THE QUARTERLY JOURNAL OF EXPERIMENTAL PSYCHOLOGY, 1996, *49B* (1), 60–80

Within-compound Associations Mediate the Retrospective Revaluation of Causality Judgements

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The role of within-compound associations in the retrospective revaluation of causality judgements was investigated in a two-stage procedure in which the subjects were asked to learn whether or not different food stimuli caused an allergic reaction in hypothetical patients. In the compound-cue stage a number of compound cues, each consisting of a competing stimulus and a target stimulus, were associated with the reaction across a series of trials, whereas in the single-cue stage the subjects had the opportunity to learn which of the competing cues, when presented alone, caused the reaction. Each target stimulus was presented with the same competing cue across all compound trials in the consistent condition, but with a different competing cue on each trial in the varied condition. In a forward procedure, in which the single-cue stage preceded compound cue training, judgements of the causal effectiveness of the target stimuli were reduced or blocked by training them in compound with a competing cue that had been previously paired with the reaction. Moreover, the magnitude of this reduction was comparable in the consistent and varied conditions. This was not true, however, when the single- and compound-cue stages were reversed in the backward procedure. Judgements for target cues compounded with competing cues that were subsequently paired with the reaction were reduced only in the consistent condition. If it is assumed that stronger associations were formed between the competing and target stimuli during the compound-cue stage in the consistent condition than in the varied condition, this pattern suggests that the retrospective revaluation of causality judgements can be mediated by the formation of within-compound associations.

When Dickinson, Shanks, and Evenden (1984) suggested that human causality judgements can be mediated by the associative learning processes manifest in conditioning, their claim was based upon the finding that such judgements show the selective learning effects observed in conditioning. Specifically, they demonstrated that causality judgement can be *blocked*. Blocking, which was first reported for animal conditioning by Kamin

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We should like to thank Ian McLaren for valuable discussions of the issues addressed by this paper and for his comments on an earlier draft.

(1969), refers to the fact that when a compound of two cues is paired with an outcome, the amount learned about the target cue is reduced if the competing cue has been pretrained as a pedictor of the outcome. Under these circumstances, the competing cue is said to block learning about the target cue. The generality of blocking has been established not only for a variety of animal conditioning procedures, but also recently for human conditioning (Martin & Levey, 1991; Hinchy, Lovibond, & Ter-Horst, 1995). What Dickinson et al. (1984) showed was that causality judgements could also be blocked by pretraining a competing cue as the cause of an outcome. This pretraining reduced the extent to which subjects judged a target cue to be an effective cause following compound training with both cues.

Dickinson et al. (1984) illustrated the application of associative learning theory to causality judgement in terms of both the attentional process of Pearce and Hall (Pearce & Hall, 1980; Kaye & Pearce, 1984) and the variable reinforcement rule of Rescorla and Wagner (1972). According to such theories, learning consists of the acquisition of associative strength by a cue through its temporal pairing with the outcome so that the task of any particular associative theory is to specify the rules or processes that determine the increment or decrement in associative strength accruing from a learning episode. Rescorla and Wagner (1972), for example, suggested that the change in the associative strength of a cue, ΔV, is given by:

$$\Delta V = \alpha \cdot \beta \cdot (\lambda - \Sigma V) \quad (1)$$

where ΣV is the sum of the associative strengths of all the cues present during the learning episodes and λ is the value of ΣV required to predict fully the occurrence of the outcome. Lambda has a positive value on episodes when the outcome occurs but is zero in the absence of the outcome. The term $\lambda - \Sigma V$ can be referred to as the "error term" in that it represents the extent to which the occurrence of the outcome is predicted by the cues on that episode. When the error term is zero, the outcome is fully predicted, and no further learning occurs. Alpha and beta are learning rate parameters that reflect properties of the cue and the outcome, respectively. Rescorla and Wagner suggested that α is determined by the salience of the cue.

Blocking occurs because pretraining endows the competing cue with a positive associative strength so that the error term is reduced in magnitude during compound training relative to a control condition in which the competing cue has not been pretrained. The consequence of this reduction in the error term is to attenuate the size of the increments in associative strength accruing to the target cue during compound training. Not only does the Rescorla–Wagner rule provide an explanation of the blocking of causality judgements, it also predicts the way in which such judgements are controlled by variations in the contingency between a putative cause and an outcome (e.g. Dickinson et al., 1984; Wasserman, Elek, Chatlosh, & Baker, 1993).

Although the demonstration of the blocking of causality judgements provided the original impetus for associative accounts, a variation on this paradigm has also generated the most problematic evidence for such explanations. While replicating the blocking observed by Dickinson et al. (1984), Shanks (1985) reported that judgements of the target cue were also affected by the status of the competing cue in a backward procedure in which the order of compound training and the training of the competing cue alone was

TABLE 1
Design of a Retrospective Revaluation Experiment

Stage 1	*Stage 2*	*Test*
AB+ CD+	A+ C−	B <D

A and C: competing cues; B and D: target cues; +: outcome; − : no outcome

reversed—an effect recently replicated by Williams, Sagness, and McPhee (1994) and previously extended to diagnostic learning by Chapman (1991). The design of the backward procedure is illustrated in Table 1. In the first stage of such a study (e.g. Chapman, 1991, Experiment 3; Shanks, 1985, Experiment 3; Williams et al., 1994, Experiment 2) the subjects receive episodes in which target cues, B and D, are presented in compound with two competing cues, A and C, respectively, and these compounds are paired with the outcome across a number of AB+ and CD+ episodes.[1] As a result of this experience, the Rescorla–Wagner theory anticipates that both the target and competing cues in each compound should acquire associative strength in proportion to their relative saliences (Rescorla & Wagner, 1972). In the second stage, both competing cues receive further training. Cue A is paired with the outcome by itself on A+ episodes, whereas C is presented in absence of the outcome on C− episodes. This should have the effect of augmenting the associative strength of A but decreasing that of C. This difference was verified in Chapman's study by comparing the ratings of the causal efficacy of the two cues at the end of the second stage.

Of prime interest, however, are the ratings of the two target cues, B and D. Given that the competing and target cues have the same relative salience (a reasonable assumption given that the stimuli and events that took the roles of the cues were counterbalanced across A and C and across B and D in the Chapman, 1991, Shanks, 1985, and Williams et al., 1994, studies), B and D should have the same associative strength at the end of compound training in the first stage. Moreover, these strengths should not be affected by the training schedules of the competing cues in the second stage. As the target cues, B and D, are not presented during the second stage, they have no salience on these episodes and hence a zero α value, with the result that no increments or decrements of their associative strengths should occur (see Equation 1). In contrast to this prediction, however, Shanks (1985), Chapman (1991), and Williams et al. (1994) all observed that B was rated as less effective than D. Thus, the training of A and C in the second stage can retrospectively affect the attribution of causal or predictive efficacy to B and D, a process that lies outside the scope of standard associative theories.

[1] This a schematic description of the two experiments. In Shanks' (1985) experiment, the pairing of the compound of the cues with the outcome was probablistic, whereas Chapman (1991) and Williams et al. (1994) preceded the compound episodes with discrimination training between cues that were not involved in the compound training.

A recent study by Van Hamme and Wasserman (1994) has produced a significant advance in our understanding of this retrospective revaluation process by demonstrating that it can occur on an episode-by-episode basis. Across a series of episodes, some of which contained an outcome and some not, their subjects received two compound cues composed of a common cue X and cues unique to each compound, A and B, to generate the compounds AX and BX. When asked to rate the causal efficacy of each cue after every episode, not surprisingly AX+ enhanced and AX− episodes reduced the ratings for A. More important, however, was the finding that these episodes also changed the rating for B, with the AX+ episodes decreasing the rating and AX− augmenting it. Thus, the absent cue underwent a change in causal judgement that was opposite in sign to that for the presented cue.

Not only did Van Hamme and Wasserman (1994) demonstrate the dynamic nature of retrospective revaluation, they also suggested a formal revision to the Rescorla-Wagner equation to encompass this process. While noting that the β learning-rate parameter for the outcome has non-zero (and potentially different) values on episodes when the outcome is present and omitted in the original formulation (Rescorla & Wagner, 1972), they argued that the same might be true for the α parameter for the cue. Specifically, they suggested that α for a cue has a negative value on episodes when that cue is absent. Markman (1989) and, more recently, Tassoni (1995) have made the corresponding suggestion in the case of a connectionist network governed by the least mean squares learning algorithm by coding an absent cue with a negative activation of the respective input unit.

The consequences of this revised coding for retrospective revaluation can be illustrated by reconsidering the backward procedure (see Table 1). On the initial A+ episodes in Stage 2, the error term in Equation 1 will be positive because the associative strength of A will be less than λ after the compound training in Stage 1, whereas the α value for B will be negative in the absence of this cue. Consequently, the associative strength of B will suffer a decrement on the A+ episodes. By contrast, the error term will be negative on C− episodes as the outcome is omitted, with the result that λ is zero. This negative error will then interact with the negative α for the omitted target cue D to yield a positive increment in the associative strength of D. A reiteration of these processes across the episodes of Stage 2 will produce a progressive increase in the associative strength of D and a decrement in that for B, thus producing a retrospective revaluation effect. Note that in this modified Rescorla–Wagner model only the associative strengths of the cues actually presented on an episode enter into the error term.

An obvious omission in this revised application of the Rescorla–Wagner rule is any specification of the processes that determine whether or not a particular absent cue should take on negative rather than zero α value. For example, we need a process that would endow B but not D with a negative α on A+ episodes in order to predict revaluation (see Table 1). A number of authors (Chapman, 1991; Markman, 1989; Tassoni, 1995) have suggested that only the omission of an expected cue should generate a negative α or a negative activation on its input unit in a network and that it is the formation of within-compound associations during the first stage of training that provides the basis for this expectation in the case of B but not D. Thus, an association is formed not only between A and the outcome and between B and the outcome during the AB+ training but also between A and B themselves. Rescorla and his colleagues (see Rescorla

& Durlach, 1981) have provided extensive evidence for the formation of such within-compound associations during compound conditioning with animals. As a result of this within-compound association, the presentation of A on the A+ episodes in Stage 2 should produce an expectation of B, but not D, via the within-compound association between A and B. If it assumed that an expectation of a cue in its absence endows this stimulus with a negative α, a selective loss of associative strength by cue B during A+ episodes is anticipated. Correspondingly, only D should have a negative α on C− episodes and thus acquire associative strength during these episodes.

According to this account, therefore, retrospective revaluation depends on the formation of within-compound associations so that manipulations that interfere with such associations should attenuate the revaluation.[2] The purpose of the present experiment was to assess this prediction by using a variation of the design outlined in Table 1, which employed multiple target and competing cues. The use of multiple cues allowed us to investigate the effect of whether or not each target cue was consistently paired with the same competing cue during compound training on the assumption that consistent pairing favours the formation of within-compound associations.

Experimental Design

The scenario was that employed by Van Hamme and Wasserman (1994), in which each subject plays the role of an allergist who is asked to judge the likelihood that different foods cause an allergic reaction in a hypothetical patient. Thus, the foods play the role of the causal cues and the allergic reaction the role of the outcome. In order to arrive at their judgements, the subjects are shown a number of meals taken by the patient, each of which consists of two different foods during compound training but only a single food during training with the competing cues. During compound and competing cue training the subjects are asked to learn to predict whether the meals produce allergic reactions, with feedback being given after each trial about the occurrence of the reaction.

Table 2 illustrates the trials received by the two groups of subjects, group consistent and group varied, who were trained and tested in the backward condition. Every subject was trained concurrently on three different contingencies: AB+A+, CD+C−, and EF−E−. The first, compound stage of this training consisted of three trial blocks (Trial Blocks 1–3), each of nine trials with a different compound cue being presented on each trial (AB+, GR+, HS+, CD+, . . .). The nine trials in each block were divided into three triplets, with the compound cues of each triplet being trained under the same contingency. Under the AB+A+ and CD+C− contingencies the compound cues were associated with the outcome on each trial, whereas the compound cues trained under the

[2] It should be noted that this explanation of retrospective revaluation in terms of within-compound associations assumes an elemental rather than configural analysis of compound stimuli. Our claim that the representation of a cue retrieved via a within-compound association takes on the opposite α value to the retrieval cue itself assumes that cues and their representations are processed elementally. This assumption is compatible with the demonstration by Williams et al. (1994) that blocking and retrospective revaluation of contingency judgements depend on training schedules and instructions that engender an elemental rather than a configural strategy.

TABLE 2
Design of the Backward Procedure

		Stage				
		1			*2*	
		Trial Blocks				
Group		*1*	*2*	*3*	*4–6*	*Test*
Consistent	AB+A+	AB+	AB+	AB+	A+	B
		GR+	GR+	GR+	G+	R
		HS+	HS+	HS+	H+	S
	CD+C−	CD+	CD+	CD+	C−	D
		JV+	JV+	JV+	J−	V
		KW+	KW+	KW+	K−	W
	EF− E−	EF−	EF−	EF−	E−	F
		LX−	LX−	LX−	L−	X
		MY−	MY−	MY−	M−	Y
Varied	AB+A+	AB+	GB+	HB+	A+	B
		GR+	HR+	AR+	G+	R
		HS+	AS+	GS+	H+	S
	CD+C−	CD+	JD+	KD+	C−	D
		JV+	KV+	CV+	J−	V
		KW+	CW+	JW+	K−	W
	EF− E−	EF−	LF−	MF−	E−	F
		LX−	MX−	EX−	L−	X
		MY−	EY−	LY−	M−	Y

Note: Competing cue triplets: A, G, H; C. J, K; E, L, M. Target cue triplets: B, R, S; D, V, W; F, X, Y. +: outcome; − : no outcome.

EF− E− contingency were presented in the absence of the outcome. Within each trial block, the cues from the different contingencies were presented in a random order. In summary, 9 target cues were presented in compound with 9 competing cues, and three cues of each type were trained under each contingency.

The second stage was also composed of three 9-trial blocks (Trial Blocks 4–6), each consisting of a triplet of cues from the three contingencies. In this stage, however, only the competing cues were presented (A+, G+, H+, C−, . . .). Competing cues from the AB+A+ contingency were paired with the outcome, whereas those from the CD+C− and EF− E− contingencies were presented in the absence of the outcome. Finally, all subjects were asked to rate the causal effectiveness of the 9 target cues (B, R, S, D, . . .) in the test stage.

Given this design, retrospective revaluation is demonstrated if the target cues from the AB+A+ contingency are rated as less effective in causing the outcome than those trained under the CD+C− contingency. Moreover, the degree of revaluation can be assessed by comparison with ratings for the EF− E− contingency under which neither the compound nor the competing cues are paired with the outcome. Complete revaluation occurs if the ratings for the AB+A+ target cues are no higher than those from the EF− E− contingency.

The critical feature of this design concerns the difference in the compound training received by consistent and varied groups during the first stage. In the consistent group, each target cue (e.g. B) is compounded with the same competing cue across the three training trials received by the target during Stage 1 (AB+, AB+, AB+). By contrast, each target is paired with a different competing cue on each of the three trials (AB+, GB+, HB+) for the varied group. The rationale for this difference is predicated upon the assumption that stronger within-compound associations are formed between a target cue and competing cues when the target cue is consistently paired with same competing cue across trials rather than with a different cue on each trial. Thus, to the extent that retrospective revaluation depends upon the strength of such within-compounds associations, we should expect to observe greater revaluation in the consistent group than in the varied group.

To justify this prediction, let us assume that the absolute magnitude of the negative α for a target cue engaged by presenting an associated competing cue is determined directly by the strength of the association between these two cues. This means, for example, that the absolute magnitude of the negative α for target cue B engaged by presenting competing cue A during Stage 2 should be larger for the consistent group than for the varied group, because former subjects experience three A–B pairings during competing cue training in Stage 1 in contrast to the single pairing received by the varied group. However, if this is the only process differentiating the two groups, we should not necessarily expect greater retrospective revaluation in the consistent group. Although the change in the associative strength of the target cue B on Stage 2 trials with cue A should be greater in group consistent than in group varied, this difference could be counteracted by the fact that the varied group may also experience change in the associative strength of B on Stage 2 trials with competing cues G and H. As well as a single A–B pairing during compound training, these subjects also received single G–B and H–B pairings, and so the presentation of competing cues G and H might also be expected to engage the processing of target cue B in the varied group.

There are, however, good grounds for assuming that the within-compound association formed by single pairing of the competing and target cues in the varied group will be minimal. In addition to the pairing of the cues (e.g. AB+), each target and competing cue receives two presentations in the absence of the other cue (e.g. GB+, HB+ and AR+, AS+, respectively). As there is a good evidence that separate presentations of the elements of a compound either before or after compound conditioning interfere with within-compound associations (Rescorla, 1983; Rescorla & Durlach, 1981), we assume that the absence of an objective association between the competing and target cues during Stage 1 compound training for the varied group will produce little if any psychological association between these cues.

The final manipulation concerned the order in which the compound and competing cues were trained. As well as the backward condition illustrated in Table 2, two further groups were trained on a forward procedure in which the two stages were reversed so that the training with the competing cue preceded compound training. Thus, the three contingencies investigated in the forward condition were A+AB+, C− CD+, and E− EF−. With this procedure, blocking is evident if the ratings for the target cues (B, R, S) trained under the A+AB+ contingency are less than those for the cues (D, V, W) from the C− CD+ contingency.[3] Associative theory anticipates that blocking should be comparable in the consistent and varied conditions with the forward procedure. According to the Rescorla–Wagner theory, for example, on each Stage 2 compound trial a target cue of the A+AB+ contingency is paired with the outcome in the presence of a pretrained competing cue, thus reducing the error term on that trial and hence the increment in associative strength. As the associative strength of the competing cues should be equivalent in the consistent and varied conditions, the reduced learning for the target cues should be observed in the two groups. By contrast, such an attenuation of learning should not be evident when the target cues are presented in compound with untrained competing cues under the C− CD+ contingency.

Whether or not within-compound associations should influence the ratings of the targets with the forward procedure is less clear. Rescorla and his colleagues (Rescorla, 1981; Speers, Gillan, & Rescorla, 1980) have demonstrated the presence of within-compound associations for animals trained under A+AB+ contingency and that such associations tend to augment the response elicited by the target cue B on test. This they attribute to the fact that the presentation of B on test activates a representation of the competing cue A, which enhances the response to B through A's association with the outcome. If this process also operates in our causal judgement task, we should expect to observe a reduced blocking effect in the consistent group through an enhancement of the causal ratings to the target cues from the A+AB+ contingency. It should be noted, however, that this process may not operate in a causal judgement task. As the subjects are specifically asked to rate the causal efficacy of the target cues, they may base their judgements solely upon the direct associations between these cues and the outcome.

In summary, a within-compound associative analysis of retrospective revaluation predicts that the causal ratings for the target cues trained under the AB+A+ should be lower than those for the target trained under the CD+C− contingency. This retrospective revaluation effect should be reduced, however, in the varied group relative to the consistent group. By contrast, any blocking effect evident from a comparison of the target ratings for the A+AB+ and C− CD+ contingencies should, if anything, be reduced in the consistent group.

[3] Strictly speaking, a comparison between the ratings given to the target cues from the A+AB+ and C− CD+ contingencies does not provide an unconfounded measure of blocking. This is because any difference may reflect not only blocking of B, R, and S but also an enhancement of learning to D, V, and W brought about by exposure to C, J, and K alone in the first stage (Carr, 1974; Navarro, Hallam, Matzel, & Miller, 1989). The control condition against which to assess blocking is one in which the competing cues C, J, and K are not presented during the first stage of training. For the purpose of the present exposition, however, we shall refer to reduced ratings for the targets from the A+AB+ contingency relative to those from the C− CD+ contingency as "blocking".

Method

Subjects and Stimulus Material

Thirty six students at the University of Cambridge were tested individually on a voluntary basis. The three triplets of competing food cues were: biscuits, mushrooms, chicken; salmon, lettuce, 1potatoes; and bread, steak, melon; and the three triplets of target cues were: cheese, noodles, walnuts; pasta, yoghurt, oranges; and grapes, carrots, rice. Nine subjects were assigned to each cell of the factorial combination of the consistent–varied and forward–backward variables. In each of these four conditions different triplets of food names acted as the target cues in each contingency, with the assignment of particular triplets to a contingency being counterbalanced across subjects within the condition. Further, the pairing of competing and target cue triplets within a contingency was also counterbalanced across the subjects within each condition.

The food cues were presented by displaying to the subject a white card (21 cm × 9 cm) on which was printed in black ink the name(s) of the food(s) in 1-cm upper-case characters. During compound training, the names of the two foods were printed next to each other, with left–right order of the competing and target cues varying unsystematically. The appropriate outcome of a trial was also presented by displaying a card (30 cm × 21 cm) on which was printed either "ALLERGIC REACTION" or "NO REACTION" in 1.7-cm-high black upper-case characters. Causal judgements were scored on a visual-analogue scale (VAS) with 8 labelled as "definitely", 4 as "possibly" and 0 as "definitely not".

Procedure

At the start of the experiment, the following instructions were read to the subject from a script by the Experimenter (JB):

> It should be emphasized that the following exercise is not a test of your personal abilities or skills. The data will not be recorded in a personal manner. This is an exercise to gauge how the human brain forms opinions when presented with some data. If anything is unclear in the following instructions I can repeat points to you but to prevent me from influencing your performance I can't answer any direct questions. To start I would like to gauge your initial opinions of some foods. This is to check whether you hold any particularly extreme opinions of the foods that we will be using in these tests which may influence your performance. If you can just grab this opinion scale here . . . [a VAS card was presented to the subject] . . . You can use this to express your opinion to me on a scale from one to eight. I'd like you to imagine that I have fed to an ordinary individual, who is completely unknown to you, the following foods. If you can, express, using the opinion scale, the likelihood that he/she will have a nasty allergic reaction on eating these foods. He/she may not have an allergic reaction to any foods and you should base your opinion on the fact that most people do not suffer from allergic reactions and that you know nothing about this individual. Imagine you had to bet on the outcome of him/her eating the food. This is purely to test for any strong opinions of certain foods you may have that may affect your performance on the tests.

The names of the nine target food cues were then read in a random order, with time being allowed for the subject to express the rating verbally after each name. The instruction then continued with:

> I'd now like you to imagine that you are an allergist, someone who tries to discover the cause of allergic reactions in people. You have just been presented with a new patient, "Mr. X", who suffers from allergic reactions when he eats. In an attempt to discover which foods cause him

> to have allergic reactions you arrange for him to eat various foods for a meal on each day and you observe if he has an allergic reaction or not. I'm going to display to you the food he has for each meal on these cards . . . [a sample card was displayed] . . . Sometimes there will be one food on the card and sometimes two. When I present them to you if you could just read back to me what's on each card so I know that you are still paying attention to the foods. Then I'd like you to state in a "yes" or "no" fashion whether your patient will suffer an allergic reaction after eating this meal. I will then tell you whether an allergic reaction occurred. Obviously at first you will have to guess as you will not know anything about your patient, but hopefully as I continue to present meals you will begin to learn which foods cause him an allergic reaction and which do not. At the end of the presentation, I'm going to ask you, using the opinion scale again, to rate the same foods that I showed you before but now for their likelihood of causing "Mr. X", your patient, an allergic reaction, but don't worry about that; I will give you more precise instructions when the time comes.

The cue cards were then presented to the subject for each trial of Stages 1 and 2. To recap: Each stage consisted of three 9-trial blocks, each composed of one presentation of the compound or competing cues from the three contingencies. Within a trial block, these cues were presented in a random order. In the backward condition, Stage 1 consisted of training with the compound cues, whereas Stage 2 trained the competing cues alone (see Table 2). Subjects in the forward condition received competing-cue (Stage 1) and compound training (Stage 2) in the reverse order. Within these conditions, a target cue was paired with the same competing cue in every trial block of compound training for the subjects in the consistent group but with a different competing cue in each trial block in the varied group. The three contingencies were, in the backward condition: AB+A+, CD+C−, and EF−E−; and, in the forward condition: A+AB+; C+CD+, and E− EF−. After the subjects had given the "yes" or "no" response, the appropriate outcome card was displayed, and the outcome was also spoken aloud by the experimenter. Following the last trial of Stage 2, the verbal instructions continued with:

> If you can grab the opinion scale again, I'd like you to re-rate your opinion of the original foods I presented to you but now for "Mr. X" in light of the data you have just seen.

The nine target food cues were then read to the subjects again in a random order, with time being allowed for subjects to make their rating following the presentation of each cue. Finally the subjects were thanked for their time and patience, and any questions they might have were answered.

Results

All subjects learned to discriminate between the cues on the basis of their association with the outcome. Figures 1 and 2 show the percentage of trials in the forward and backward conditions, respectively, on which the subjects predicted that the cues would cause an allergic reaction by giving a "yes" response in each trial block. By the end of the first stage of training in the forward condition, all subjects gave a "yes" response more frequently to the competing cues in the A+AB+ contingency than in the C− CD+ and E− EF− contingencies. During Stage 2, the compound cues in the C− CD+ contingency acquired the capacity to elicit "yes" responses until on the final trial block the percentage of responses was comparable to that observed to the compound cues of A+AB+ contingency. In this final trial block all subjects discriminated these compound cues from those presented under the E− EF− contingency.

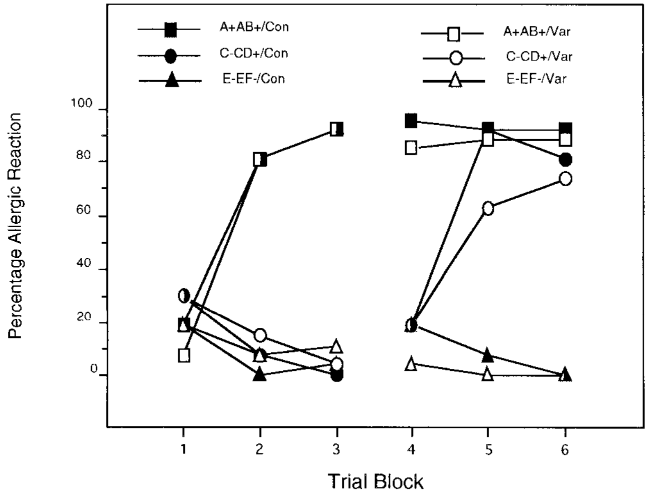

FIG. 1. Mean percentage of trials in each trial block on which the subjects identified the cues as causing an allergic reaction during training under the forward contingencies. The pairing of the competing and target cues during the compound training in Stage 2 was either consistent (Con) or varied (Var).

The corresponding pattern of acquisition was observed in the backward condition (see Figure 2). In the first stage, the compound cues of the AB+A− and CD+C− contingencies acquired the capacity to elicit prediction of the allergic reaction, and by the final block all subjects gave more "yes" responses to these compounds than to those of the EF− E− contingency. The omission of the target cues in Stage 2 produced an initial drop

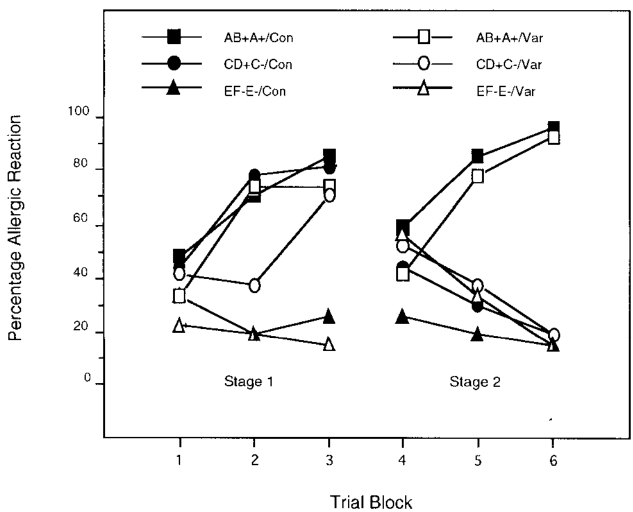

FIG. 2. Mean percentage of trials in each trial block on which the subjects identified the cues as causing an allergic reaction during training under the backward contingencies. The pairing of the competing and target cues during the compound training in Stage 1 was either consistent (Con) or varied (Var).

in responding in the AB+A+ and CD+C− contingencies, which was rapidly reacquired by the competing cues of the former contingency. By the final trial block, all subjects predicted the allergic reaction more frequently to the competing cues of the AB+A+ contingency than to those of the other contingencies.

The most important results concern the way in which training under the various contingencies changed the ratings of the causal effectiveness of the target cues. To assess this change, the initial rating given to each target cue was subtracted from the final rating given to that cue on test, and the resulting difference was then summed across the three target cues in each contingency to yield a total difference score. Thus, positive difference scores indicate that the training contingency had enhanced judgements of the causal effectiveness of the respective cues. The mean total difference scores for the target cues of the forward and backward conditions are displayed in Figures 3 and 4, respectively.

Blocking was observed in the forward condition in that the difference scores for the target cues of the A+AB+ contingencies were lower than for those of the C− CD+ contingency (see Figure 3). Indeed, blocking appeared to be complete in that difference scores for the A+AB+ contingency were, if anything, negative and no higher than those observed for the untrained target cues of the E− EF− contingency. Moreover, the magnitude of blocking was comparable in the consistent and varied conditions. A very different pattern was observed, however, in the backward condition. Here a revaluation effect corresponding to the blocking observed in the forward condition was evident only in the consistent condition (see Figure 4). In this condition the training with the AB+A+ contingency enhanced the ratings for the target cues no more than the control EF− F− contingency and less than the CD+C− contingency. In the variable condition, by contrast, the AB+A+ and CD+C− contingencies produced comparable increments in the difference scores, which were greater than those observed for the EF− E− contingency.

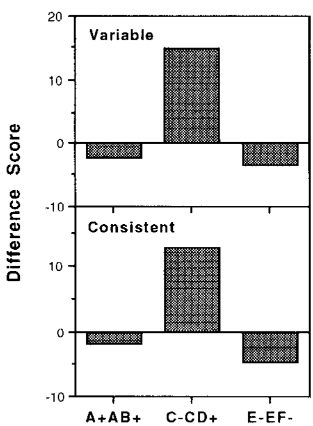

FIG. 3. Mean total difference scores for the causal ratings of the target cues trained under the forward contingencies. The bottom panel shows the scores when the pairings of the competing and target cues during compound training in Stage 2 were consistent and the top panel when the pairings were varied.

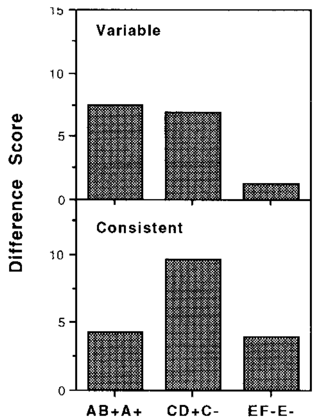

FIG. 4. Mean total difference scores for the causal ratings of the target cues trained under the backward contingencies. The bottom panel shows the scores when the pairings of the competing and target cues during compound training in Stage 1 were consistent and the top panel when the pairings were varied.

This description was verified by statistical analyses, which assessed the reliability of the contrasts against a Type I error rate of 0.05. The differences scores were initially subjected to a mixed analysis of variance in which the between-subject factors of order and consistency distinguished the scores for subjects trained with the forward and backward procedures and under the consistent and varied conditions, respectively. The within-subject factor of contingency contrasted the scores for target cues trained under the three different contingencies. To determine the source of the significant Order × Contingency interaction, $F(2, 64) = 23.47$, revealed by this overall analysis, separate analyses were conducted for the forward and backward conditions. There was a significant main effect of contingency in the forward condition, $F(2, 32) = 64.24$, which did not interact with the consistency factor, $F < 1$. Pairwise comparisons using the Newman–Keuls procedure revealed that the scores for the target cues trained under the C− CD+ contingency were significantly higher than those for the cues trained under the two remaining contingencies, which, in turn, did not differ. By contrast, the analysis of the backward condition yielded a significant Consistency × Contingency interaction, $F(2, 32) = 3.45$, although the effect of the contingency was reliable in both the consistent, $F(2, 16) = 4.21$, and varied condition, $F(2, 16) = 12.94$. Newman–Keuls pairwise comparison revealed a pattern of difference scores in the backward-consistent condition similar to that observed in the forward procedure, with the CD+C− contingency producing scores that were significantly higher than those for the other two contingencies, which, in turn, did not differ. By contrast, in the varied condition there was no significant difference between the scores for the AB+A+ and CD+C− contingencies, both of which were higher than those for cues trained under the EF− E− contingency.

The interpretation of the differences scores was not compromised by initial differences in the causal ratings assigned to the target cues. An overall analysis of the initial ratings of the target cues similar to that performed for the difference scores failed to reveal any significant main effects and interactions: $F(1, 32) < 3.42$ and $F(2, 64) < 1.14$ in all cases. The overall mean initial rating summed across the three target cues in each cell was 4.6.

Discussion

The present findings replicate the blocking and retrospective revaluation of contingency judgements observed in previous studies (Dickinson et al., 1984; Chapman, 1991; Shanks, 1985; Williams et al., 1994) and thus substantiate the general claim that such judgements discriminate against redundant predictors of the outcome. More important in the present context, however, is the evidence for the involvement of within-compound associations in retrospective revaluation. Although blocking was evident with the forward training procedure in both the consistent and varied conditions, retrospective revaluation was observed only when the competing and target cues were consistently paired during compound training with the backward procedure. As the formation of within-compound associations should depend upon consistent pairing of the competing and target cues, this finding suggests that retrospective revaluation is mediated by these associations.

Associative theories, such as that offered by Rescorla and Wagner (1972), predict that blocking should occur whether or not the target and competing cues are consistently paired during compound training. Pretraining the competing cues under the A+AB+ contingency should endow each of these cues with a positive associative strength, so that when a target cue is paired with the outcome in compound with a competing cue, the error term generated by the episode will be much reduced. As a consequence, the acquisition of associative strength by the target cues will be reduced under the A+AB+ contingency relative to the C−CD+ contingency. Moreover, a comparable reduction should occur whether or not the competing and target cues are consistently paired during compound training. The addition of within-compound associations would, if anything, reduce the magnitude of the manifest blocking effect by augmenting the response to B via its association with the pretrained competing cue A. There was no evidence for such an effect in the present study in that the blocking effect was similar in the varied and consistent groups. We did note in the introduction, however, that in a judgement rather than conditioning task the test measure should be determined solely by the properties of the target cue and not by the activation of representations of associatively related cues.

In order for associative theory to encompass examples of retrospective revaluation, we considered the possibility that an expected but omitted cue generates a negative α parameter. According to this analysis, the target cues should have a negative parameter value during training of the competing cues under the AB+A+ contingency but only in the case of subjects trained in the consistent condition. In this condition associations should be formed between each pair of target and consistent cues during compound training, so that the subsequent presentation of a competing cue evokes an expectation of its paired target cue. In the presence of this expectation, the omission of the target cue endows it with a negative α, which then functions in concert with a positive error term. As the associative strength of the competing cue alone does not fully predict the outcome, the error term, at least on the initial trials of training with the competing cues alone, should be positive. Under these circumstances, the Rescorla–Wagner rule (see Equation 1) specifies a decrement in the associative strength of the target cues.

This account also predicts that a complementary process should also operate for the target cues trained under the CD+C− contingency. Once again, each target cue should have a negative α on episodes involving the presentation of the competing cue with which it was consistently paired during prior compound training. Under this contingency, however, the α parameter acts in concert with a negative error term. As the prior compound training endowed the competing cues with a positive associative strength, the presentation of these cues in the absence of the outcome generates a negative error term, with the result that the Rescorla–Wagner rule (see Equation 1) predicts an increment in the associative strength of the absent target cue on such episodes.

Thus, this analysis claims that the retrospective revaluation observed in the present studies reflects a combination of a decrement in the associative strength of the target cues trained under the AB+A+ contingency and an increment in the strength of cues trained under the CD+C− contingency. In general, the independent evidence for incremental and decremental processes is somewhat mixed. As we have already noted, Van Hamme and Wasserman (1994) observed both a decrement in the causal ratings of an absent cue on episodes when the outcome was presented and an increment on episodes when the outcome was omitted. The analogue of this latter change has also been reported in the case of animal conditioning. Both Kaufman and Bolles (1981) and Matzel, Schachtman, and Miller (1985) reported that exposure to the CD+C− contingency enhanced the conditioned response controlled by the target cue relative to a control group that did not receive any training with the competing cue alone. By contrast, the evidence that exposure to an AB+A+ contingency decreases the conditioned response to the target cue is less secure. Although Kamin (1969) reported just such an effect, he attributed it to processes other than retrospective revaluation, and subsequent attempts to replicate this effect have been unsuccessful (e.g. Kalat & Rozin, 1972; Schweitzer & Green, 1982).

Although the dependence of retrospective revaluation upon within-compound associations allows such effects to be encompassed by formal associative learning rules, such as that offered by the modified Rescorla–Wagner theory, the nature of the psychological processes by which these associations function to control learning remains to be determined. As we have already noted, Markman (1989) and Tassoni (1995) suggested that within-compound associations result in an absent but expected cue being coded by a negative activation of the respective input unit within a connectionist network. Moreover, the relaxation of a constraint that McLaren, Kaye, and Mackintosh (1989) imposed upon the activation values of their units in a connectionist model of associative learning provides a process by which this coding could take place.

McLaren et al. (1989) assumed that a representational unit for a cue can be activated both by an external input excited by presenting the cue itself and by internal inputs excited, for example, through within-compound associations. In addition, the activation level of a unit is also controlled by the output of a modulator whose function it is to assess the extent to which the occurrence of the cue represented by the unit is unexpected or surprising. This modulator boosts the activation of the unit by an amount determined by the difference between its external and internal inputs. Thus, if the presentation of a cue is unpredicted, the internal input will be zero, and the boost will be large. By contrast, if the internal activation equals the external activation, the occurrence of the cue will be expected, and no modular boost will be applied to the unit.

As described, this model predicts that the representational unit of a target cue could well have a net negative activation level during the training of the competing cue in the backward consistent procedure of the present study. The presentation of the competing cue activates the representational unit for the associated target cue via an internal input, and in the absence of any external input the modulator delivers a strong negative boost to this unit. If the magnitude of this boost outweighs the direct internal input, the target unit takes on net negative activation levels during these episodes. As the target unit activation level functions like the α parameter in connectionist learning algorithms, this model anticipates an enhancement of the connection weight between the target and outcome units under the consistent CD+C− contingency and a decrement in this weight under the consistent AB+A+ contingency. In fact, it was to prevent just such retrospective revaluation that McLaren et al. (1989) arbitrarily constrained activation levels so that the modulator could not induce negative values (McLaren, personal communication). The present results suggest that this constraint should be removed.

It should be noted, however, that the prediction of retrospective revaluation by the McLaren et al. (1989) model is parameter-dependent. During the presentation of competing cue alone, the representational unit for an associated target cue will receive two inputs; the first is a positive input from the unit for the competing cue, and the second is the negative input from the modulator. As we have already discussed, retrospective revaluation depends upon the influence of the modulator dominating the target unit so that it takes on a net negative activation level. It is clear, however, that there are other forms of learning for which the model would have to assume dominance by the positive input from the associated cue unit. One such phenomenon is mediated conditioning. Holland (1981) initially trained rats to associate a food with a tone before pairing the tone with toxicosis induced by an injection of lithium chloride as the outcome. The idea behind this study was to assess whether this procedure could bring about mediated conditioning of an aversion from the food. The assumption is that presentations of the tone during aversion conditioning activate a representation of the associated food, thus allowing this representation to enter into association with the noxious state induced by the lithium. The results of Holland's (1981) justify this assumption in that the animals showed a mediated aversion to the food, and subsequent research by Holland and his colleagues (Holland, 1983; Holland & Forbes, 1982) has shown that an associatively activated representation of a food cue can act like the actual presentation of the cue in a variety of conditioning procedures. To explain such mediated conditioning, the modified McLaren et al. model could assume that the cues and procedures employed by Holland were such as to maximize the positive input to the target unit at the expense of the negative influence from the modulator.

The McLaren et al. (1989) model is not the only associative theory that provides a non-arbitrary account of the role of within-compound associations in retrospective revaluation. In his SOP model of conditioning, Wagner (1981) assumes that stimuli are represented by nodes in an associative memory which are composed of a number of elements. Each of these elements can be in one of three states at any moment in time: one inactive state (I) and two active states 1 (A1) and 2 (A2). The presentation of an unexpected stimulus, be it a cue or outcome, causes a transition from I to A1 for some proportion of the elements whose state then decays back to I through A2. Exciting a node via an associative connection, however, causes a state transition directly from I to A2. Changes in the associative connection between nodes depend upon the temporal overlap of their states. To the extent that the elements of two nodes are concurrently in A1, there is an increment in the strength of an excitatory connection between them, whereas when the elements of one node are in A1 while those of another are in A2, an inhibitory connection from the first to the second is strengthened.

The occurrence of blocking follows directly from these learning processes. During the initial episodes of pretraining to the competing cues under the A+AB+ contingency, the nodes for the competing cues and the outcome are concurrently in A1 thus strengthening excitatory connections between them. This means that presentation of a competing cue will come to excite a proportion of the elements of the outcome node into A2 prior to the presentation of the outcome itself, and, as a result, there are fewer elements to be activated into A1 when the outcome occurs during compound training. Consequently, the increments in the excitatory connection between the target and outcome nodes will be much reduced relative to training under the C− CD+ contingency, thus producing the blocking effect. Note that the degree of blocking will be the same whether or not a target cue is compounded with the same competing cue on each episode in the consistent condition or with a different competing cue in the varied condition, as long as, on average, the competing cues all have the same associative strength.

As it stands, the SOP model does not anticipate retrospective revaluation even when within-compound excitatory associations are formed during the compound stage of the consistent AB+A+ and CD+C− contingencies. When the competing cue is presented alone, a proportion of the elements of the target node should enter A2 due to excitation via the within-compound association, but as the SOP model assumes that cue elements in A2 are ineffective in engaging the learning processes, these episodes should be without consequence for associative connections involving the target cue. The SOP learning process can be readily extended, however, in a symmetrical fashion, so that learning can result from these episodes. Our suggestion is that excitatory connections are formed between nodes to the extent that their elements are concurrently in the same state, whether this be A1 or A2. Correspondingly, inhibitory connections are strengthened to the extent that the elements are in different states. Thus, an inhibitory connection is strengthened not only when the cue elements are in A1 and the outcome elements in A2, as Wagner (1981) suggested, but also when the states of the elements are reversed.

The consequences of this modification are most readily apparent in the case of the CD+C− contingency. The presentation of the competing cue alone following compound training should excite the elements of both the target and outcomes nodes into the A2 states via the within-compound and competing cue–outcome excitatory associations, respectively, which were established during compound training. This concurrent and congruent activation of the elements of the target and outcome cues will serve to strengthen the excitatory connection between their representational nodes, thus producing retrospective revaluation of the causal efficacy of the target cue. Experience with the AB+A+ contingency may also contribute to this revaluation. As in the case of the CD+C− contingency, presentation of the competing cue alone should ensure that target cue and outcome elements are concurrently in A2. In this case, however, the excitatory consequences of this overlap will be counteracted by the presentation of the outcome on these episodes. The occurrence of the outcome itself will excite the remaining, inactive elements of its representational node into A1, thus bringing about an incongruence of the state for some of the elements of the target cue and outcome nodes. Whether the model predicts a net decrement or increment in the associative strength of the target cue depends upon which of the processes engaged by congruent and incongruent elemental states is the stronger. At the very least, however, the net increment in the associative strength of the target cue should be smaller under the AB+A+ than under the CD+C− contingency. Thus, retrospective revaluation follows naturally from the SOP model once the full set of learning conditions is specified as a symmetrical function of elemental activation states.

Whatever the relative merits of these different associative accounts, the demonstration that retrospective revaluation but not blocking depends upon a consistent relation between the competing and target cues is problematic for other theories of causal judgement. The main alternatives to a purely associative account assume that subjects base their judgements in one way or another upon a computation conducted at the time of testing. For example, Shanks and Dickinson (1987) proposed that the target cue and the compound of the target and competing cues acquire independent associative strengths during training and that the causal judgement is based upon a rule that computes the difference between these strengths. Others have argued that such judgements are based upon the computation of the contingency between a putative cause and an outcome (e.g. Cheng & Novick, 1992), and Melz, Cheng, Holyoak, and Waldman (1993) have recently discussed the application of this type of theory to cue selection effects, such as blocking and retrospective revaluation. Without going into details, the important point in the present context is that all these theories assume that the subjects compute the judgement at the time of testing based upon evidence accumulated separately for the compound and competing cue stage of training. Thus, these theories assume that the same processes mediate blocking and retrospective revaluation. Given this assumption, the order in which training occurs should have no effect upon the way in which the consistency with which the competing and target cues are compounded impacts upon the judgement. As the present results are clearly at variance with this prediction, this study not only identifies the detailed associative processes that may mediate retrospective revaluation but also discriminates in favour of a purely associative account of causality judgement in general.

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Manuscript received 22 May 1995
Accepted revision received 24 August 1995

Des associations intracomposé sous-tendent la réévaluation rétrospective de jugements de causalité

Le rôle d'associations intracomposé dans la réévaluation rétrospective de jugements de causalité est étudié avec une procedure en deux étapes au cours de laquelle les sujets doivent apprendre si divers stimuli nutritifs causent des réactions allergiques chez d'hypothétiques patients. Dans l'étape à indice composé, un certain nombre de ces indices, constitués chacun d'un stimulus cible et d'un stimulus en compétition, sont associés à la réaction au travers d'une série d'essais, tandis que dans l'étape à indice simple, les sujets peuvent apprendre quel indice en compétition, présenté seul, provoque la réaction. Chaque stimulus cible était associé au même indice en compétition lors de tous les essais composés de la condition homogène, mais avec un stimulus en compétition différent lors des essais de la condition variée. Dans une procedure antérograde, au cours de laquelle l'étape à indice simple précède l'entraînement avec l'indice composé, l'estimation de l'efficacité causale des stimuli cibles est réduite ou bloquée lorsqu'on les utilise conjointement avec un indice compétitif préalablement associé avec la réaction. De plus, l'amplitude de cette diminution est comparable dans les conditions homogène et variée. En revanche, cet effet disparaît lorsqu'on inverse les étapes à indice simple et composé dans une procédure rétrograde. Les évaluations d'indices cibles liés à des indices en compétition ultérieurement associés à la réaction sont réduites seulement dans la condition homogène. Si l'on suppose que des associations plus fortes se sont crées entre les stimuli cible et en compétition au cours de l'étape à indice composé de la condition homogène, par rapport à la condition variée, ce pattern suggère que la réévaluation rétrospective des jugements de causalité peut être sous-tendue par la constitution d'associations intracomposé.

La formación de asociaciones intracompuesto media la reevaluación retrospectiva de los jucios de causalidad

Se examinó el papel de las asociaciones intracompuesto en la reevaluación retrospectiva de los juicios de causalidad, mediante un procedimiento de dos estadios en el que los sujetos debían aprender si distintos alimentos causaban una reacción alérgica en unos pacientes hipotéticos. En la fase de claves compuestas varios agregados de estímulos, consistentes en un estímulo competidor y un estímulo crítico, fueron asociados con la reacción a lo largo de varios ensayos, mientras que en la fase de claves únicas los sujetos tuvieron la oportunidad de aprender cuál de las claves competidoras causaba la reacción cuando era presentada por sí sola. En la condición fija, cada estímulo crítico fue presentado siempre junto a la misma clave competidora mientras que en la condición variable era presentado junto a una distinta clave competidora en cada ensayo. En un procedimiento hacia adelante, en el que la fase de clave única precedía al entrenamiento con claves compuestas, los juicios acerca de la eficacia causal del estímulo crítico fueron reducidos o bloqueados debido a la presentación del mismo en compuesto con una clave competidora que había sido previamente emparejada con la reacción. Además, la magnitud de esta readucción fue equivalente en las condiciones fija y variable. Sin embargo, esto no ocurrió despues de un procedimiento hacia atrás, en el que se invirtió el orden de las fases de claves únicas y compuestas. Los juicios relativos a las claves críticas presentadas en compuesto con claves que luego serían emparejadas con la reacción sólo fueron alterados en la condición fija. Si suponemos que se formaron asociaciones más potentes entre los estímulos crítico y competidor durante la fase de claves compuestas en la condición fija que en la variable, este patrón de resultados indica que la reevaluación retrospectiva de los juicios de causalidad puede estar mediada por la formación de asociaciones intracompuesto.