Research Report

COMPETITION BETWEEN OUTCOMES

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Abstract—*In both Pavlovian conditioning and human causal judgment, competition between cues is well known to occur when multiple cues are presented in compound and followed by an outcome. More questionable is the occurrence of competition between outcomes when a single cue is followed by multiple outcomes presented in compound. In the experiment reported here, we demonstrated blocking (a type of stimulus competition) between outcomes. When the cue predicted one outcome, its ability to predict a second outcome that was presented in compound with the first outcome was reduced. The procedure minimized the likelihood that the observed competition between outcomes arose from selective attention. The competition between outcomes that we observed is problematic for contemporary theories of learning.*

When a cue (i.e., an antecedent event) is followed by an outcome (i.e., a subsequent event), the association that is ordinarily formed may be assessed predictively (i.e., by presenting the cue and assessing whether participants predict the outcome) or diagnostically (i.e., by presenting the outcome and assessing whether participants diagnose the cue). Moreover, when two cues are presented together prior to an outcome, the cue with the higher predictive value ordinarily competes with the other cue for predicting the outcome. Examples of cue competition include overshadowing (Pavlov, 1927), blocking (Kamin, 1968), and the relative stimulus-validity effect (Wagner, Logan, Haberlandt, & Price, 1968; Wasserman, 1974). Cue competition occurs in both humans and animals (e.g., Balaz, Gutsin, Cacheiro, & Miller, 1982; Kamin, 1968; Matute, Arcediano, & Miller, 1996; Shanks, 1985; Wasserman, 1990) and is now an established phenomenon that is addressed by many models developed in areas as diverse as neural networks, animal conditioning, causal attribution, and categorization (e.g., Gluck & Bower, 1988; Kruschke, 1992; Rescorla & Wagner, 1972; Van Hamme & Wasserman, 1994).

In contrast, much less attention has been given to competition between outcomes. Competition between outcomes is important because most neural networks and contemporary associative theories of learning anticipate an absence of such competition. That is, presentation of a cue should evoke the expectation of all outcomes that were previously paired with that cue. Despite this clear prediction, competition between outcomes has rarely been investigated. Some studies have demonstrated competition between multiple effects of a common cause in causal judgment tasks (Chapman, 1991; Matute et al., 1996; Price & Yates, 1993, 1995; Shanks, 1991; Waldmann & Holyoak, 1992, Experiment 2), but most of those studies presented effects before causes (i.e., diagnostic training). Consequently, the apparent competition between effects observed in those studies could be interpreted as competition between cues rather than between outcomes (e.g., Shanks & López, 1996). Moreover, in the few instances in which effects were not presented before causes (e.g., Matute et al.), effects and causes were presented simultaneously. Thus, even though all of those studies seemingly demonstrated competition between effects, none can be unambiguously interpreted as demonstrating competition between outcomes (i.e., events presented after their cues).

In a previous study offering some evidence of competition between outcomes (Esmoris-Arranz, Miller, & Matute, 1997), we used rats as subjects and auditory stimuli as events. Cue-Outcome 1 pairings were followed by a phase in which the cue signaled an Outcome 1–Outcome 2 compound. At test, Outcome 2 was presented to determine if the rats behaved as if the cue had occurred. For this reason, before testing with Outcome 2, we paired the cue with footshock so that occurrence of the cue produced fear. Rats with initial cue→Outcome 1 experience showed less fear than rats lacking the initial cue→Outcome 1 pairings. Thus, this study seemingly demonstrated blocking between outcomes.

However, this study has an alternative interpretation. According to G. Hall (personal communication, September 22, 1994), when the cue→footshock pairings were given, the cue might have activated representations of Outcome 1 and Outcome 2, which consequently could have competed at that time for association with the footshock. In this view, Outcome 1 and Outcome 2 could be interpreted as cues that competed for an association with the footshock outcome, rather than as outcomes that competed for diagnosing the cue.

A second issue in interpreting this previous study arises from our testing by presenting Outcome 2. This constituted diagnostic testing (despite the training procedure being predictive), and thus did not directly test the critical prediction of associative theories that competition between outcomes would not occur with predictive testing (i.e., presentation of the cue). Moreover, in other work, we (Matute et al., 1996) observed competition between effects in humans when we tested diagnostically, but not when we tested predictively. This pattern of results suggests that there may be differences in stimulus competition between diagnostic and predictive testing; however, we did not address the focal issue here concerning competition between outcomes because we trained with simultaneous presentation of causes and effects.

The present study assessed competition between outcomes using both predictive training and predictive testing procedures, so that the competing elements were unambiguously outcomes (i.e., subsequent events) during the treatment and testing phases. We used a blocking design in which a cue (C) predicted Outcome 1 (O1) in Phase 1 and a simultaneous compound of O1 and Outcome 2 (O2) in Phase 2. Moreover, the preparation avoided cover stories (such as were used in most prior research on this issue), thereby minimizing the role of extraexperimental knowledge. Toward this end, rats served as subjects.

Another concern was to minimize the biological significance of the competing outcomes. Rescorla (1980b) suggested that biologically significant stimuli demand more attention than stimuli of low biological significance. Thus, if O1 were biologically significant (e.g., food or footshock), it might compete with O2 by distracting the subject from O2. Although perceptual distraction is a potential basis of outcome

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competition, we wanted to determine whether competition between outcomes could occur on the basis of associative competition rather than distraction. To minimize the possibility of competition between outcomes being due to distraction, we used outcomes that during training were of low biological significance. We achieved this by embedding the stimulus competition treatment in a sensory preconditioning procedure so that O2 was not made biologically significant until after the competitive training phase.

METHOD

Subjects

The subjects were 18 male (225–360 g) and 18 female (180–255 g) experimentally naive, Sprague-Dawley rats. They were allowed free access to food, but were limited to water for 10 min each day, in their home cages. Each subject was assigned to one of three groups (EXP, CON1, and CON2, *n*s = 12) counterbalanced for sex.

Apparatus

The 12 experimental chambers were 30.5 cm long by 26.0 cm wide by 26.7 cm high. A houselight provided dim illumination. The ceilings and side walls of the chambers consisted of clear Plexiglas, and the remaining walls were sheet metal. The floors were steel rods, which could deliver 5 s of 0.5-mA, constant-current footshock.

All chambers were equipped with speakers that could deliver a complex tone (3000 and 3200 Hz), which served as the potentially blocked outcome (O2), and a click train (six/second), which served as the cue (C); both were 8 dB above a 74-dB background. Also available was a white noise 6 dB above background, which served as the blocking outcome (O1). The noise was only 6 dB above background to minimize the noise overshadowing the tone, thereby maximizing sensitivity to blocking. All conditioned stimuli were 5 s in duration.

Near the floor in each chamber, there was a niche measuring 5.4 × 3.5 × 4.0 cm. A water-filled lick tube, present except during training, protruded 1.7 cm from the back. An infrared photobeam, 0.5 cm in front of the tube, monitored animals' licking.

Procedure

Table 1 summarizes the procedure. The daily sessions within each phase of treatment were 60 min in duration. On Day 1, subjects were acclimated to their experimental chambers. On Days 2 through 6, Phase 1 treatment occurred. For Group EXP, this treatment consisted of four daily C→O1 pairings, with the onset of O1 at the termination of C. Group CON1 received four daily unpaired exposures to C and to O1, with any two events separated by a minimum of 5 min. Group CON2 received equivalent exposure to the chambers. On Day 7, all subjects received Phase 2 treatment, which consisted of four C→O1O2 pairings, with the onset of the O1O2 simultaneous compound occurring at the termination of C. On Day 8 (Phase 3), all subjects received four pseudorandomly distributed O2→footshock pairings, with the onset of footshock occurring at the termination of O2. In order to restabilize baseline drinking, on Days 9 and 10, we returned the lick tubes to the chambers for daily reacclimation sessions during which no nominal stimuli occurred.

Testing occurred on Day 11. All animals were allowed to drink from the lick tubes for 5 cumulative seconds, at which time C was presented for 15 min. Thus, all subjects were drinking at the onset of C. The dependent variable was time to complete an additional 5 cumulative seconds of licking in the presence of C (i.e., duration of lick suppression). One subject each from Groups EXP and CON2 was eliminated for exhibiting unusual fear of the experimental context (i.e., taking more than 60 s to complete their first 5 cumulative seconds of licking prior to the onset of C).

Prior to statistical analysis, suppression data were converted to log (base 10) scores to better meet the assumptions of parametric analysis.

Table 1. *Experimental design*

Group	Phase 1	Phase 2	Phase 3	Test
EXP	C→O1	C→O1O2	O2→footshock	C
CON1	C/O1	C→O1O2	O2→footshock	C
CON2	Context only	C→O1O2	O2→footshock	C

Note. The cue (C) was a click train; the pretrained outcome (O1) was a white noise; the added outcome (O2) was a tone. → = followed by; / = unpaired.

RESULTS

Analysis of times to complete the first 5 cumulative seconds of drinking on the test day (i.e., before the onset of C) detected no differences between groups, $p > .10$. Thus, baseline drinking immediately prior to the onset of C was homogeneous. Figure 1 depicts suppression in the presence of C. Inspection reveals that Group EXP suppressed to

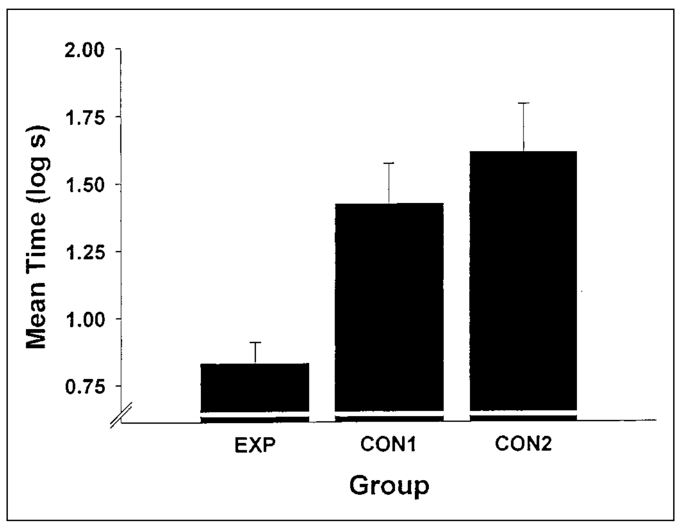

Fig. 1. Mean time in log seconds to drink for 5 cumulative seconds in the presence of the cue during the test phase. Error bars denote the standard error of means. Group EXP received daily C→O1 pairings in Phase 1, whereas Groups CON1 and CON2 did not. All groups received C→O1O2 pairings in Phase 2 and O2→footshock pairings in Phase 3.

C less than did Groups CON1 and CON2. A one-way analysis of variance detected differences among groups, $F(2, 31) = 8.62$, $p < .001$. Planned comparisons found that Group EXP suppressed less to C than did Groups CON1 and CON2, $Fs(1, 31) = 8.98$ and 15.01, respectively, $ps < .01$. These results indicate that C signaled O2 poorly in Group EXP relative to the control groups, thereby providing evidence of blocking of outcomes in Group EXP.

Group CON1 was equated with Group EXP in exposure to all stimuli, so the lower responding observed in Group EXP cannot be attributed to nonassociative differential habituation to C. Group CON2 was included to determine the degree to which the difference between Groups EXP and CON1 was due to low responding by Group EXP or high responding by Group CON1. The similar behavior of Groups CON2 and CON1 relative to the behavior of Group EXP indicates that the difference between Groups EXP and CON1 arose from low responding by Group EXP. This finding is consistent with our expectation that stimulus competition would lower responding in Group EXP relative to control groups.

DISCUSSION

The current experiment demonstrates competition—specifically, blocking—between outcomes with both predictive training and predictive testing procedures, thereby making the competing events unambiguous outcomes that in the framework of most existing theories of learning should not compete. Testing with Stimulus C constituted a predictive test, obviating interpretation in terms of diagnostic testing causing subjects to process O1 and O2 as cues, which might be expected to compete because competition between cues is well documented. Moreover, the study minimized possible roles of both prior knowledge (by our using novel stimuli and naive nonhuman subjects) and high biological significance of the competing outcomes at the time of training (by our using neutral outcomes).

The competition between outcomes observed in Group EXP depended on C→O1 pairings in Phase 1. Thus, the response impairment was blocking, rather than overshadowing. This distinction is important because overshadowing, but not blocking, is potentially subject to an interpretation in terms of one stimulus simply distracting subjects from the other stimulus. If distraction had contributed to the observed response impairment in Group EXP, similar impairment should have occurred in Groups CON1 and CON2 because they also experienced O1 and O2 in compound during Phase 2.

Although our explanation assumes that O1 and O2 competed as potential outcomes of C, there are two alternatives that should be considered. First, the contingency between C and O2 was weaker in Group EXP than in Group CON2 because Group EXP received exposure to C without O2 during Phase 1, whereas Group CON2 did not. This difference might explain the differential responding between these groups. However, this explanation also predicts that Groups EXP and CON1 should not have differed because they experienced the same contingency between C and O2; the data refute this prediction, and hence contingency interpretations of the present results.

Second, several researchers have suggested that the associative status of stimuli absent on a trial can be altered, provided that the presented stimuli reactivate their representations (i.e., retrospective revaluation). In this framework, the presentation of O2 during Phase 3 should have activated a representation of O1 (due to an O1-O2 within-compound association formed during Phase 2), with that representation possessing either positive associability (Holland, 1981, 1983; Holland & Forbes, 1982; Ward-Robinson & Hall, 1996) or negative associability (Dickinson & Burke, 1996; Van Hamme & Wasserman, 1994). If the activated representation of O1 possessed positive associability during Phase 3, O1 should have become an excitatory second-order conditioned stimulus for footshock during that phase. By contrast, if the reactivated representation of O1 possessed negative associability, O1 should have become a conditioned inhibitor for footshock. The models that assume activated representations of absent cues have positive associability make predictions contrary to our results. However, if the reactivated representation of O1 had negative associability during Phase 3, O1 should have become inhibitory (i.e., lost associative strength) with respect to the footshock in all three groups. Then at test, C should have activated representations of both O1 and O2, which should have summated associatively to produce a response in all three groups, with O1 inhibiting responding and O2 eliciting responding. Because the C-O1 association would be expected to be stronger in Group EXP than in either of the two control groups, the inhibitory potential of O1 should have been more evident in Group EXP. This could explain our results. However, until there is a principled rule that predicts when the associability of an activated representation of a physically absent stimulus will be negative as opposed to positive, explanations provided by these models will necessarily be post hoc. A clearer specification of the conditions in which reactivated representations of absent stimuli can change their associative status, and whether they will have negative or positive associability, is required before the retrospective revaluation framework can be viewed as providing a viable explanation of the present results.

Our results in the present study are consistent with some often-overlooked work by Rescorla (1980a, pp. 90–101). As part of a larger work concerned more with second-order conditioning than with stimulus competition, he reported research with pigeons in which he found single-phase blocking (i.e., with the C→O1 and C→O1O2 trials intermixed) between outcomes. For example, in his second experiment, he gave subjects C→O1O2 trials intermixed with C→O1 trials and observed evidence of an impaired C-O2 association relative to subjects that had not received C→O1 pairings. Thus, those studies might be viewed as demonstrating competition between outcomes using predictive training and testing. However, those experiments were not followed by additional demonstrations or theoretical elaboration beyond Rescorla's suggestion (1980a, p. 101) that O1 perceptually distracted subjects from O2, an interpretation that is in terms of perceptual processes and is perhaps less interesting than one based on associative competition. Notably, a distraction explanation of Rescorla's findings is particularly plausible because O1 had acquired biological significance because it had been paired with food before the C→O1O2 pairings in his study (i.e., second-order conditioning, in contrast to our sensory preconditioning design, which ensured that competing outcomes did not gain biological significance until after C→O1O2 training was complete). Perhaps for this reason or perhaps because an associative interpretation of competition between outcomes was contrary to most theories of learning, his results were largely ignored. However, the convergent findings of our experiment and Rescorla's study (despite different procedures, species, valences of unconditioned stimuli, and biological significance of outcomes during compound trials) suggest that competition between outcomes is a robust phenomenon.

The competition between outcomes observed in this study is problematic for contemporary theories of learning because such theories were designed to explain competition between cues (i.e., predictors of outcomes) and implicitly assume that outcomes will not compete. For example, Gluck and Bower (1988) and Rescorla and Wagner (1972) would anticipate that all three groups in our study would respond equally, and we interpret Wagner's (1981) SOP model to predict more responding by Group EXP than by either control group.

As prevailing contemporary theories do not anticipate competition between outcomes, one might ask what new sorts of theories might be developed to address the present observations. Based on the present data, we can only speculate. Two types of models that might explain our results come to mind. One is an extension of attentional models of learning (e.g., Mackintosh, 1975).[1] Possibly, an outcome that is already associated to the target cue commands more attention than the same outcome when it has not been previously associated. In this framework, activation during Phase 2 of the C-O1 association that was established in Phase 1 may have distracted the subject from O2. A second interpretation might be based on an extension of traditional interference theory, which has been reinvigorated in recent years by Bouton (e.g., 1993). Bouton has demonstrated that associations between a single cue and contradictory outcomes that are acquired in separate phases (e.g., excitatory training and extinction, latent inhibition and excitatory training, and excitatory conditioning and counterconditioning) can interfere with retrieval of one another. Possibly, interference between two associations to a common cue occurs even when the two outcomes are not contradictory. (However, facilitation of retrieval, rather than interference, might be expected if the two outcomes were themselves associated.) This position is attractive because it casts the behavioral phenomenon of blocking as a performance deficit rather than an acquisition deficit, a view that appears to apply to many (if not all) examples of blocking between cues (e.g., Balaz et al., 1982; Blaisdell, Gunther, & Miller, 1997). Thus, an extension of interference theory to situations in which two outcomes are trained in compound could possibly account for the present findings.

Despite these speculations, the most important implication of the present data is that the observed similarity of competition between outcomes and competition between cues (see Esmoris-Arranz et al., 1997) encourages serious consideration of models in which cues (i.e., antecedent events) and outcomes (i.e., subsequent events) are treated comparably, at least when they are equated for biological significance. Outside the domain of stimulus competition, we (Gunther, Miller, & Matute, 1997) have reached a similar conclusion.

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