreign to most associative learning theories. However, although we have not yet tested whether this idea can account for the present results, there are some studies that strongly suggest that both animal (Miller & Barnet, 1993) and human subjects (Gerolin & Matute, 1998) can acquire bidirectional associations between events. For example, in the studies reported by Gerolin and Matute (1998), subjects were shown several cards that contained a figure in one side and a color in the other one. After seeing several trials in which the color side was always presented before the figure side, subjects were presented one figure and asked which color was at the other side. Their responses were impressively accurate, as compared to a control group of subjects who had experienced a training phase in which the color and figures had been presented in an inconsistent manner. This does not necessarily imply that a backward inhibitory association between O and X was formed in the present experiments, but it does suggest that such possibility should also be considered.

Another possibility is the one that we have been implying throughout this chapter. Because the effect appears to be so strongly dependent on the interaction between the (physical or temporal) contexts used for Stage 2 and testing, we have assumed that the activation of the competing association during testing (i.e., A → O) prevents the activation of the target association (i.e., X → O). At this point, two new possibilities emerge. First, it might be that the test context activates one of two different associations such as, for example, Context → (A → O) versus Context → (X → O). If this were the case, this process might be similar to that described by Bouton (1993, 1994), according to which, if a cue is activating one outcome (e.g., X → O1), it cannot simultaneously activate another one (e.g., X → O2). The only difference would be that a higher order association, rather than a simple one, would be required to explain our effect. Second, it might also well be that the test context is strongly activating the representation of A, rather than that of X, and thus, A, rather than X, is activating the outcome representation (i.e., context → A → O rather than context → X → O). If we assume that there is a limit in the amount of activation that a given event representation can support (in this case, the representation of O), and if A is fully activating it, this would make X ineffective in activating the representation of O. This could explain why X fails to produce a response. However, this last explanation alone does not explain why the representation of A, which is presumably strongly activating the outcome representation when X is presented, fails to produce a response. In order to explain this, we should probably assume that the representation of cues that are present in a given trial (in this case X) differs from the representation of cues that are absent (e.g., Wagner, 1981), and that subjects do not respond to cues that are absent (in this case, cue A) unless they expect them to immediately occur, such as, for example, in sensory preconditioning experiments. At this point, one more possibility should be considered. Namely, that the potential inhibitory association between X and A (see above) is what prevents responding to the representation of the outcome which is activated by A when X is presented during testing. A related explanation has been suggested by Mackintosh and Bennett (1997) to account for a different phenomenon (i.e., Espinet et al., 1995), but it also appears plausible in the present case.

Finally, if, as the data apparently suggest, cue competition takes place during retrieval, rather than during acquisition, it might also be a good idea to revive the older theories that explained the formation of associations in terms of pure contiguity (i.e., without recourse to cue competition during acquisition). Although this view seems contrary to today's dominant views, there is an increasing body of data suggesting that contiguity is sufficient for the formation of associations (e.g., Dickinson & Charnock, 1985; Matute, 1994; 1996; Matute et al., 1996; Miller & Barnet, 1993; Miller & Matzel, 1988; Rescorla, 1992). This assumption allows for a more symmetrical interpretation of competition between cues and between outcomes (whether compounded or not), because cues and outcomes would be treated similarly as contiguous (but not competing) associates. In this framework, competition could occur between intact associations for activation of a given event during retrieval, rather than between cues that compete for associative strength.

VII. Conclusions

Through this chapter, we have shown that cues can compete with each other even when they are not trained in compound. The acquisition of a second cue-outcome association interferes with (but does not destroy) a previously acquired association between the same outcome and a different cue. The experiments also suggest that this occurs whenever the target cue, X, is tested in a (temporal or physical) context in which the competing association ($A \rightarrow O$) is more strongly activated. These results are problematic for all current theories of cue competition, and strongly suggest that theories of cue competition need to be revised to account for competition in the absence of compound training.

An interesting finding has been the observation that competition between cues is subject to the same manipulations that have been used in the study of many other, apparently unrelated, interference paradigms. As an instance, studies of counterconditioning and extinction have also shown that the acquisition of a second cue-outcome association interferes with (though does not destroy) a previously acquired association between the same cue and another outcome, and that, likewise, this too is context-specific. This observation calls for integration of cue competition research into the larger body of literature that studies interference between outcomes (e.g., counterconditioning and extinction) as well as the other interference paradigms. Unfortunately, however, current theories of cue competition do not account for interference between outcomes, and current theories of interference between outcomes do not account for competition between cues.

We have suggested several avenues through which theories of interference between outcomes could be extended to explain these results. Although it is clear that a great deal of experimental work still needs to be done before a complete explanation of competition between (compounded and noncompounded) cues and outcomes can be constructed, we should probably assume that associations are acquired as a function of mere contiguity (i.e., events do not compete during acquisition) and are not subject to unlearning. If this is true, both elementally- and compound-trained associations to the same outcome or to the same cue could compete during retrieval, as a function of (a) their relative associative strength, and (b) their relative activation in the (temporal or physical) context in which retrieval takes place. Or, alternatively, it is also possible that some form of inhibition is created during cue competition treatment, and that these inhibitory associations are affected by the same manipulations that have been shown to affect interference between outcomes (e.g., extinction). In any case, the most important point in these studies should be that they allow for a more symmetrical interpretation of studies showing interference between cues and between outcomes, as well as of studies showing interference in compounded and in noncompounded situations.

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