

Short article

Backward blocking: The role of within-compound associations and interference between cues trained apart

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Most theoretical accounts of backward blocking place heavy stress on the necessity of the target cue having been trained in compound with the competing cue to produce a decrement in responding. Yet, other evidence suggests that a similar reduction in responding to the target cue can be observed when the outcome is later paired with a novel cue never trained in compound with the target cue (interference between cues trained apart). The present experiment shows that pairing another nonassociated cue with the same outcome may be sufficient to produce a decremental effect on the target cue, but the presence of a within-compound association between the target and the competing cue adds to this effect. Thus, both interference between cues trained apart and within-compound associations independently contribute to backward blocking.

Kamin's (1968) blocking effect was a watershed in the history of associative learning. There, initial training with one stimulus (A-US pairings) dramatically reduced responding to a new stimulus (B) that was added to the original one during a second phase of training (AB-US

pairings). This blocking effect suggested that two or more cues compete with one another for association with an outcome. In causal terms, blocking suggests that organisms not only take into account how a potential cause covaries with the effect, but they also consider how this

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cause competes with rival determinants of the effect.

Rescorla and Wagner's (1972) associative learning theory can nicely explain such *forward blocking*, in which element training precedes compound training, because it hypothesizes that all of the associative strength of the outcome becomes attached to the initial cue prior to the presentation of the added target cue. However, that theory cannot explain *backward blocking*, in which element training follows compound training, because no change in associative strength should occur to the nonpresented target cue during the second phase of training with the competing cue alone (Miller & Matute, 1996; Shanks, 1985; Wasserman & Berglan, 1998). Backward blocking thus represents a new watershed in the history of associative learning, as the dominant theory is unable to explain the effect.

Several accounts have now been offered to explain backward blocking. One advanced by Van Hamme and Wasserman (1994) hypothesizes that a representation of the nonpresented target cue can be retrieved by other cues, such as the competing cue with which the target cue was paired in the initial phase of training. Such retrieval effectively informs the organism of the absence of the target cue, prompting a change in its associative strength opposite to that of the presented cue. Therefore, reinforcement of the presented competing cue leads to an increment in its associative strength, but to a decrement in the associative strength of the nonpresented target cue—backward blocking. Dickinson and Burke (1996) proposed a revision of Wagner's (1981) SOP (Standard Operating Procedures) model that also allows for changes in the associative strength of nonpresented cues in a similar fashion. In a very different vein, Miller and Matzel (1988) proposed that blocking is not an associative *learning* effect, but rather a *retrieval* effect; when the target cue is presented at testing, its associative strength is compared to that of the competing cue, which results in a lower response to the target cue. Regardless of the specific mechanism that may be responsible for backward blocking, all of these models place heavy stress on the necessity of the target cue having been trained in

compound with the competing cue for backward blocking to occur; that is, the decremental effect is due to further pairings of the outcome and the specific cue that had been trained in compound with the target cue.

A possibly rival account of backward blocking arises from research showing that, after pairing one cue with an outcome, training of a novel second cue with the same outcome can weaken responding to the first-trained cue (Matute & Pineño, 1998; Pineño & Matute, 2000). This retroactive interference effect is similar to backward blocking because, in both cases, responding to the target cue is reduced by later pairings of a competing cue with the same outcome. The key difference is that, in backward blocking, the target and the competing cue are presented together in the first training phase, which presumably permits the development of a within-compound association between the target cue and the competing cue. But, retroactive interference does not require that the two cues are ever presented in compound, although each of the cues must be paired with the same outcome (Pineño & Matute, 2000). Perhaps retroactive interference can explain at least part of the response reduction observed in backward blocking. Contrary to current associative explanations of backward blocking, this possibility would suggest that at least part of the decremental effect is independent of a within-compound association between the target and the competing cue. Our study sought to unravel the possibly independent contributions to backward blocking of within-compound association and interference between cues trained apart.

The design of our experiment is outlined in Table 1. In the first experimental condition, Cues A and B are paired with each other and with Outcome 1 in Phase 1; then, Cue A alone is paired with Outcome 1 in Phase 2. Backward blocking would be evidenced by a drop in the causal ratings of Cue B, despite its not having been presented in the second phase.

The second experimental condition was designed to ascertain whether a similar drop in responding to the target cue can be observed even

Table 1. Design summary of the experiment

Rating 1	Training Phase 1	Rating 2	Training Phase 2	Rating 3
A to G	AB→O1 CD→O2 EF→O3	A to G	A→O1 G→O2 —	A to G

Note: The letters A to G denote the different cues; O1, O2, O3 denote the different outcomes; and the — indicates that neither the individual cues in Compound EF nor the corresponding outcome were presented in that training phase.

when there is no within-compound association between the target cue and its competing cue. So, this experimental condition was kept as similar as possible to the backward blocking condition, except for the fact that the competing cue trained in Phase 2 was a novel cue that had not been trained in compound with the target cue in Phase 1. In this condition, Cues C and D are paired with each other and with Outcome 2 in Phase 1; then Cue G is paired with Outcome 2 in Phase 2. If the same drop in ratings of target Cues C and D occurs here as for Cue B, then within-compound association would be unnecessary to produce a response decrement akin to backward blocking. But, if the drop is greater for Cue B than for Cues C and D, then within-compound association would be necessary to produce at least part of the response decrement observed in backward blocking.

Finally, we included Cues E and F that were paired with each other and with Outcome 3 in Phase 1. Neither Cue E nor Cue F nor Outcome 3 were presented in Phase 2. Cues E and F represent control cues that allow us to assess any decrements to Cue B (which would indicate backward blocking) or to Cues C and D (which would indicate interference between cues trained apart). Escobar, Pineño, and Matute (2002) compared interference between cues trained apart and blocking; however, their experiments lacked the control condition for backward blocking equivalent to Cues E and F given here.

Method

Participants and apparatus

A total of 105 psychology students at the University of Deusto volunteered to participate.

From 1 to 5 participants were studied concurrently on identically configured computer workstations. The experiment was programmed using VisualBasic. Instructions and task stimuli were presented on the screen, and participants had to make their responses with the mouse and/or computer keyboard.

Stimuli

The names of seven foods served as cues: grapes, chicken, yogurt, cheese, eggs, carrots, and macaroni. On trials in which two cues were presented, the right or left position of each cue on the screen was randomized. The outcomes were three allergic reactions that the patient could exhibit: itchiness, nausea, and fever. These cues and outcomes were counterbalanced according to a Latin square.

Design

Table 1 illustrates that, in Phase 1, three compound cues (AB, CD, and EF) were each paired with one of three different outcomes (O1, O2, and O3, respectively). Compound AB was followed by O1 in Phase 1; in Phase 2, only Cue A was presented and was followed by O1. Compound CD was followed by O2 in Phase 1; in Phase 2, novel Cue G was presented and was followed by O2. Neither of the elemental cues in Compound EF nor the corresponding outcome, O3, were presented in Phase 2, so that Cues E and F could serve as controls to determine to what extent the other absent cues in Phase 2 would change their values. Each type of trial was presented 30 times in a pseudorandom order in each training phase.

We expected ratings of Cue B, whose associate and outcome were trained in Phase 2, to be lower than ratings of control Cues E and F, as in our two published reports of backward blocking (Wasserman & Berglan, 1998; Wasserman & Castro, 2005). We were especially concerned with two other comparisons. First, comparing ratings of Cues C and D, whose outcome had been paired with a novel cue in Phase 2, to ratings of control Cues E and F allowed us to determine whether a ratings decrement to the target cue can occur without the participation of within-compound association. Second, comparing ratings of Cue B to ratings of Cues C and D allowed us to determine whether a within-compound association between the target and its associate plays an isolable role in the response decrement in backward blocking.

Procedure

The procedure of the experiment was very similar to that of Wasserman and Berglan (1998). Only minor changes were made, related to the language in which the experiment was conducted (Spanish instead of English) and to differences in the experimental design. An English translation of the instructions presented to participants is given in Appendix A.

To see whether strong initial opinions would influence later performance, participants were first asked to rate the likelihood that the foods

could cause each of the three allergic reactions in an ordinary individual. Participants had to enter their ratings of the relation between each of the foods and each of the three allergic reactions along a scale numbered from 0 to 9.

After entering these initial ratings, participants were instructed to imagine that they were allergists who had to investigate which foods caused certain allergic reactions in one of their patients. On each learning trial, the food(s) that the patient had eaten on a given day appeared centred at the top of the screen; participants had to predict the reaction that the patient would exhibit. Once the participants chose one of the allergic reactions, the actual outcome appeared below, along with information about whether their choice was correct or incorrect. The percentage of correct predictions was shown at the bottom of the screen.

On two other occasions, participants had to rate the extent to which each of the foods could cause each of the reactions: after Phase 1 training and after Phase 2 training. The procedure for collecting these ratings was similar to that used to request the initial ratings, except that participants were now told that they had to rate the likelihood of an allergic reaction *in their patient* after eating each of the foods.

Preanalysis of the data

We eliminated the data from 13 participants who apparently paid little attention to the experimental

Table 2. Mean ratings for all cues with their corresponding outcomes in each rating period

Cue	Rating period 1		Rating period 2		Rating period 3	
	Mean	SE	Mean	SE	Mean	SE
A	0.34	0.11	6.20	0.31	8.15	0.15
B	0.35	0.12	6.10	0.31	4.72	0.39
C	0.20	0.08	6.25	0.30	5.52	0.37
D	0.19	0.07	6.27	0.30	4.98	0.38
E	0.17	0.06	6.35	0.29	5.39	0.37
F	0.16	0.06	6.25	0.30	5.76	0.36
G	0.42	0.12	0.41	0.17	8.15	0.18

Note: Cues A and G are the potential competing cues; Cues B, C, D, E, and F are the different target cues. Rating Period 1 provided initial ratings prior to any training. Rating Period 2 followed Phase 1 training (AB→O1, CD→O2, EF→O3). Rating Period 3 followed Phase 2 training (A→O1, G→O2).

task—8 gave a rating of zero to all seven cues in the third rating period, and 5 rated the relationship of Cues A and G with their corresponding outcomes (i.e., $A \rightarrow O1$ and $G \rightarrow O2$) lower than the relationship of Cues A and G with those outcomes that had never been paired with these cues. An alpha level of .05 was adopted for all statistical tests.

Results

The causal ratings of all seven cues with their corresponding outcomes in each of the three rating periods are provided in Table 2. Initial ratings, before experimental training, were low and similar. After Phase 1, the ratings of all cues with their corresponding outcomes increased, whereas the rating of Cue G, which was not presented in this phase, was very low, confirming that training proceeded robustly and discriminatively. More interesting results came after Phase 2. Table 2 shows the final ratings of the target cues. Because Cues C and D, on the one hand, and Cues E and F, on the other hand, received the same treatment, we averaged their values for statistical analysis. As expected, participants rated the target cues differently: $B (M = 4.72) < C/D (M = 5.25) < E/F (M = 5.58)$.

A 3 (rating period: 1 vs. 2 vs. 3) $\times 3$ (cue: B vs. C/D vs. E/F) analysis of variance (ANOVA) yielded a significant main effect of rating period, $F(2, 182) = 231.74$, $MSE = 12.16$, showing that ratings of the target cues expectedly changed due to training. The main effect of cue was marginally significant, $F(2, 182) = 2.96$, $MSE = 1.91$, $p = .05$. Critically, the Rating Period \times Cue interaction was significant, $F(4, 364) = 5.24$, $MSE = 1.24$, confirming that ratings of the target cues changed differently in the different rating periods.

Simple effects analyses confirmed that significant differences held among the three cues in Rating Period 3, $F(2, 182) = 6.72$, $MSE = 2.50$, but not in Rating Periods 1, $F(2, 182) = 1.65$, $MSE = 0.57$, or 2, $F(2, 182) = 0.73$, $MSE = 1.32$. Planned comparisons revealed that ratings of Cues C/D were lower than ratings of Cues E/F, $F(1, 91) = 5.90$, $MSE = 0.80$, showing interference between cues trained apart. Moreover,

ratings of Cue B were lower than ratings of Cues C/D, $F(1, 91) = 3.99$, $MSE = 3.20$, showing that within-compound associations do contribute to the response deficit observed in the backward blocking condition. These two key results thus reveal that compound training of the target and competing cues is not necessary for a decremental effect to occur (the difference between Cues C/D and Cues E/F) as well as that a different decremental effect occurs that does depend on compound training of the target and competing cues (the difference between Cue B and Cue C/D).

We also compared ratings after Phase 1 to final ratings after Phase 2. Ratings of Cue B decreased from the end of Phase 1 ($M = 6.10$) to the end of Phase 2 ($M = 4.72$), $F(1, 91) = 17.77$, $MSE = 4.93$, consistent with backward blocking. Ratings of Cues C/D also decreased from the end of Phase 1 ($M = 6.26$) to the end of Phase 2 ($M = 5.25$), $F(1, 91) = 12.57$, $MSE = 3.69$, consistent with interference between cues trained apart. Finally, ratings of control Cues E/F also decreased ($M = 6.30$ and $M = 5.58$, at the end of Phase 1 and Phase 2, respectively), $F(1, 91) = 5.95$, $MSE = 4.09$, perhaps due to forgetting or to some more general interference effect.

Discussion

When competing Cue A, associated with target Cue B in Phase 1, was given further pairings with Outcome 1 in Phase 2, causal ratings of Cue B decreased (i.e., backward blocking). Moreover, when novel Cue G, never associated with target Cues C or D in Phase 1, was paired with Outcome 2 in Phase 2, causal ratings of Cues C/D also decreased (i.e., interference between cues trained apart). Importantly, causal ratings of Cue B were lower than causal ratings of Cues C/D, showing that the rating decrement was larger when a within-compound association existed than when it did not. These results suggest that interference between cues trained apart and within-compound associations each participate in backward blocking. Training another nonassociated cue with the same outcome may be sufficient to produce a decremental effect to

the target cue, but establishing a within-compound association between the target cue and the competing cue adds to this effect.

Other research projects have implicated within-compound association in backward blocking (Dickinson & Burke, 1996; Wasserman & Berglan, 1998; Wasserman & Castro, 2005). We too found that within-compound association contributes to backward blocking; however, something else appears to be contributing to lowered causal ratings. As shown by the retrospective interference condition in our experiment, a response decrement can appear even in a situation in which there is no within-compound association between the competing and target cues. This decrement has remained largely unnoticed in the above-mentioned experiments, because most used a design that reduced their sensitivity to the retroactive interference effect that we observed in the present experiment. Prior investigations used within-subject designs in which participants were exposed to both the backward blocking and control conditions; critically, the same outcome was paired with all of the experimental cues. For example, Compound AB was paired with O1 in Phase 1, and Cue A was paired with O1 in Phase 2, just as in our experiment. However, control Compound EF, instead of being paired with a *different* outcome (O3 in our design), was also paired with the *same* outcome as Compound AB (O1 in our design). In this case, Cue A→O1 pairings in Phase 2 might interfere, not only with its associate—Cue B—but with its control cues—Cues E and F—as well. Thus, the control conditions in earlier studies were unable to reveal any interference that might have occurred without the participation of within-compound association, because these control cues themselves might have been affected by interference between cues trained apart. Support for this possibility is to be found in Wasserman and Berglan (1998, see also Wasserman & Castro, 2005), who observed that ratings of control Cues E and F decreased from EF→O1 training to testing without any intervening training with Cues E or F, with just A→O1 training.

One might suggest that the difference between Cues C/D and E/F occurred because the G→O2

trials given in Phase 2 increased the probability of the Outcome 2 in the absence of Cues C and D, thereby reducing the overall contingency between these cues and O2. However, past research on interference between cues trained apart reveals that this effect is context- and trial-order dependent; the effect disappears if the interfering association (here, G→O2) and the target associations (here, C→O2 and D→O2) are trained in a single phase or if the test occurs in a different context (Escobar, Matute, & Miller, 2001; Matute & Pineño, 1998; Pineño, Ortega, & Matute, 2000). These manipulations do not affect the cue–outcome contingency and, therefore, make the disparity between Cues C/D and E/F difficult to explain in terms of differential contingency.

Several theoretical models can be adapted to explain our results. As mentioned earlier, the revised Rescorla–Wagner model of Van Hamme and Wasserman (1994) already explains the role of within-compound association in backward blocking: A representation of the nonpresented target cue can be retrieved by other cues, such as the competing cue with which the target cue was paired in the initial phase of training. Such retrieval effectively informs the organism of the absence of the target cue, prompting a change in its associative strength that is opposite to that of the presented cue. This model can be adapted to explain interference between cues trained apart by assuming that the revaluation of an absent cue cannot only occur if its representation is triggered by one or more previously associated cues, but also if the outcome itself elicits a representation of the nonpresented target cue. Whenever the outcome occurs alone, without its original signal, the absence of this cue might become salient, and, thus, its associative strength might be reduced. One simply needs to assume that associations can work not only in the forward direction (i.e., cues activate the representation of their associated cues and outcomes), but also in the backward direction (i.e., outcomes themselves can activate the representation of the cues that used to precede them; see Gerolin & Matute, 1999). Hence, according to this extended

explanation, backward blocking is due to the activation of the absent target cue from two different sources: the competing cue and the outcome. The revised SOP model (Dickinson & Burke, 1996) can be extended in a similar manner to account for the present results.

Other associative accounts can be considered. Chapman (1991) suggested that early AB→O1 trials are rehearsed during A→O1 training, so that participants actually experience AB→O1 trials intermixed with A→O1 trials. In this case, the original Rescorla–Wagner model could explain reduced responding to Cue B without further modification. On the other hand, during G→O2 trials, participants might sometimes erroneously recall Cues C and D as having been paired with Cue G, due to the common outcome, thus rehearsing CG→O2 or DG→O2 trials. If that were the case, then ratings of Cues C/D should also decrease, but not as much as ratings of Cue B, because recall of AB→O1 trials is, presumably, more accurate. Despite the plausibility of this explanation, the small number of trial types in our task makes such false memories unlikely.

Still, other features of this kind of interference might be troublesome for any associative explanation. Interference between cues trained apart tends to vanish after certain contextual manipulations, after a temporal interval, or if the appropriate retrieval cues are presented after the interfering experience (Matute & Pineño, 1998; Pineño & Matute, 2000; Pineño et al., 2000). These effects imply something other than a reduction in associative strength.

Another possible account is Le Pelley and McLaren's (2001) connectionist model, APECS (Adaptively Parametrised Error Correcting System), which attributes backward blocking and interference to impaired retrievability. According to APECS, when Cues AB and CD are not presented in Phase 2 (but their associated outcomes are), a negative bias unit develops, which limits the ability of these stimuli to activate their corresponding outcomes. Thus, low responding to Cues B, C, and D should be observed in later testing. However, because of the A→O1 trials, the connection of the AB unit with O1 will be

strengthened as well. So, AB is involved in two opposite processes: (a) an increase in the negative bias of the AB unit, which will decrease Cue B's ability to activate O1 at testing, and (b) an increase in the excitatory AB–O1 connection, which will increase the ability of Cue B to activate O1 at testing. These opposing mechanisms lead APECS to predict that backward blocking can be weak or even nonexistent. In the case of Cues C/D, the only connection that is strengthened during Phase 2 is the negative bias unit with the CD unit; no conflicting excitatory association occurs. Therefore, responding in testing should be lower to Cues C/D than to Cue B. But, we observed just the opposite result.

Another way to explain these findings is to incorporate the assumptions of Bouton's (1993) retrieval theory of interference into the revised Rescorla–Wagner model or into the revised Wagner SOP model. According to Bouton, organisms process information not only about cues and outcomes, but also about the physical and temporal contexts in which these cues occur. When different associations involving the same target cue and different outcomes are simultaneously activated, they will compete with one another, and interference will be observed. In this case, temporal and physical contextual cues are critical to disambiguate the meaning of the target cue. If a given context activates one cue–outcome association, then the retrieval of the other cue–outcome association will be impaired. One could extend these ideas to the reverse situation in which one common outcome is associated with several cues (as in our experiment). If one assumes that interference in the retrievability of associations arises not only when one cue is paired with several different outcomes, but also when one outcome is paired with several different cues, then this approach can be applied to our experiment. From this point of view, the activation of the Cue G→O2 association would reduce the retrievability of the associations between Cues C/D and O2; that would explain the observed interference effect. Most interestingly, there should be no reason why this process cannot participate in the backward blocking condition; in

this case, the activation of the Cue A→O1 association should, to some extent, impair the retrieval of the target Cue B→O1 association, thus producing at least part of the decrement in responding to Cue B (see Matute & Pineño, 1998, for detailed explanation of this approach; see also Miller & Escobar, 2002, for a related attempt to explain interference).

Regardless of these or other possible theoretical explanations, our study has experimentally disentangled the independent contributions of within-compound association and interference between cues trained apart to backward blocking. We expect future research on both forward and backward blocking to continue to be a provocative and fertile enterprise in the study of both human and animal behaviour.

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APPENDIX A

Instructions (translated from Spanish)

1. Instructions for the initial ratings

First screen

This is an exercise to gauge how people form opinions. Before we begin the experiment, we would like to get your initial opinions of some foods. This is to check whether you happen to hold any opinions about the foods that we will be using in these tests.

We would like for you to imagine that an ordinary individual, who is completely unknown to you, has eaten certain foods. You will see a list of foods on the next computer screen that appears. We will ask you to rate the likelihood that this individual would have three nasty reactions (itchiness, nausea, and fever) after eating each of those foods. This person may not have these reactions to any foods.

We would like for you to remember the following two facts before continuing:

1. You should base your opinions on the fact that most people do not suffer from nasty reactions to any foods.
2. You have no reason to believe that this individual is any different from most people.

Second screen

Several foods are listed below, each one with three 0-to-9 ratings that correspond to three problematic reactions. Using these rating scales, please rate the likelihood that each food will cause each of the reactions in this individual.

2. Instructions presented before Phase 1

Now we would like you to imagine that you are a specialist who tries to discover which foods can cause the development of several reactions in people.

You have just been presented with a new patient, Mr. X, and you have to discover which foods cause him to have different reactions. With this purpose, you arrange for him to eat various foods for a meal on each day, and you observe if he has any reaction. The results of the daily tests will be shown to you on a series of screens. You will see a separate screen for each day of the test. On each screen you will be told what the patient ate that day and if there was a reaction. Please read the food names carefully and remember that your task as a specialist is to determine which food or foods are causing a reaction.

After seeing each day's foods, you will be asked to predict which reaction each meal caused in your patient. If you think that your patient will suffer itchiness, press <I>; if you think that he will suffer nausea, press <N>; if you think that he will suffer fever, press <F>. After you make your prediction, the computer will inform you which was the correct response. Obviously at first you will have to guess since you will not know anything about your patient, but hopefully you will begin to learn the relationship between each food and each reaction.

Later in the experiment, you will again be asked to rate the foods you previously rated. But in those future ratings, we would like for you to rate the likelihood that each food would cause Mr. X, your patient, to have each different reaction. You should use all of the knowledge that you have acquired during the daily tests when you make your ratings in the future.

3. Instructions presented before rating Periods 2 and 3

On this screen, we would like for you to rate the foods again, but now for Mr. X, your patient. You will have to indicate the likelihood that the foods would cause Mr. X to suffer from each reaction. The rating scale is identical to the one you used previously. When you make your ratings this time, please consider all of the information that you have received throughout the experiment, not just the information from the last day.