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Cue competition effects in human causal learning

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Five experiments involving human causal learning were conducted to compare the cue competition effects known as blocking and unovershadowing, in proactive and retroactive instantiations. Experiment 1 demonstrated reliable proactive blocking and unovershadowing but only retroactive unovershadowing. Experiment 2 replicated the same pattern and showed that the retroactive unovershadowing that was observed was interfered with by a secondary memory task that had no demonstrable effect on either proactive unovershadowing or blocking. Experiments 3a, 3b, and 3c demonstrated that retroactive unovershadowing was accompanied by an inflated memory effect not accompanying proactive unovershadowing. The differential pattern of proactive versus retroactive cue competition effects is discussed in relationship to amenable associative and inferential processing possibilities.

Keywords: Cue competition; Blocking; Unovershadowing; Retrospective revaluation.

Cue competition effects are robust in human causal learning (HCL) as they are in Pavlovian conditioning. For example, when a compound of stimuli signals a reinforcing outcome (AX+), the added experience with one of the stimuli alone also signalling reinforcement (A+) can lead to a decrease in the response to X (so-called blocking), whereas experience with A alone without reinforcement (A−) can increase the response to X (so-called release from overshadowing, or unovershadowing), when compared to no A-alone experience (Dickinson, Shanks, & Evenden, 1984; Wagner, 1969).

A major difference in the particulars of the cue competition effects in the two situations is in their degree of dependence on the order of the experiences described. In Pavlovian conditioning, the aforementioned influence of A training, in conjunction with AX+, was initially seen to depend heavily upon the A trials preceding the AX+ trials (e.g., Kamin, 1968, 1969; but see Kaufman & Bolles, 1981), and the common associative theories developed to explain the effects (e.g., Mackintosh, 1975; Pearce, 1987; Pearce & Hall, 1980; Rescorla & Wagner, 1972; Wagner, 1981) have been built around this feature. In contrast, in HCL the influence of A experience is less dependent upon its order with respect to the AX+ trials (e.g., Shanks, 1985), and the theories offered to explain the effects in this circumstance have emphasized this fact (e.g., Cheng, 1997; Dickinson & Burke, 1996; Le Pelley & McLaren, 2001; Van Hamme & Wasserman, 1994).

Given the empirical and theoretical importance of this difference in the cue competition effects observed in HCL versus Pavlovian conditioning, it is understandable that considerable research had been devoted to the explicit comparison of the

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proactive influence (i.e., when A trials precede AX+) and the retroactive influence (i.e., when A trials follow AX+) of the cue competition in HCL. Some of what is known is the following.

First, although there are more robust retroactive cue competition effects in HCL than expected on the basis of Pavlovian conditioning observations and theories (e.g., Luque & Vadillo, 2011; Shanks, 1985), it has been most common to observe lesser retroactive than proactive effects (e.g., Chapman, 1991; Lovibond, Been, Mitchell, Bouton, & Frohardt, 2003; Melchers, Lachnit, & Shanks, 2004, 2006; Mitchell, Lovibond, Minard, & Lavis, 2006).

Second, the lesser retroactive versus proactive cue competition effects have been most evident in comparisons of retroactive versus proactive blocking rather than comparisons of retroactive versus proactive "unovershadowing." Although there is some evidence of retroactive blocking (e.g., Hannah, Crump, Allan, & Siegel, 2009; McCormack, Butterfill, Hoerl, & Burns, 2009; Vadillo, Castro Matute, & Wasserman, 2008; Wasserman & Castro, 2005), Chapman (1991) offered a direct comparison of retroactive versus proactive blocking to show the former to be less. Likewise, Lovibond et al. (2003) and Mitchell et al. (2006) showed that retroactive blocking was less robust than proactive blocking. There is no similar systematic evidence on whether retroactive unovershadowing is also less than proactive unovershadowing.

Third, there is some evidence that retroactive cue competition is more susceptible to concurrent processing interference than is proactive cue competition. It has been demonstrated that the proactive blocking effect can be diminished by the requirement of a concurrent task (De Houwer & Beckers, 2003; Experiment 2), so that such interference is not unique to retroactive cue competition. However, Aiken, Larkin, and Dickinson (2001) employing a design in which AX+ trials were contrasted with either A− or A+ trials, showed that the *differential* cue competition was more interfered with by a secondary task when the A alone trials followed, rather than preceded, the compound trials. Since this study did not include comparison conditions that could isolate separate blocking versus unovershadowing effects, it could not comment on whether the greater interference was a result of diminished retroactive versus proactive blocking, diminished retroactive versus proactive unovershadowing, or both.

Fourth, there is evidence that retroactive cue competition is dependent upon within-compound associations in a way that proactive cue competition is not. Two relevant studies are those by Dickinson and Burke (1996) and Larkin, Aitken, and Dickinson (1998), which manipulated the consistency of the stimulus pairings during compound training. Wasserman and Berglan (1998) and Wasserman and Castro (2005) further demonstrated that retroactive unovershadowing and retroactive blocking occurred only in participants who remembered which cues were trained in compound. Likewise, Melchers et al. (2004, 2006), Mitchell, Killedar, and Lovibond (2005), and Vandorpe, De Houwer, and Beckers (2007; Experiment 1) demonstrated that cue competition was correlated with memory of the compounds in the retroactive order, but not in the proactive order. In addition, Luque, Flores, and Vadillo (2013) reported that retroactive blocking and retroactive unovershadowing were facilitated when the compounds consisted of high preexperimental associates, as compared to low preexperimental associates, whereas proactive blocking and proactive unovershadowing were not similarly influenced.

The present series of experiments was designed to provide further comparisons of retroactive and proactive cue competition effects, with appropriate comparison conditions, to be able to speak to the separable blocking and unovershadowing influences that appear to be involved.

In Experiment 1, we conducted an independent assessment of proactive blocking, proactive unovershadowing, retroactive blocking, and retroactive unovershadowing, each in comparison to an appropriate null treatment. The results indicated less retroactive than proactive cue competition, due to diminished retroactive as compared to proactive blocking, without diminished retroactive as compared to proactive unovershadowing.

Experiment 2 replicated the results of Experiment 1 on proactive and retroactive cue competition effects, again showing retroactive unovershadowing without retroactive blocking, with the further assessment of the effects of a concurrent memory task. The concurrent processing task interfered with retroactive unovershadowing more than with either proactive unovershadowing or proactive blocking. Since retroactive blocking was not observed, the experiment was silent on whether it would be equally diminished.

Experiments 3a, 3b, and 3c provided evidence consistent with the supposition that the presentation of A− after AX+ in a retroactive unovershadowing design produced recall of the compound AX, a consequence that it did not have as a result of proactive unovershadowing training.

The conclusions are that while blocking and unovershadowing occur in proactive cue competition, retroactive cue competition is more restricted to unovershadowing, and that the retroactive unovershadowing that does occur is more susceptible to concurrent interference and more involving of memory retrieval than is forward unovershadowing. The implications for theoretical interpretation are addressed in the General Discussion.

EXPERIMENT 1

Whereas there is considerable evidence that retroactive cue competition effects are less robust than proactive effects, it is less clear whether this difference is peculiar to retroactive blocking or is equally true of retroactive unovershadowing. Experiment 1 was designed to compare proactive and retroactive blocking, as well as proactive and retroactive unovershadowing when separately contrasted with appropriate control conditions.

The experimental situation was similar to that of Van Hamme and Wasserman (1994) and Castro and Wasserman (2007) and consisted of asking participants to suppose they are allergists who have to learn which foods produce an allergic reaction in a fictitious patient, Mr. X. Participants were presented with a sequence of slides in which a Mr. X was reported to have eaten a particular food or pair of foods and then to have experienced an allergic reaction or not. After viewing the experiences of Mr. X, participants were asked to rate the extent to which the foods of experimental interest caused an allergic response.

The experiment involved four different training conditions: Proactive blocking, retroactive blocking, proactive unovershadowing, and retroactive unovershadowing. One group of participants was trained with the proactive and retroactive blocking conditions, in counterbalanced orders, and another with the proactive and retroactive unovershadowing conditions.

Table 1 summarizes the particulars of training and testing. In the proactive blocking condition, the participants received six trials in which food A was always paired with an allergic reaction (A+), and food I was not (I−). Subsequently, there were two compounds of interest, AB+, which had been preceded by the reinforcement of one of the elements, and CD+, which was not so preceded. Some buffer trials (IJ− and KL−) were included to force participants to discriminate between reinforced and nonreinforced compounds. In test, the focus was on the participant's final evaluation of the comparable untreated elements B versus D. In order to reduce variability, rather than relying in a single test of each target cue, participants were asked to rate B and D, each alone, and in compound with the previously nonreinforced cues J and L. The case of retroactive blocking involved the same experiences, but with the element training (E+ M−) and compound training (EF+, GH+, MN−, and OP−) in the opposite order (with tests of the target cue, F, and the control cue, H, alone and in compounds with the previously nonreinforced N and P). All subjects were evaluated on both comparisons, in balanced orders.

The second group received the unovershadowing conditions. As seen in Table 1, in the proactive unovershadowing condition one of the compounds (AB+) was preceded by nonreinforced trials with one of its components (A−), whereas the other compound (CD+) was not so preceded. The retroactive unovershadowing condition involved the same experiences, but in the opposite order—that is, training with EF+, GH+, MN−, and OP− followed by E− and M+. The testing with

Table 1. *Design of Experiments 1 and 2*

	Proactive			*Retroactive*		
Group	*Phase 1*	*Phase 2*	*Test*	*Phase 1*	*Phase 2*	*Test*
Blocking group	A+ (6) I− (6)	AB+ (6) CD+ (6) IJ− (6) KL− (6)	B, BJ, BL, D, DJ, DL, J, L	EF+ (6) GH+ (6) MN− (6) OP− (6)	E+ (6) M− (6)	F, FN, FP, H, HN, HP, N, P
Unovershadowing group	A− (6) I+ (6)	AB+ (6) CD+ (6) IJ−(6) KL− (6)	B, BJ, BL, D, DJ, DL, J, L	EF+ (6) GH+ (6) MN− (6) OP− (6)	E− (6) M+ (6)	F, FN, FP, H, HN, HP, N, P

Note: Letters A–P represent different foods that could be followed (+) or not followed (−) by an allergic reaction in a hypothetical patient. The numbers in parenthesis indicate the frequency of each trial type.

B versus D in the proactive case and F versus H in the retroactive case was identical to that in the blocking conditions.

Method

Participants

A total of 32 undergraduate psychology students at Yale University participated in the experiment for course credit. They were tested individually and had no previous experience in similar research. The participants were randomly assigned to a "blocking" group ($n = 16$) or an "unovershadowing" group ($n = 16$).

Materials

The stimuli were presented and data collected with a personal computer connected to a 15-inch colour screen and programmed with the E-prime software (Version 1.1; Psychology Software Tools, Inc., Pittsburgh, PA). The stimuli were the pictures of 16 different foods (apple, avocado, banana, broccoli, carrots, coffee, eggs, grapes, ice-cream, lemon, mushroom, meat, peppers, strawberry, toast, and tomato).

Procedure

The major features of the task and the programming environment were patterned after Castro and Wasserman (2007). The full instructions, which are presented in the Supplemental Material, asked the participants to learn, through information presented on the computer screen, which foods or combinations of foods caused allergic reactions to a fictitious patient.

The proper task began with a block of 36 training trials presented to the participant. At the beginning of each trial, the sentence "Mr. X ate" appeared on the top-left portion of the screen simultaneously with the picture of a food or a pair of foods. The presentation of the stimuli was followed 2 s later by the phrase, "Do you think Mr. X will have an allergic reaction?", and the participants were required to answer "yes" or "no" by clicking the respective buttons. After the participant entered a response, feedback was provided on the bottom of the screen for 3 s. The feedback consisted of the words "CORRECT" or "INCORRECT", in yellow, over the sentence "Allergic reaction", in red, for the reinforced (+) trials, or "No allergic reaction", in green, for the nonreinforced (−) trials. The top panel of Figure 1 exemplifies the presentation of a pair of foods and the middle panel the modification that would occur if the subjects responded that the pair was followed by an allergic reaction, and that this was, in fact, the programmed relationship. The trial terminated with a new screen of 1-s duration reporting the cumulative percentage of correct responses.

Upon completion of the first block of 36 training trials, the participants were presented with the following message: "*Now we would like you to rate the likelihood that each food or each combination of foods causes Mr. X to have an allergic reaction*". During this phase, the picture of a food or pair of foods appeared in the top centre of the screen, and the participants were asked to rate "*to what extent does*

Figure 1. *Example of the screens presented to the participants during training (top and middle panels) and testing (bottom panel) in Experiment 1.*

(do) this (these) food (foods) cause an allergic reaction in Mr. X?" The participant entered his or her rating by clicking over one number from 0 to 100 in an 11-point scale. The bottom panel of Figure 1 depicts an example of one test trial. The participants were required to rate eight foods or pairs of foods.

Next, the participants were presented with the following sentence: "You have finished the first part of the experiment. Please take a few moments to relax. The instructions for the second part are the same as in the beginning. They will be displayed again when you continue." Then, the instructions were repeated, and the participants received another block of 36 training trials and eight testing trials, involving an entirely new set of foods.

For every subject, one block of 36 training trials and eight testing trials represented a proactive condition, and the other block represented a retroactive condition. For half of the participants in each group the proactive condition was presented first, and for the other half the retroactive condition was presented first.

The assignment of specific foods to the conditions A–P was partially counterbalanced across participants of each group by means of their different allocation in one of four subgroups, each with a different assignment of foods as A–P. This counterbalancing ensured that the critical compounds AB, CD, EF, and GH were composed equally often by the same pairs of foods. The position (right vs. left) of the pictures of foods forming a compound was equated across the experiment. That is, in half of the trials the stimuli were presented in one position (e.g., EF), and in the other the relative position was reversed (e.g., FE). The order of testing of the various elements and compounds was independently determined for each participant by a random order generator.

The experiment was run in two replications, each consisting of 16 participants distinguished by assignment to one of the two cue competition contingencies, blocking or unovershadowing, and within each such group to one of the two orders of experience with the proactive and retroactive conditions and the four different food assignments.

Statistical analysis

The blocking and unovershadowing effects were examined by computing the mean causal values assigned by each subject to the test trials involving the target cue (i.e., B, BJ, and BL in the proactive order and F, FN, and FP in the retroactive order) and to the test trials involving the control cue (i.e., D, DJ, and DL in the proactive order and H, HN, and HP in the retroactive order). Following Vandorpe and De Houwer (2005, 2006) the dependent variable was examined through a "cue competition index". In the case of blocking, the index was computed as the mean causal rating for compounds involving the control cues (D/H) minus the mean causal ratings for compounds involving the target cues (B/F). In the case of unovershadowing, the index was computed as the mean causal rating for compounds involving the target cues (B/F) minus the mean causal ratings for compounds involving the control cues (D/H.) The statistical reliability of the effects was assessed by a 2 (contingency: blocking vs. unovershadowing) × 2 (order: proactive vs. retroactive) × 2 (replications) mixed-design analysis of variance (ANOVA).

Results and discussion

Figure 2 presents the mean causal ratings to the target and control cues in the blocking (top plots) and unovershadowing (bottom plots) groups for each of the proactive (left-hand plots) and retroactive (right-hand plots) orders. The top plots indicate that there was a noticeable proactive blocking effect in the form of lower ratings to the target cue than to the control cue (left-hand plot), but no evident retroactive blocking in similar comparison (right-hand plot). Accordingly, the cue competition index for the proactive blocking condition ($M = 22.081$, $SEM = 6.380$) was substantially higher than the index for the retroactive blocking condition ($M = -0.225$, $SEM = 7.407$). Conversely, the bottom plots indicate that there was a clear unovershadowing effect in the form of an enhancement of responding to the target cue as compared to the control cue in both the proactive condition (left-hand plot) and the retroactive condition (right-hand plot). Consequently, the cue competition index was similar and substantial in both the forward ($M = 18.969$, $SEM = 4.735$) and backward ($M = 25.631$, $SEM = 7.767$) unovershadowing conditions.

The statistical analyses using the cue competition index confirmed that blocking and unovershadowing were differentially dependent on the order of training: The ANOVA revealed a reliable Contingency × Order interaction, $F(1, 28) = 4.419$, $p = .049$, $\eta_p^2 = .131$. Subsequent comparisons indicated that the difference between proactive and retroactive blocking was reliable, $t(30) = 2.237$, $p = .033$, Cohen's $d = 0.817$, while the difference between proactive and retroactive unovershadowing was not reliable, $t(30) = 0.668$, $p = .510$, Cohen's $d = 0.244$. Likewise, the difference in the magnitude of the blocking and unovershadowing was reliable in the retroactive case, $t(30) = 2.385$; $p = .024$, Cohen's $d = 0.871$, but not in the proactive case, $t(30) = 0.382$; $p = .706$, Cohen's $d = 0.139$. Furthermore, the cue competition index was significantly greater than zero in the case of proactive blocking, $t(15) = 3.461$, $p = .03$, Cohen's $d = 1.787$, proactive unovershadowing, $t(15) = 4.006$, $p = .001$, Cohen's $d = 2.069$, and retroactive unovershadowing, $t(15) = 3.300$, $p = .005$, Cohen's $d = 1.704$, but not in the case of retroactive blocking, $t(15) = -0.30$, $p = .976$, Cohen's $d = 0.155$.

In summary, Experiment 1 demonstrated both proactive blocking and proactive unovershadowing, whereas, in contrast, only retroactive unovershadowing was observed. These results are in agreement with several other studies that have shown that whereas the incremental "retroactive unovershadowing" resulting from A− was substantial and reliable, any decremental "retroactive blocking" resulting from A+ was not observed (Beckers, Vandorpe, Debeys, De Houwer, 2009; Larkin et al., 1998; Le Pelley & McLaren, 2001). Several additional studies (Chapman, 1991; Lovibond et al., 2003; Mitchell et al., 2006) have reported retroactive blocking, but have been consistent with the observation of Experiment 1 that it was less robust than was proactive blocking.

In contrast to the available evidence of diminished retroactive as compared to proactive blocking, Experiment 1 found relatively equivalent retroactive and proactive unovershadowing. This suggests that the observation that there is less retroactive

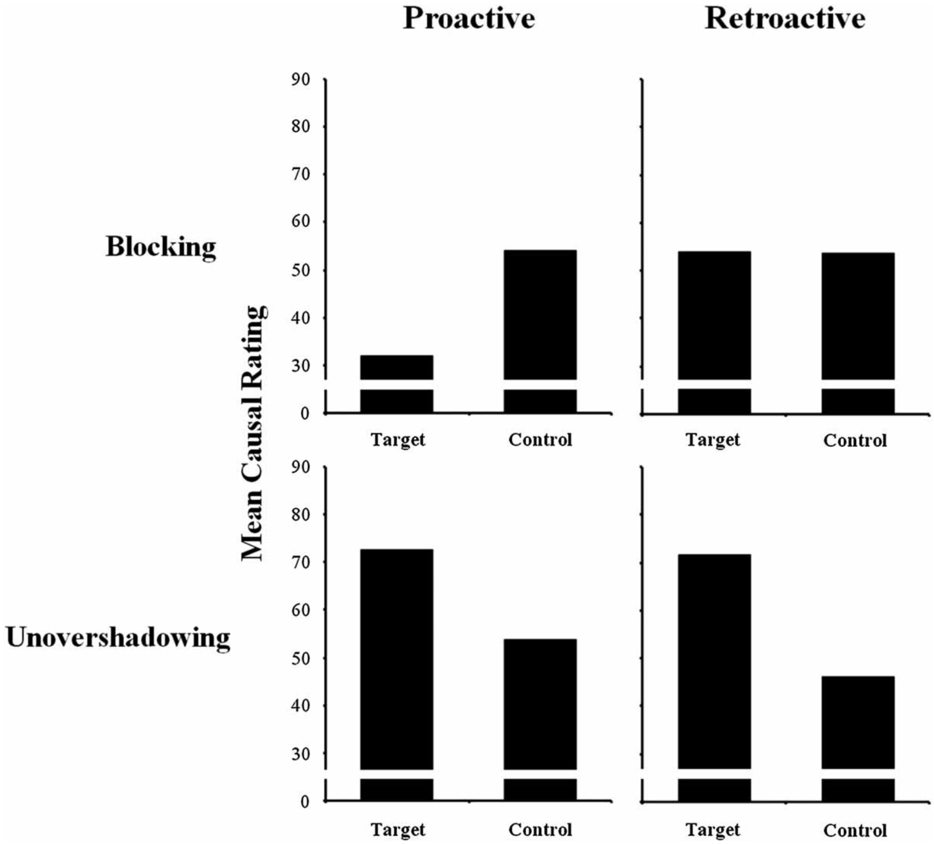

Figure 2. *Mean causal ratings in trials involving the target and control cues during testing in Experiment 1. The top plots depict the data of the proactive (left-hand plot) and retroactive (right-hand plot) blocking comparisons and the bottom plots the data of the proactive (left-hand plot) and retroactive (right-hand plot) unovershadowing comparisons. Regarding statistical analyses, see the text for means and standard errors of the means of the cue competition indexes.*

than proactive cue competition effect, in designs in which blocking and unovershadowing are compared with each other, rather than to appropriate controls (e.g., Melchers et al., 2004, 2006), could be due to the fragility of retroactive blocking and less attributable to diminished retroactive than to proactive unovershadowing.

EXPERIMENT 2

There is some evidence that retroactive cue competition effects are more susceptible to being interfered with by competing task demands than are similar proactive effects (Aitken, Larkin, & Dickinson, 2001). However, the available findings, like the aforementioned studies of Melchers et al. (2004, 2006), have involved comparisons of blocking and unovershadowing treatments and have not provided assessments of whether the separate effects of either blocking or unovershadowing (or both) are more susceptible to interference in a retroactive than in a proactive sequence. Experiment 2 involved a replication of the design of Experiment 1 with and without a companion competing task. It was designed to investigate the effects of a concurrent memory task on proactive and retroactive unovershadowing, both of which were substantial in Experiment 1, and potentially allowed similar assessments under conditions of proactive and retroactive blocking, although retroactive blocking was not observed in Experiment 1.

In Experiment 2, some participants were asked to remember a three-digit number and report it upon demand, after which the number was replaced by another to be remembered, and reported, in continuous fashion. Otherwise the comparisons of proactive and retroactive blocking and unovershadowing were exactly like those described in Experiment 1.

Method

Participants

A total of 32 undergraduate psychology students at Yale University participated in the experiment for course credit. They were tested individually and had no previous experience in similar research. The participants were randomly assigned to one of four groups ($n = 8$): blocking load, blocking no load, unovershadowing load, unovershadowing no load.

Materials and procedure

The contingencies involved in the causal learning task of Experiment 2 were identical to those of Experiment 1, as summarized in Table 1. That is, in one condition the participants were trained and tested on proactive and retroactive blocking in counterbalanced orders, and in another condition they were trained in proactive and retroactive unovershadowing in similar counterbalanced orders. The critical difference was the introduction in each condition of a "load" group, in which the participants performed a digit-remembering task concurrently with the causal leaning task, in addition to a no-load group equivalent to that in Experiment 1.

At the beginning of the experiment, participants in the load groups were introduced to the digit remembering task as described in the Supplemental Material, which was followed by the instructions for the causal learning task, which were identical to those of Experiment 1.

At the beginning of each trial, the computer presented a screen saying "*Remember the following number:*" Then a three-digit number selected from a list of randomized numbers was added to the screen for 1 s. After 3 s of blank screen, the food for that trial was presented, and the participant made a prediction and received feedback in a manner identical to that in Experiment 1. Immediately thereafter, a new screen appeared with the text "*Type the number you were remembering and press RETURN to move to the next trial*", and the participant had an opportunity to report the three-digit number. Participants in the load groups also were asked to perform the digit remember task during testing. Apart from this, the procedure for the load group and that for the respective no load group was identical.

Statistical analysis

As in Experiment 1, the blocking and unovershadowing effects were examined by computing the mean values assigned by each subject to the test trials involving the target cue (i.e., B, BJ, and BL in the proactive orders and F, FN, and FP in the retroactive orders) versus the test trials involving the control cue (i.e., D, DJ, and DL in the proactive orders and H, HN, and HP in the retroactive orders). The dependent variable for the statistical analyses was the same cue competition index, based upon the difference between the response to the target and control cues, as that used in Experiment 1. The statistical reliability of the blocking and unovershadowing effects was assessed separately by a 2 (order: proactive vs. retroactive) × 2 (load condition: no load vs. load) mixed-design ANOVA.

Results and discussion

Blocking effects

The main results of the blocking contingency are depicted in Figure 3. The top plots indicated that in the no-load groups there was an observed proactive blocking effect, in the form of less responding to the test compounds involving the target cue than to the test compounds involving the control cue, but no retroactive blocking effect, replicating the findings concerning the similar comparisons in Experiment 1. Likewise, the bottom plots show that in the load groups the comparisons of

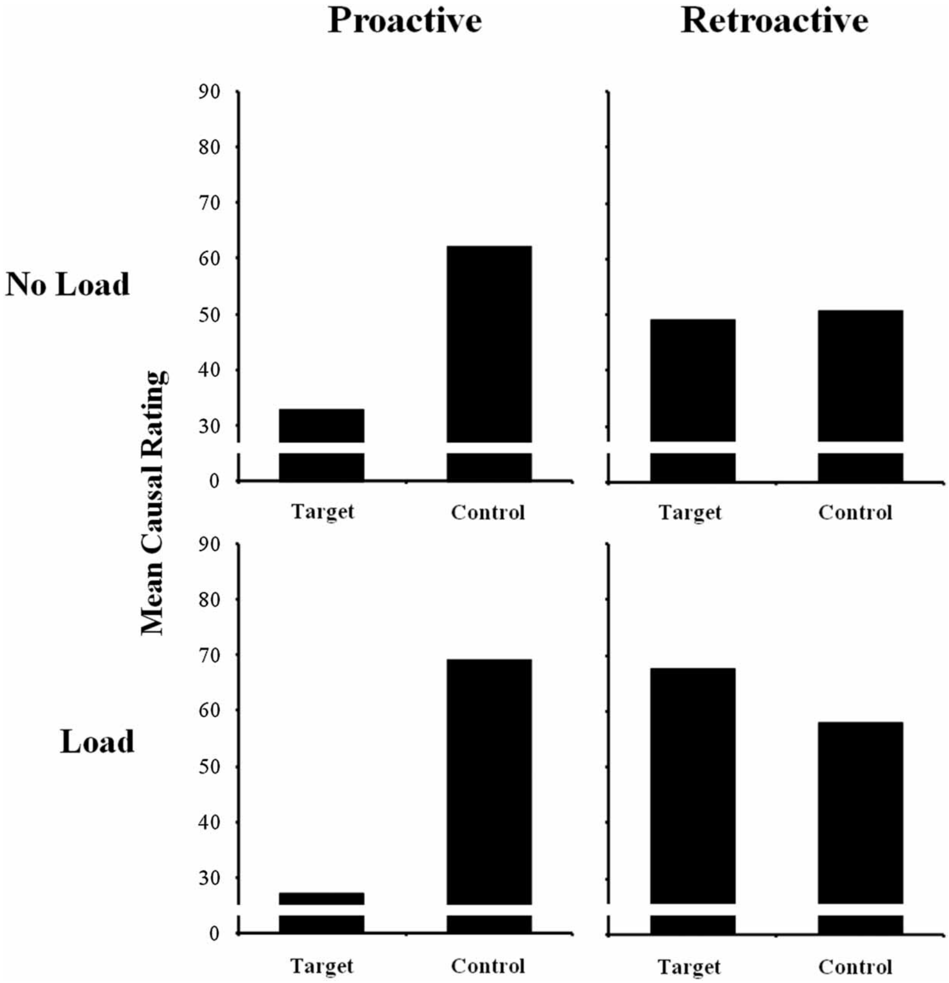

Figure 3. *Mean causal ratings in trials involving the target and control cues during testing in the blocking group of Experiment 2. The top plots depict the data of the proactive (left-hand plot) and retroactive (right-hand plot) blocking comparisons for the "no cognitive load" group and the bottom plots the corresponding data for the "cognitive load" group. Regarding statistical analyses, see the text for means and standard errors of the means of the cue competition indexes.*

responding to the target and control stimuli yielded a similar proactive blocking effect and absence of retroactive blocking effect. These observations were confirmed by the statistical analyses with the cue competition index, which showed a reliable main effect of order, $F(1, 14) = 10.133$, $p = .007$, $\eta_p^2 = .420$, and no reliable effect of load, $F(1, 14) < 1$, nor Load × Order interaction, $F(1, 14) < 1$. The main effect of order and the absence of Load × Order interaction suggest that the presence of proactive blocking and the absence of retroactive blocking that was observed in Experiment 1 are relatively insensitive to the load manipulation. The essential finding was that the cue competition index was reliably greater than zero in the proactive order ($M = 35.625$, $SEM = 9.020$), $t(15) = 3.950$, $p = .001$, Cohen's $d = 2.039$, but not in the retroactive order ($M = 3.958$, $SEM = 6.953$), $t(15) = -0.569$, $p = .578$, Cohen's $d = 0.298$.

Unovershadowing effects

The more interesting findings involving the unovershadowing effects are depicted in Figure 4. The top plots indicate that, as in Experiment 1, with no cognitive load, there was an evident unovershadowing effect in the form of greater responding to the target than to the control cues in both the proactive and retroactive conditions. In comparison, the bottom plots show that with the memory load there was still substantial proactive unovershadowing, with greater responding to the target than to the control cues, but no apparent retroactive unovershadowing. The statistical analysis with the cue competition index indicated a reliable Load × Order interaction, $F(1, 14) = 13.719$, $p = .002$, $\eta_p^2 = .495$. Given this interaction, further analysis revealed that (as in Experiment 1) there was no reliable difference between the cue competition index of the proactive and retroactive conditions in the no load group, $t(14) = 0.333$, $p = .774$, Cohen's $d = 0.178$. In contrast, in the load group the cue competition index was reliably greater in the proactive condition

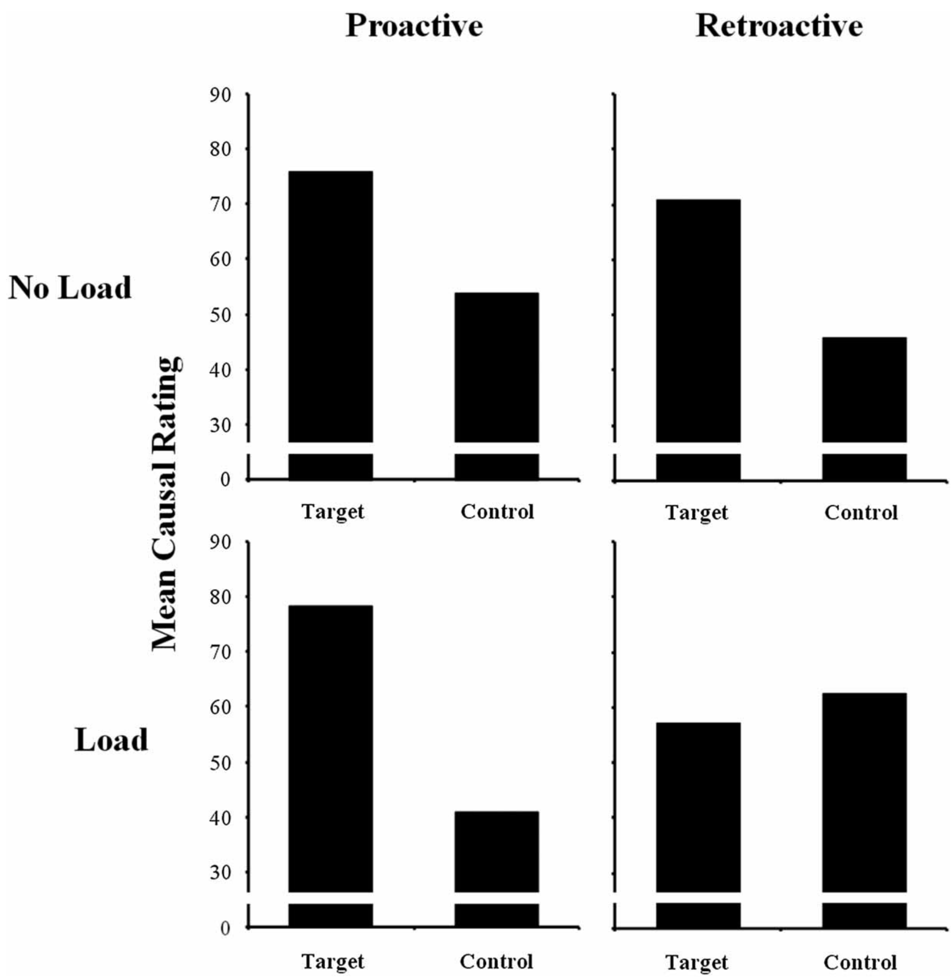

Figure 4. *Mean causal ratings in trials involving the target and control cues during testing in the unovershadowing group of Experiment 2. The top plots depict the data of the proactive (left-hand plot) and retroactive (right-hand plot) unovershadowing comparisons for the "no cognitive load" group and the bottom plots the corresponding data for the "cognitive load" group. Regarding statistical analyses, see the text for means and standard errors of the means of the cue competition indexes.*

than in the retroactive condition, $t(14) = 4.905$, $p < .001$, Cohen's $d = 2.622$. Furthermore, the cue competition index was reliably greater than zero in the proactive no-load ($M = 22.085$, $SEM = 7.069$), $t(7) = 3.124$, $p = .017$, Cohen's $d = 2.362$, retroactive no-load ($M = 24.999$, $SEM = 5.774$), $t(7) = 4.330$, $p = .03$, Cohen's $d = 3.273$, and proactive load ($M = 37.501$, $SEM = 12.372$), $t(7) = 3.031$, $p = .019$, Cohen's $d = 2.291$, conditions, but did not differ reliably from zero in the retroactive load condition ($M = -5.418$, $SEM = 13.815$), $t(7) = -0.392$, $p = .707$, Cohen's $d = 0.296$.

In conclusion, whereas proactive unovershadowing and proactive blocking were not degraded by the concurrent memory task employed in Experiment 2, the retroactive unovershadowing that was observed in the no-load conditions in Experiment 1 and Experiment 2 was not observed in the load condition of Experiment 2. Since there have been some reports of cognitive interference with proactive cue competition (De Houwer & Beckers, 2003; Liu & Luhmann, 2013), perhaps the most secure conclusion at this point is that proactive effects appear to be less susceptible to interference than retroactive effects. The present data are consistent with the findings of Aitken, Larkin, and Dickinson (2001) who found that a concurrent secondary task that did not interfere with proactive blocking did interfere with a nonspecific retroactive cue competition effect. Since Experiment 2 provided independent assessments of proactive and retroactive blocking and unovershadowing, the data allow the more specific conclusion that retroactive unovershadowing appears to be more susceptible to interference than is the corresponding proactive unovershadowing.

EXPERIMENT 3A

There is substantial evidence that retroactive cue competition effects are more dependent upon the memorial relationship between the manipulated cue and the compound in which it was trained than are corresponding proactive effects (e.g., Melchers et al., 2004, 2006; Mitchell et al., 2005; Vandorpe et al., 2007). Experiment 3a provides further evidence of this fact, via a variation on an inflated-memory assessment employed by Johnson and her colleagues in which participants are asked to judge the frequency of occurrence of items that have previously been presented different numbers of times, but also imagined different numbers of times (e.g., Johnson, Raye, Wang, & Taylor, 1979, Johnson, Taylor, & Raye, 1977). The striking result of Johnson's studies is that the judgements of the frequency of occurrence of items increased not only as a function of the number of presentations of the item but also as a function of the number of times that the item was provoked into memory by a retrieval cue. Based on these findings, we reasoned that if the retroactive unovershadowing effect observed in Experiments 1 and 2 was dependent upon the unovershadowing stimulus, E, provoking a retrieval of the memory of the compound, EF, in which the target stimulus, F, previously occurred, it might be expected that the participants would show an inflated judgement of the frequency of occurrence of the compound, EF, relative to an equally presented comparison compound.

Thus, Experiment 3a employed a retroactive unovershadowing treatment as in Experiments 1 and 2, but also required posttraining judgements of the frequency with which different compounds occurred. To evaluate whether subjects retrieved the memory of the compound involved in retroactive unovershadowing, Experiment 3a repeated the basic procedure, in which the two compounds of interest (EF+ and GH+) occurred six times each, but in the company of other compounds, which occurred from two to 10 times (see Table 2), followed by a phase of training in which E− was presented six times alone. After training, participants were asked not only to judge how likely the target and control elements, F and H, were to cause an allergic reaction, but also how frequently the various compounds containing them and other stimuli had occurred.

Method

Participants

A total of 16 undergraduate psychology students at Yale University participated in the experiment for

Table 2. *Designs of Experiments 3a, 3b, and 3c*

	Training		*Test*	
Experiment	*Phase 1*	*Phase 2*	*Frequency ratings*	*Causal ratings*
Experiment 3a Retroactive unovershadowing	EF+ (6) GH+ (6) AB+ (2) O+ (3) P− (3) IJ−(4) MN− (6) KL−(8) CD+ (10)	E− (6) M+ (6)	EF, GH, AB, IJ, MN, KL, CD	F, FN, FP, H, HN, HP, N, P
Experiment 3b Proactive unovershadowing	E− (6) M+ (6)	EF+ (6) GH+ (6) AB+(2) O+ (3) P−(3) IJ−(4) MN−(6) KL−(8) CD+ (10)	EF, GH, AB, IJ, MN, KL, CD	F, FN, FP, H, HN, HP, N, P
Experiment 3c Retroactive & proactive unovershadowing	EF+ (6) GH+ (6) A− (6) O+ (6) MN− (2) IJ− (10)	E− (6) M+ (6) AB+ (6) CD+ (6) OP− (2) KL− (10)	EF, GH, AB, CD, MN, OP, IJ, KL	F, H, B, D, N, P

Note: Letters A–P represent different foods that could be followed (+) or not followed (−) by an allergic reaction in a hypothetical patient. The numbers in parentheses indicate the frequency of each trial type.

course credit. They were tested individually and had no previous experience in similar research.

Materials and procedure

The materials and procedure were essentially the same as those for the retroactive unovershadowing condition of Experiment 1. As seen in Table 2, the procedure of Phase 1 involved training with two reinforced compounds, EF+ and GH+, and one nonreinforced compound, MN-, which were experienced six times, as in Experiment 1, in the company of several other compounds that were experienced fewer or more times, AB+ (2 times), IJ− (4 times), KL− (8 times), and CD+ (10 times), as well as two single stimuli, O+ and P−, each presented three times. The second phase was identical to Experiment 1 with six trials of each of E− and M+. The most critical difference was the addition of a "frequency judgement test" interposed between training and the regular causal judgement test. The instructions for the frequency judgement test were as follows: "*Now we would like you to provide us with some additional information about what Mr. X ate during his allergy tests. Mr. X did not have the chance to eat all of the foods in equal combination with each other. Please, indicate how often you observed Mr. X to have eaten the following combinations*". Then the picture of a pair of foods appeared in the top centre of the screen and the participants were asked to rate "*How many times did Mr. X eat these foods together?*" The participant entered his or her rating by clicking over one number from 0 to 10 in an 11-point scale. The participants were required to rate the compound EF (which was the target compound) and GH (which was the equally occurring comparison) as well as the compounds AB, IJ, KL, and CD, in random orders. Upon completion of the frequency judgement test, the participants received exactly the same causal judgements test as that of Experiment 1.

The experiment was conducted in four identical replications of four participants each. The four participants in each replication received the same four balanced food assignments of cues A–P as in Experiment 1.

Statistical analysis

The unovershadowing effect was evaluated as in Experiments 1 and 2 by computing a cue competition index based on the differential causal ratings assigned by the participants to the target and control cues, F and H, respectively, and statistically analysed by a one-sample *t*-test. In order to examine whether the participants were sensitive to the different frequencies with which the different compounds were presented during training, a trend analysis was conducted on the judged frequencies of occurrence of the control compounds that were experienced 2 (AB), 4 (IJ), 6 (GH), 8 (KL), and 10 (CD) times. The frequency effect of special interest was evaluated through an "inflated frequency index", computed as the judged frequency to compound EF minus the judged frequency to compound GH, and was analysed by a one-sample *t*-test.

Results and discussion

The left-hand plot of Figure 5 depicts the mean casual ratings to the target and control cues in testing. There was a retroactive unovershadowing effect, as in Experiments 1 and 2, in the form of greater responding to the target than to the control cue. This was confirmed by the observation that the cue competition index was reliably greater than zero ($M = 36.875$, $SEM = 6.875$), $t(15) = 5.364$, $p < .001$, Cohen's $d = 2.780$.

The important additional observations are depicted in the right-hand plot of Figure 5. As may be seen, the participants were appropriately sensitive to the frequency with which the compounds had occurred. Specifically, the participants assigned a monotonically increasing judged frequency of occurrence to the control compounds, as their actual frequency increased from 2 to 10, which was confirmed by the reliability of the linear trend, $F(1, 12) = 74.983$, $p < .05$. In contrast, the compound in which the target cue was included (EF) was judged to have occurred with a greater frequency than the equally experienced control compound, GH, and numerically greater than the next more frequently occurring control compound. The inflated frequency index was significantly different from zero ($M = 1.250$, $SEM = 0.536$), $t(15) = 2.331$, $p = .034$, Cohen's $d = 1.204$.

These results appear to present a novel indication of the retroactive influence of the E- training on the memory of the previously experienced EF+ compound. The compound, in addition to

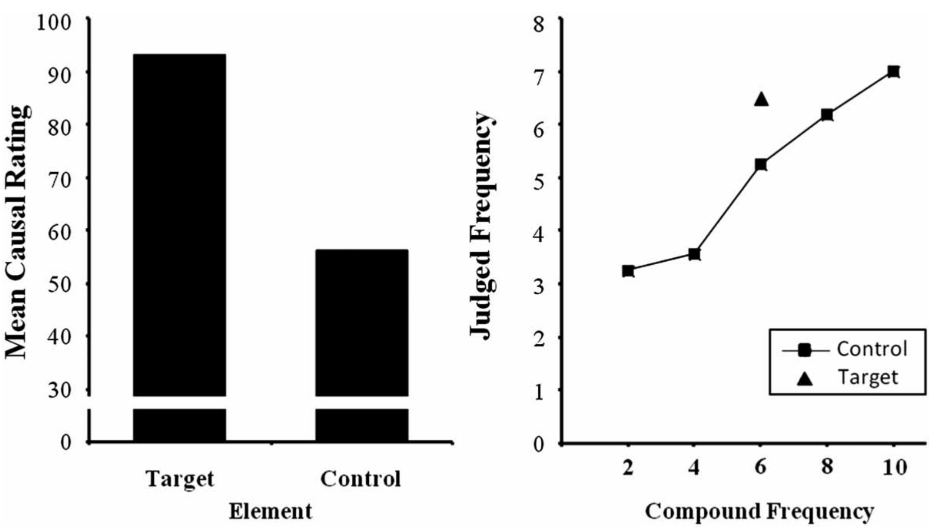

Figure 5. *The left-hand plot presents the mean causal ratings to the target and control cues during the causal judgement test of Experiment 3a. The right-hand plot presents the mean judged frequency of occurrence of target and control compounds as a function of their actual frequency of occurrence in Experiment 3a. Regarding statistical analyses, see the text for means and standard errors of the means of the cue competition and inflated frequency indexes.*

containing a component, F, of increased causal value, appeared to have an inflated frequency of occurrence. It is quite possible, however, that the inflated judged frequency of EF was due to a conflating of the remembered number of occurrences of the compound and the subsequent occurrences of the component, E. The participants may have estimated how frequently food resembling E and EF occurred, not just EF. Experiment 3b was designed to discriminate between these alternatives.

EXPERIMENT 3B

If the subjects in Experiment 3a judged the target compound EF to have occurred more frequently than the control compound GH, because they conflated the number of EF+ and the number of E− occasions, one would expect the same error of judgement if the E− occasions occurred prior to the EF occasions, as well as after the EF occasions. Alternatively, if the subjects in Experiment 3a judged the target compound, EF, to have occurred more frequently, because the E− occasions recalled the previously experienced EF compound into memory, a similar inflated memory effect should be precluded if EF is not experienced, and retrievable, until after E− is presented. To test these alternatives, Experiment 3b was designed exactly like Experiment 3a (see Table 2), but to involve a proactive, rather than a retroactive, overshadowing, comparison, with E− experience prior to that of EF+.

Method

Participants

A total of 16 undergraduate psychology students at Yale University participated in the experiment for course credit. They were tested individually and had no previous experience in similar research.

Materials and procedure

All of the materials, procedure, and statistical analysis were identical to those of Experiment 3a, except that the two training phases involving E− and EF+ were reversed, so as to emulate a proactive unovershadowing condition (see Table 2).

Results and discussion

The left-hand plot of Figure 6 depicts the mean casual ratings to the target and control cues in testing. In agreement with Experiments 1 and 2, there was a substantial proactive unovershadowing effect in the form of more responding to the target than to the control cue. Statistical comparison showed again that the cue competition index was reliably different from zero ($M = 24.375$, $SEM = 7.410$), $t(15) = 3.263$, $p = .005$, Cohen's $d = 1.685$.

The data from the frequency test depicted in the right-hand plot of Figure 6 indicate that, as in Experiment 3a, the judged frequency of the control compounds increased monotonically with their programmed frequency of occurrence, which was confirmed by a reliable linear trend, $F(1, 12) = 142.116$, $p < .05$. Although there was somewhat greater frequency judged to the EF compound than to the GH compound, unlike Experiment 3a, the inflated frequency index did not differ significantly from zero ($M = 0.375$, $SEM = 0.427$), $t(15) = 0.878$, $p = .394$, Cohen's $d = 0.453$.

The finding of a reliable inflated memory effect in Experiment 3a, but not in Experiment 3b, is consistent with the supposition that retroactive unovershadowing and proactive unovershadowing differ in that the former, but not the latter, is accompanied by memorial retrieval of the compound by its manipulated component.

EXPERIMENT 3C

Although the results of Experiments 3a and 3b are congruent with the hypothesis of differential memory of the target compound in the retroactive as compared with the proactive unovershadowing condition, they would be more convincing if the differential frequency judgement were observed after direct comparison of the proactive and retroactive conditions in the same experiment. Therefore, in Experiment 3c we examine the

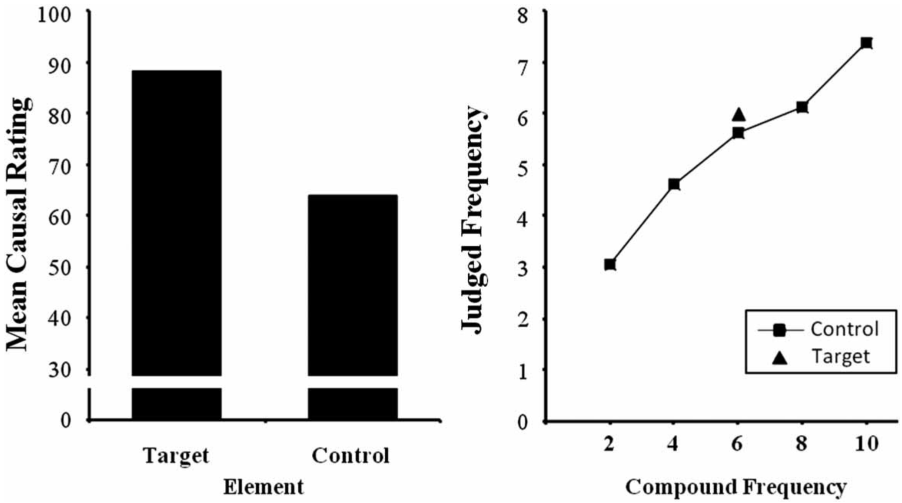

Figure 6. *The left-hand plot presents the mean causal ratings to the target and control cues during the causal judgement test of Experiment 3b. The right-hand plot presents the mean judged frequency of occurrence of target and control compounds as a function of their actual frequency of occurrence in Experiment 3b. Regarding statistical analyses, see the text for means and standard errors of the means of the cue competition and inflated frequency indexes.*

inflated memory effect through a within-subjects design involving both retroactive and proactive unovershadowing conditions. The design of the experiment is outlined in Table 2. As can be seen, the experiment is a within-subjects instantiation of Experiments 3a and 3b, so that for each participant the compound phase of retroactive unovershadowing coexisted with the element phase of proactive unovershadowing, and, subsequently, the element phase of retroactive unovershadowing coexisted with the compound phase of proactive unovershadowing. A further difference from Experiments 3a and 3b is that in the present experiment there were only two filler compounds to contrast numerically with the critical compounds, presented either 2 times (MN and OP, for the retroactive and proactive orders, respectively) or 10 times (IJ and KL, for the retroactive and proactive orders, respectively).

Method

Participants

A total of 32 undergraduate psychology students at Yale University participated in the experiment for course credit. They were tested individually and had no previous experience in similar research.

Materials and procedure

All of the materials, procedure, and statistical analysis were identical to those of Experiments 3a and 3b, except for the following. First, the experiment is a within-subjects design, as described above (see Table 2). Second, the order of the test trials was partially counterbalanced across participants to control the relative positions of the compounds and components of comparative interest. Specifically, in Subgroup 1 the order was: IJ, MN, EF, GH, KL, OP, AB, and CD in the frequency judgement test and N, F, H, P, B, and D in the causal judgement test. Subgroup 2 was identical to Subgroup 1 except that the order of presentation of each target compound and component (e.g., EF and F) in relationship to its respective control (e.g., GH and H) was reversed. In Subgroup 3 the respective orders were: KL, OP, AB, CD, IJ, MN, EF, and GH, and P, B, D, N, F, and H. Subgroup 4 was identical to Subgroup 3 except that the order of testing of each target compound and component in relationship to its control was reversed. The several orders ensured that each target and its respective control were always tested in contiguous trials and that the sequential position of the target and control cues of the proactive and retroactive orders was counterbalanced. Third, the causal judgements test was simplified, so that target and control cues were only tested alone. Since there were four different food assignments (as in Experiments 3a and 3b) and four test orders, there were a total of 16 different participant conditions. The experiment was conducted in two replications of these conditions.

Results and discussion

The left-hand plot of Figure 7 depicts the mean casual ratings to the target and control cues in testing. In agreement with Experiments 3a and 3b (as well as Experiments 1 and 2), there was a clear proactive and retroactive unovershadowing effect in the form of more responding to the target than to the control cue in each condition. The mean cue competition index was significantly greater than zero in both the retroactive ($M = 36.563$, $SEM = 4.130$), $t(31) = 8.853$, $p < .001$, Cohen's $d = 3.180$, and proactive ($M = 37.500$, $SEM = 3.045$), $t(31) = 12.314$, $p < .001$, Cohen's $d = 4.423$, orders, with a 2 (order) × 2 (replication) ANOVA showing no reliable difference between the two, $F(1, 30) < 1$.

The data from the frequency test depicted in the right-hand plot of Figure 7 indicate that, as in Experiments 3a and 3b, the judged frequency of the control compounds increased monotonically with their programmed frequency of occurrence in the retroactive as well as in the proactive orders. More importantly, the target compound was judged with higher frequency than its control in the retroactive order (which is consistent with Experiment 3a) but not in the proactive order. ANOVA revealed that the inflated frequency index was reliably greater in the retroactive case than in the proactive case, $F(1, 30) = 5.516$, $p = .031$, $\eta_p^2 = .147$, with no reliable effect of replication, $F(1, 30) = 2.174$, $p = .151$, $\eta_p^2 = .068$, or Order × Replication interaction, $F(1, 30) < 1$. Further analyses compared the judged frequency of the target compounds from the retroactive

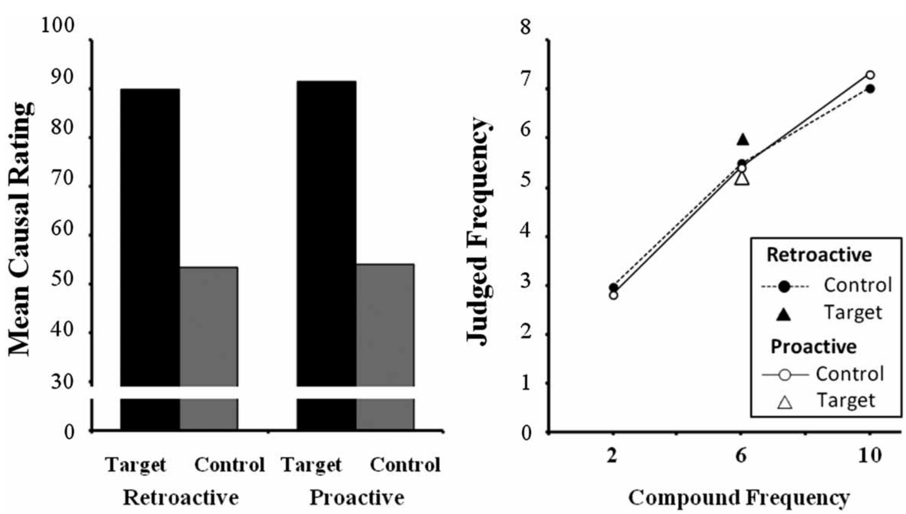

Figure 7. *The left-hand plot presents the mean causal ratings to the target and control cues during the causal judgement test of Experiment 3c. The right-hand plot presents the mean judged frequency of occurrence of target and control compounds as a function of their actual frequency of occurrence in Experiment 3c. Regarding statistical analyses, see the text for means and standard errors of the means of the cue competition and inflated frequency indexes.*

versus the proactive treatments across the 32 participants. In agreement with the differential results of the inflated frequency indexes, this measure was also reliable ($M = 0.81$, $SEM = 0.278$), $t(31) = 2.919$, $p = .006$, Cohen's $d = 1.049$, attesting to the greater judged frequency of the target compound in the retroactive than in the proactive orders.

The overall results of Experiments 3a, 3b, and 3c provide reasonable evidence for an "inflated memory effect" that is more evident in association with a retroactive unovershadowing contingency than with a similar proactive contingency. The data, to our knowledge, are the first to make use of the inflated memory evaluation in investigation of causal learning, but are congruent with the findings of Johnson et al. (1979, 1977) in showing that an inflated memory of an item can occur when the item may be assumed to be provoked in memory by a retrieval cue (Experiments 3a and 3c), distinguishable from other similar treatments that do not support such retrieval (Experiments 3b and 3c). The observations of Experiment 3 add another dimension to the findings that distinguish retroactive and proactive cue competition effects on the basis of the importance of effective within-compound associations (Dickinson & Burke, 1996; Larkin et al., 1998; Melchers et al., 2004, 2006; Mitchell et al., 2003; Vandorpe et al., 2007; Wasserman & Berglan, 1998; Wasserman & Castro, 2005). It needs to be acknowledged that there are other possible explanations of the "inflated memory" effect observed in Experiment 3 that the employed designs cannot rule out. For example, it can be argued that there was a *more accurate* judgement of the frequency of the target compound in the proactive condition than in the retroactive condition because the frequency test occurred more immediately after the compound training and more separated from the potentially confusing element training. We did not see evidence of differential accuracy in the frequency test with the control and filler compounds that were differentially separated from training, but this and other possibilities remain open to future research.

GENERAL DISCUSSION

The experiments that we have reported all demonstrated retroactive as well as proactive cue competition effects. The notable contrast is that the retroactive cue competition effects were more restricted and differentially associated with other evidence of memorial processing than were the related proactive cue competition effects. Experiments 1 and 2 showed that whereas proactive cue competition may be independently seen in both blocking and unovershadowing, retroactive cue competition was largely (if not solely) attributable to unovershadowing, and not to detectable blocking. Experiment 2 demonstrated that retroactive unovershadowing, as observed in Experiment 1, was vulnerable to interference by a concurrent memory task, whereas similar proactive unovershadowing was not detectably diminished by the same task. Experiment 3 observed that an AX+/A− sequence that produced retroactive unovershadowing, as in Experiments 1 and 2, also led subjects to overestimate the frequency of AX occurrences, whereas an A−/AX+ sequence that produced proactive unovershadowing did not demonstrably do so. The several findings hold a number of implications for candidate theories of human causal learning.

The cue competition effects, such as blocking (Kamin, 1968) and release from overshadowing (Wagner, 1969), that were observed in Pavlovian conditioning importantly inspired modern theories of associative learning (e.g., Mackintosh, 1975; Pearce & Hall, 1980; Rescorla & Wagner, 1972; Wagner, 1981). In turn, these models, by anticipating that there might be similar cue competition effects in human causal learning, substantially encouraged investigation in this domain (Dickinson et al., 1984; Gluck & Bower, 1988; Shanks & Dickinson, 1987).

The Rescorla–Wagner model exemplifies the aforementioned theory type. It assumes that the trial-by-trial increase in associative strength to any conditioned stimulus (CS) is computed as $\Delta V = \alpha\beta(\lambda - \sum V)$, where $\sum V$ is the aggregate associative strength of all of the cues present on that trial, and α and β are learning rate parameters representing the salience of the CS and the unconditioned stimulus (US), respectively. The rule made it understandable that increasing the associative strength of A by reinforced A+ trials would increase the $\sum V$ on subsequent AX+ trials and thus diminish ΔV_X—that is, lead to blocking. Likewise, decreasing any associative strength that A might have (by virtue of prior training or by generalization from other stimuli) through nonreinforced A− trials would decrease the $\sum V$ on subsequent AX+ trials and thus increase ΔV_X—that is, lead to unovershadowing.

The Sometimes Opponent Processes (SOP) model (Wagner, 1981) deals with cue competition in a more complex, but related, manner. It assumes that stimulus presentation activates a sequence of representative nodes, Al followed by A2, with the relationship that the A2 node recurrently inhibits activity in the A1 node, making it transiently less susceptible to activation by its normally initiating stimulus. The learning assumption is that the temporal contiguity of CS and US can produce both excitatory and inhibitory CS–US associations depending on the overlapping nodal activities: Excitatory CS–US association is assumed to be proportional to the momentary product of the concurrent $A1_{CS}$ and $A1_{US}$ activity; inhibitory CS–US association is assumed to be proportional to the momentary product of the concurrent $A1_{CS}$ and $A2_{US}$ activity. The consequence of an acquired associative tendency is subsequently to allow initial A1 activity of the CS to provoke some A2 activity in the US node, or to suppress other associative activation of the A2 node of the US, depending upon the sign and magnitude of the association. By these assumptions, blocking results from the fact that A+ training causes A to become capable of activating the A2 node of the US upon AX+ occasions, leading to diminished activation of the A1 node of the US and, thus, to both diminished excitatory learning as well as increased inhibitory learning to X. By the same token, if A is rendered less excitatory by previous nonreinforcement, subsequent AX+ training should produce more excitatory learning (and less inhibitory learning) to X than in situations in which A is not so pretreated.

These trial-by-trial associative models yield the strong prediction, previously well documented (e.g., Chapman, 1991; Lovibond et al., 2003; Melchers et al., 2004, 2006; Mitchell et al., 2006) and confirmed in the present studies, that cue competition effects should be greater following proactive than following retroactive treatment. However, neither the Rescorla–Wagner model nor SOP, as described, anticipates that the training of A alone *following* the training of AX+ will have *any* influence on the tested response to X. The theories are designed to capture the facts of proactive cue competition, but do not anticipate the retroactive cue competition in human causal learning as observed by Shanks (1985) among others, and as reported here.

Van Hamme and Wasserman (1994) and Dickinson and Burke (1996) proposed modifications to the Rescorla–Wagner and the SOP models, respectively, that were calculated to account for the finding of retroactive cue competition in human causal learning. The alterations both involved the supposition that on the occasions of A training after AX+ training, a representation of the “absent” X stimulus that might be retrieved from memory would be decremented or incremented in associative strength, opposite in direction to the consequences for the A stimulus that was present. As amended, both the modified Rescorla–Wagner model and the modified SOP model predict some measure of retroactive cue competition, but, notably, the modified SOP model predicts less robust retroactive than proactive cue competition, due, specifically, to retroactive blocking being less robust, than retroactive unovershadowing, as was the pattern observed in Experiments 1 and 2 (Larkin et al., 1998). Whether these modified models will prove more useful than their original versions will surely depend on their abilities to cope as well within the domain of Pavlovian conditioning, as in coping with the facts of retroactive cue competition in human causal learning. In the present context, the more immediate challenge is that, although they can accommodate to various degrees the relative amounts of proactive and retroactive blocking and overshadowing reported in Experiments 1 and 2 (Larkin et al. 1998; Wasserman & Castro, 2005), they do not provide a natural account of the distractor and inflated memory effects reported in Experiments 2 and 3.

The major alternative to such associative models are rule-based models in which the effective computation is assumed to occur at the time of judgement, based upon the aggregate information available at the time. The probabilistic contrast model proposed by Cheng and Novick (1990, 1992) is a good example, addressed to cue competition effects. The approach begins from the assumption that causal judgement is related to a comparison of the experienced probability of an effect in the presence versus the absence of a given candidate cause, or ΔP (Jenkins & Ward, 1965), but further specifies that causal judgement is not thereby sufficiently determined. In situations with multiple possible causes, as in cue competition experiments, it is supposed that the effective causal strength of a given cue depends on such a comparison of the probability of the effect in the presence versus absence of the target cause, but on occasions when any alternative cause is kept constant. According to this reasoning, the diminished causal judgement to X when AX+ occasions are in the context of additional A+ occasions—that is, blocking—is because there is diminished difference between the probability of the effect when X is present (i.e., in the AX trials) than when X is absent, but A is also present, (i.e., A+ trials). By the same reasoning, the increased causal judgement to X when AX+ occasions are in the context of additional A– occasions—that is, unovershadowing—is because there is increased difference between the probability of the effect on the AX+ trials when X is present than on the comparison A– trials when X is absent.

Such a rule-based model, based upon the aggregate information at the time of judgement, allows for retroactive as well as proactive cue competition effects, as frequently observed, and confirmed in the present studies. However, the basic approach, as contained in the probabilistic contrast model, as described, anticipates that the training of A alone, either before or after the training of AX+, will have *equal* influence on the tested response to X. The approach well captures the fact of retroactive as well as proactive cue competition, but does not anticipate the pattern of differences between the two. It is interesting to note that the same evaluation may be made of the comparator theory of Stout and Miller (2007), which explains cue competition effects as a result of a comparison of the relative strength of the target stimulus with the strength of the manipulated cue with which it is in compound. It predicts both proactive and retroactive performance effects, but no difference between the two.

Rule-based models, of course, need not be restricted to such simple calculation as emphasized by the probabilistic contrast model (Cheng & Novick, 1990) that was designed to address the fact of cue competition, but have been widely identified with broader formulations of inferential reasoning (e.g., Cheng, 1997; Waldmann & Holyoak, 1992) that embody a variety of causal models that people may have, including the notion of hidden as well as observable variables (Luhmann & Ahn, 2011). Any such model is able to offer an account for the fact observed in Experiments 1 and 2, that unovershadowing was more demonstrable than blocking. Assume that the compound AX is followed by an effect (and that potential causes do not interact). If one additionally learns that A alone is also followed by an effect, it remains uncertain whether X alone would also be followed by an effect; in contrast, if one learns that A is not followed by an effect, it may be better concluded that X would be followed by an effect.

Propositional theories of human causal learning (e.g., Mitchell, De Houwer, & Lovibond, 2009) are sufficiently welcoming of additional suppositions about human learning and decision making that they can easily accommodate certain of the results of Experiments 2, 3a, and 3c that might appear less congenial to associative interpretation. It is common to assume that propositional reasoning requires the availability of cognitive resources that are under limited-capacity restraints. Reports (e.g., De Houwer & Beckers, 2003; Sternberg & McClelland, 2009; Waldmann & Walker, 2005) that cue competition effects can be interfered with by added task demands, have been taken as consistent with this notion and the supposition that cue competition is, in fact, dependent upon propositional reasoning. To follow this reasoning, in regard to the findings of Experiment 2 (and related observations of Aiken et al., 2001) one might still wish for rationalization of why retroactive cue competition, as seen in retroactive unovershadowing, is more uniquely dependent on such propositional reasoning than is proactive cue competition, as seen in proactive blocking and proactive unovershadowing.

There is a similarity in the invited propositional interpretations of Experiments 3a, 3b, and 3c. Scheduling A alone experience either following AX+ training (Experiments 3a and 3c) or before AX+ training (Experiments 3b and 3c) produced an unovershadowing effect, but only the former was accompanied by an inflated judgement of the frequency of the AX trials, in relationship to the frequency of occurrence of other compounds. It is possible that inferential reasoning contributed to both proactive and retroactive unovershadowing, but the inflated memory of AX that accompanied the retroactive unovershadowing is suggestive of a functional importance of the retrieval of the AX memory in the retroactive case but not in the proactive case.

If one is not a committed adherent to either associative or propositional theory, one might think that the most obvious theoretical interpretation of the pattern of cue competition effects observed in the present experiments and related studies would involve both processes. It is possible that both associative and propositional influences are at work, associative influences being only effective in producing proactive cue competition, and inferential reasoning effective in producing both proactive and retroactive cue competition, but more singularly so in the retroactive case. This would lead to the expectation that cue competition would be (a) more robust in proactive than in retroactive instantiations, and (b) more evident in retroactive unovershadowing than in retroactive blocking. It would further lead to the expectation that retroactive unovershadowing would be (c) more interfered with by a secondary task than would proactive unovershadowing, and (d) more evidently associated with memorial retrieval of the compound training.

If one takes a broader view of the determinants of causal judgements, it is reasonable to assume that some judgements may be based upon simple associations, as might be described by such formulations as the Rescorla–Wagner model or SOP, while other causal judgements are based upon evidentiary searches and sophisticated inferential reasoning quite beyond this. This is not a new thought, but was articulated well by Hume (1748/1910) who pointed out that whereas philosophers, when acting like philosophers, might follow careful rules of reasoning in making causal judgements, others—and philosophers much of the time—make causal attributions based on the simpler association of sense data. Nor is it an ancient view. In more modern overview, associative influences are part of what Kahneman (2011) assumes to be included in a fast-responding System 1, whereas inferential reasoning is a major determinant of a slower responding System 2.

A theoretical gambit proposed by Chapman (1991), and advanced by Melchers et al. (2004), and more recently explored by Ludvig, Mirian, Sutton, and Kehoe (2010), has been conceived as an extension of the Rescorla–Wagner model, but should be recognized as a two-process formulation that uses the error-correction rule to operate upon two different sets of information. It assumes two potential products of training experience. There is associative learning, which is assumed to proceed in the trial-by-trial manner of the Rescorla–Wagner model. In addition, experienced trials are assumed to be stored as episodic memories that can be subsequently replayed to computational consequences. The robust proactive cue competition, as commonly seen, can be taken to be dominated by the trial-by-trial associative learning. The more fragile retroactive cue competition can be assumed to reveal the added memorial computation. For example, according to this view, when A+ or A− is experienced after AX+, there would not only be the trial-initiated associative learning, but also the potential for "replay" or "rehearsal" of some number of remembered trials of A+ or A− in the context of remembered trials of AX+. The computational consequence of any rehearsal of A− prior to AX+ would presumably lead to a reduction in the associative value of A upon the rehearsal of AX+ and thus to an increase in the associative value of X—that is, to retroactive unovershadowing in relationship to a control compound without such element nonreinforcement. It is notable that by this manner of account, retroactive blocking should be less anticipated than retroactive unovershadowing, since a decrease in the value of X should depend on the rehearsal of A+ driving the associative value of AX above what is supported by reinforcement.

This particular two-process approach would have to be more fully fleshed out than it has been, to include the rules for what of an episode is stored and retrieved from memory—for example, whether it includes not only the stimulus events but the $\sum V$ and behavioural responses at the time. Likewise, decision must be made about what initiates retrieval and replay. For instance, it could be assumed that the replay may simply occur because there is a periodic sampling of episodes from memory (Ludvig et al., 2010; Ratcliff, 1990), or because episodes are retrieved by an associated cue (Chapman, 1991; Melchers et al., 2004). The fact that in Experiments 3a and 3c there was an inflated memory of the target compound (AB) but not of the equally experienced control compound (CD), favours the idea that rehearsal of the AB compound was cued by the subsequent presentations of A.

This replay reasoning is as accommodating as other invokings of a presumed vulnerability to competing task demands (e.g., De Houwer & Beckers, 2003; Le Pelley, Oakeshott, & McLaren, 2005). The results of Experiment 2, showing that a secondary memory task had more of an interfering effect upon retroactive unovershadowing than upon proactive unovershadowing, could be taken as support for a two-process account in which relatively automatic associative processes are held largely responsible for proactive blocking and unovershadowing, whereas episodic memory processing is required for retroactive unovershadowing. Perhaps most in need of specification is how the computations based upon the trial-by-trial experienced episodes combine with the computations based upon the replayed episodes, to yield a summary causal judgement. But this would be equally true of any two-process account.

In presenting the SOP model, Wagner (1981) offered the characterization that it was a model of automatic memory processing that might be relatively sufficient to address phenomena of Pavlovian conditioning and habituation in inarticulate animals, but avoided any assumptions about controlled processing, such as that presumed (e.g., Shiffrin & Schneider, 1977) to be important in approaching more complex issues of human learning and performance. Studies of human causal learning have since provided a challenging testing ground for the degree to which the contained associative principles are more generalizable, or can be made so with thoughtful changes, or require more fundamental supplementation.

Supplemental Material

Supplemental content (the full instructions that were given to the participants in each of the experiments) is available via the "Supplemental" tab on the article's online page (http://dx.doi.org/10.1080/17470218.2015.1014378).

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