Backward associations: Differential learning about stimuli that follow the presence versus the absence of food in pigeons

ELIOT HEARST

Indiana University, Bloomington, Indiana

During training intended to establish positive and negative backward associations, pigeons received periodic 3-sec illuminations of a grain magazine, with food simultaneously available on 50% of the illuminations. For backward-positive subjects, a red keylight followed food trials only; for backward-negative subjects, it followed no-food trials only. During this training, the birds hardly ever pecked the red stimulus (no evidence of backward conditioning). However, when the red stimulus subsequently preceded and signaled grain for all birds, the backward-positive subjects pecked sooner and more often than did the backward-negative subjects, and control subjects performed at an intermediate level. Increases in the amount of original training did not significantly change the facilitatory effects of the backward-positive stimulus, but seemed to enhance the retarding effects of the backward-negative stimulus. These group differences cannot be attributed to what happened after the backward stimuli during original training. The features of the present technique that could possibly have produced strong and long-lasting positive and negative backward associations are discussed in comparison to prior research that has indicated weak or transitory evidence of true backward conditioning.

In conventional studies of Pavlovian backward conditioning, a presumably neutral stimulus (CS) is presented only after an unconditioned stimulus (US). Although the effects of such a procedure have been investigated in many experiments, including those of Pavlov himself, considerable skepticism remains about the existence, nature, and reliability of learning in animals exposed to such an arrangement. For various reasons, some reviewers of the literature (e.g., Hall, 1984; Mackintosh, 1974) have questioned the reality of excitatory backward conditioning; its appearance has been said, if anything, to be a transitory phenomenon, often replaced by the CS's gradual development of conditioned inhibitory powers due to the relatively long US-free intervals that follow each CS (see also Miller & Spear, 1985).

Other reviewers (e.g., Ayres, Haddad, & Albert, 1987; Razran, 1956, 1971; Spetch, Wilkie, & Pinel, 1981) have argued that the overall evidence for the existence of excitatory backward conditioning is strong and undebatable, especially when noxious USs are employed. Spetch et al. concluded that failure to accept the legitimacy of the phenomenon seems to reflect theoretical biases held by many workers in the field, because acceptance of its reality

would violate traditional conceptions of CSs as signals or predictors and would fail to conform to modern views about the roles of informativeness, redundancy, and contingency in Pavlovian conditioning. Moreover, following a line of reasoning offered by several previous writers, Spetch et al. stressed the possibility that backward associative learning confers an evolutionary advantage on organisms; for instance, they can learn to react defensively to a novel stimulus (e.g., characteristics of an unfamiliar predator) detected after a sudden but unsuccessful attack.

The pigeon autoshaping experiments reported here differ in procedure and rationale from much of the prior work on backward associations. Although Spetch et al.'s (1981) criteria for a rigorous demonstration of backward conditioning were implicitly followed (there was no temporal overlap between the US and CS events; control groups were included to determine whether the particular backward pairings were crucial for the observed outcomes; the possibility was eliminated that the backward CS gained its powers because of some forward trace relationship to the US on the next trial), the present research relied on special postacquisition assays of the effects of various backward relationships between US and CS events. Typically, backward conditioning has been assessed via presentation of CS-alone test trials that either are interspersed with the trials involving backward pairings or are given after the pairings phase is completed (see Mackintosh, 1974). However, subjects may have learned about US-CS relationships even when they fail to display measurable conditioned responses via the typical assays. I attempted to evaluate this possibility by converting the formerly backward stimulus into a standard, reinforced

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forward CS during the final, transfer phase of the experiment. The CS's acquisition of excitatory powers (elicitation of keypecking) was examined in relation to acquisition in other groups that had been treated differently in the earlier phase (cf. Meck, 1985).

A novel yet major goal of the present research was to compare two potential types of backward conditioning, which were expected to yield opposite behavioral effects. Besides the birds exposed to a procedure in which a keylight CS followed only food delivery (conventional backward conditioning), the studies also included birds for which the same keylight CS followed only the absence of food (i.e., the grain magazine light came on but food was unavailable). This comparison between stimuli that follow US presence and those that follow US absence was implemented by arranging for food to accompany only half of the daily magazine illuminations during original training. Thus, in *backward-positive* groups, the keylight would follow only the presentation of food, whereas in *backward-negative* groups, the keylight would follow only the absence of food.

By the use of several control, or baseline, treatments (no keylights after any kind of trial; the same number of keylights as in the positive and negative groups, but presented randomly after food or no-food trials), it ought to be possible to determine whether prior exposure to a positive correlation between a backward CS and food yields facilitatory effects and whether prior exposure to a negative correlation yields retarding effects, as revealed when the CS precedes and signals food for all subjects in the final phase. Any group differences at that time must be due to the previous formation of some kind of backward associations. They cannot be attributed to forward effects of the stimuli that followed food or no food (or both) in the earlier phase because the periods extending from backward CS termination until the next trial were identical in all these groups.

In each of the experiments in this report, the effects of backward-positive training are compared with those of backward-negative training. In separate experiments, I examined such factors as (1) how much original training is given, because some of the aforementioned research suggests changes in the valence of a backward stimulus as training progresses; (2) whether the magazine illuminations are themselves signaled or unsignaled during original training (see Dolan, Shishimi, & Wagner, 1985; Williams & Overmier, 1988); and (3) whether both backward-positive and backward-negative stimuli are presented to individual subjects, as compared to presentation of only one of these types of stimuli.

General Method

Subjects. Experimentally naive female White Carneaux pigeons, approximately 3 to 8 years old, served as subjects. They were maintained at 75% of their free-feeding weights and had been deprived of food for about 23 h at the beginning of the experimental sessions, which occurred daily. The birds were individually housed under constant illumination, with water always available.

Apparatus. Except for Experiment 4, standard Lehigh Valley Electronics pigeon keypecking chambers were employed. Depending

on the experiment, either two or four of these chambers were in use simultaneously, but subjects run at the same time did not necessarily receive the same experimental treatment. In all of the chambers, the response key (2.5-cm in diameter) was in the center of the front panel, approximately 25 cm above the floor. An Industrial Electronics Engineers in-line projector, mounted behind the translucent key, permitted illumination of the key with three different stimulus displays: a .35-cm wide, 2.2-cm long white vertical line centered on a black background, or a solid red or green field. A force of about .15 N against the key activated a microswitch and was recorded as a peck. A continuously lit houselight (GE 1820 bulb mounted 7 cm above the key) was shielded from direct view by a metal casing that deflected light toward the ceiling.

During the training and testing phases, mixed grain was periodically accessible to the subjects for 3 sec via a raised hopper within an aperture approximately 10 cm above the floor and centered under the key. The aperture was illuminated with white light (Sylvania 28ESB bulb) during time when grain was available and during equally brief times when the explicit absence of a reinforcer was scheduled. A photocell circuit detected entries of a pigeon's head into the lit aperture. The number of photocell interruptions closely matched the number of trials on which food was present in the magazine. The correspondence of these numbers, as well as occasional informal observation of the birds, indicated that birds soon ceased entering the magazine when it was lit but no food was there. The constant background masking noise level in the boxes was approximately 84 dB. Electromechanical equipment in an adjacent room recorded keypecks and controlled the programming of stimuli and reinforcers.

The two boxes used in Experiment 4 were basically the same as those employed in the other work, except that they were Grason-Stadler chambers fitted with a specially constructed front panel (to enable prior research unrelated to the present studies). The pecking key was in the same position on the panel as for the other boxes, but the grain magazine was located in the lower left section of the panel (about 10 cm above the floor), rather than directly under the key. Furthermore, the (unshielded) houselight (Sylvania 28ESB bulb) was situated in the center of the ceiling and was not directly above the response key.

Procedure. All birds were first given 2 consecutive days of magazine training. On the first day, the experimenter gently held the subject and directed its head toward the lighted magazine and raised hopper, from which the bird was allowed to eat for 5–10 sec. Then the bird was released, the box was shut, and the subject received 5–10 food presentations of about 10 sec each, followed by 30 3-sec presentations separated by variable times averaging 30 sec. On the second day, all birds were placed in the chambers and given 30 additional 3-sec food deliveries on the 30-sec schedule. Almost all the birds ate reliably throughout the second day of magazine training and the rest of the experiment. New subjects replaced the few birds that did not eat regularly during magazine training or, even more rarely, that had initially eaten well but entered the magazine on fewer than 80%–90% of the grain presentations during the first two or three sessions of subsequent training.

The training phase began on the third day. The experiments differed somewhat depending on the specific factors under study, but all sessions consisted of an equal number (25 or 26) of two types of trials: one (positive) involving 3-sec grain availability in the lit magazine and the other (negative) involving 3-sec illumination of the magazine without grain. In some experiments, both kinds of trials were preceded by a 6-sec illumination of the keylight with the vertical line, whereas in other experiments, the magazine illuminations were not signaled in any way. All grain presentations were response-independent, so that the condition with a keylight signal preceding grain was essentially an autoshaping procedure with 50% reinforcement.

The novel aspect of the experiments concerned the 6-sec key illuminations that could follow magazine illuminations. During the

training phase, the key was lighted red immediately after all grain deliveries for one group and immediately after all magazine illuminations without grain for another group. Control groups (not included in all experiments) received either (1) no red-light presentations at all, or (2) red lights immediately after half the positive and half the negative trials. In Experiments 1-3, no key illuminations occurred after the trials that were not followed by a red light, but in Experiment 4, a 6-sec green light was presented after such trials.

Several different sequences of food and no-food trials were constructed by the experimenter and were applied in an irregular daily order over the course of work with a subject. No kind of trial occurred more than three consecutive times within any of these predetermined sequences. The variable intertrial intervals (ITIs), during which the key was dark, averaged 45 sec (range: 15-75 sec).

Except for Experiment 2, in which the number of training sessions was explicitly manipulated, the training phase lasted seven sessions. On the day after completion of that phase, the birds began the transfer (test) phase, in which the formerly backward stimulus or stimuli now preceded and signaled magazine illuminations. Half of the 6-sec key-color presentations were followed by grain and half by the lit magazine with no grain. The transfer phase continued for five sessions and no backward stimuli were presented during this time. The ITI conditions were the same as those employed during the training phase.

Throughout an experiment, the total number of trials with at least one keypeck, the total number of trials until the first trial with a peck, and the total number of keypecks per stimulus were recorded daily on printout and electromechanical counters.

EXPERIMENT 1

The first experiment was an attempt to establish the basic sensitivity of our general technique. Would a transfer task involving the placement of all subjects on a forward conditioning procedure permit assessment of the presumed excitatory and inhibitory powers acquired by stimuli that had consistently followed the presence and absence of food, respectively? As a baseline for detecting both positive and negative effects, two comparison groups were used: one that had never been exposed to the backward stimulus during original training and another that had received presentations of the backward stimulus equally often after food and no-food trials.

Method

Thirty experimentally naive pigeons were assigned to four groups that were treated differently during the 7-day training phase that followed learning to eat from the magazine. Throughout this phase, the members of all groups received 50 daily illuminations of a 6-sec vertical line on the response key, followed immediately by grain presentations on 25 trials, and by mere lighting of the magazine on the other 25 trials. For the backward-positive group (B+; $n=8$), a 6-sec red illumination of the key followed all grain presentations; no stimulus followed the no-food trials. For the backward-negative group (B-; $n=8$), the red keylight followed only the 25 no-food trials. For the no backward group (B⁰; $n=8$), red lights were never presented. For the backward-nondifferential group (B^N; $n=6$), red keylight illuminations followed a random half (i.e., 12 or 13) of both the food and the no-food trials, for a total of 25 daily presentations of the red light (equalling the number in the B+ and B- groups).

For all 30 subjects, the five test sessions after completion of the training phase contained 50 daily trials on which 6-sec presentations of the red keylight were followed immediately by grain on

25 trials, and by the magazine light alone on 25 trials. Half of the subjects in each group received food on the first trial of a particular day and the other half received no food on that initial trial.

Results and Discussion

During the 7-day training phase, the four groups did not differ reliably in the total number of pecks to the vertical-line stimulus that preceded illumination of the magazine [$F(3,26) = 1.47, p > .20$]. All birds learned to peck at this stimulus (autoshaping), and total responses to it over the seven sessions ranged from 656 to 5,581 pecks among the 30 subjects. Furthermore, the three groups receiving presentations of the red stimulus did not differ in total responses to that backward stimulus over the training phase ($F < 1.00$). Response levels to the red stimulus were extremely low, with only 3 of the 22 birds (not in the same group) making more than eight total responses over the seven sessions. Over the last three sessions of the phase, 18 of the 22 birds with a backward stimulus did not respond to it (the maximum was two pecks, made by only 1 bird). None of the birds in the B+ group pecked the red stimulus at all over the last 4 days of the phase.

Thus, on the basis of near-zero response measures to the red stimulus and the lack of group differences during the training phase, one would conclude that the subjects had learned nothing about the correlation between the backward stimulus and grain presentation. Furthermore, neither the presence of the backward stimulus nor its correlation with food had any detectable effects on response output to the stimulus that preceded and signaled magazine illumination.

A different story emerged from the results of the transfer phase, in which the red stimulus now preceded magazine illuminations for all 30 pigeons (with grain present in the magazine on 50% of the trials). Figure 1 displays the mean number of daily trials on which the birds pecked the red stimulus over the 5 days of testing. Group differences were most striking on the first day, with the B+ birds averaging 35.1 trials with a peck, the B^N birds 27.3 trials, the B⁰ birds 17.6 trials, and the B- birds 10.3 trials. A repeated-measures analysis of variance (ANOVA) of all the data constituting Figure 1 revealed a significant effect of treatments [$F(3,26) = 3.17, p < .05$] and of sessions [$F(4,104) = 75.35, p < .001$]. There was also a reliable treatment $\times$ sessions interaction [$F(12,104) = 3.38, p < .001$]. The treatment effect attained acceptable levels of significance only during Session 1 [$F(3,130) = 13.40, p < .001$]. For that session, individual comparisons utilizing Fisher's least-significant difference (lsd) technique revealed that the B+ group differed significantly from the B- group ($p < .01$) and from the B⁰ group ($p < .05$). The B- group also differed significantly from the B^N group ($p < .05$). No other group differences approached statistical significance.

The mean total trials before the first peck to the red stimulus in the transfer phase was another measure supporting essentially the same conclusions as the index plotted in Figure 1. The B+ birds averaged 8.5 trials to their

Figure 1. Mean number of trials with a peck to the red keylight when it preceded magazine illuminations for all subjects during the final 5-day test phase of Experiment 1. The four groups had been exposed to the backward-positive (B+), the backward-negative (B-), the no backward (B⁰), or the backward-nondifferential (B^N) treatment during original training.

first peck, the B- birds 35.4 trials. The B⁰ and B^N birds' performance fell in between with 17.5 and 19.5 trials, respectively. Treatment differences for this measure were statistically reliable [$F(3,26) = 4.17, p < .025$] and *lsd* comparisons revealed that the B+ versus B- difference was significant beyond the .01 level and the B- versus B⁰ difference was significant beyond the .05 level.

The mean total number of responses to the red stimulus on Day 1 of the transfer phase was 230.0, 164.5, 122.9, and 36.9 pecks, respectively, for the B+, B^N, B⁰, and B- groups, but high variability in this measure was apparently responsible for a nonsignificant $F(3,26)$ of 1.88.

The transfer phase of Experiment 1 thus revealed that the birds in the different groups had learned something about the correlation between the backward stimulus and food. The birds for which the red stimulus had followed only positive trials began to peck significantly sooner and responded on significantly more trials than did the birds for which the red stimulus had followed only negative trials. The data for the two control groups consistently fell between the levels for the B+ and B- birds.

Because conditioned responses to the backward stimulus did not develop during training, one might conclude that no backward excitatory conditioning had occurred in this experiment. However, transfer tests including comparisons with various control groups demonstrated the falsity of that conclusion and the sensitivity of our basic procedure. A noteworthy observation was the retardation of transfer performance produced by a stimulus that had consistently followed the absence of food. Backward as-

sociations of the kind established here may apparently be either inhibitory or excitatory. At any rate, the B+ versus B- differences must be due to some kind of backward effect because the forward effect of the red stimulus was the same in all groups receiving presentations of it during original training.

EXPERIMENT 2

Prior research, mentioned earlier in this report, has sometimes indicated that a stimulus consistently following a US may briefly acquire excitatory properties but becomes inhibitory as US-CS pairings progress (due to the long US-free intervals that the CS predicts). Therefore, it was conceivable that after extended training, the B+ stimulus in Experiment 1 would eventually lose its facilitatory power and would even be transformed into a stimulus with the opposite effect. In the next experiment, differences in transfer performance were examined after 2 and 20 days of B+ or B- training, for comparison with the 7 days given in Experiment 1. Would less training or more training than 7 days remove or magnify the differences between these two groups?

Method

Twenty-eight experimentally naive pigeons began training on either the backward-positive or the backward-negative procedure of Experiment 1 during the session after magazine training ended. Half of the birds in each of those conditions ($ns=7$) received two sessions of training, and half ($ns=7$) received 20 sessions. In all other respects, the procedure for the training and subsequent testing phases was the same as in Experiment 1, which had involved 7 days of training instead of 2 or 20 days.

Because of an apparatus failure during Session 2 of the testing phase (no grain was delivered on any trials), the data of one subject in the 2-day B+ group and one subject in the 2-day B- group had to be eliminated from consideration after the first day of that phase. The two birds are not included in the repeated-measures analysis that is highlighted in the presentation of the test-phase results, but they are represented in calculations and analyses of the training-phase data, as well as in measures of total trials to the first peck in the test phase. In this experiment, no control or comparison groups were included; only B+ and B- groups were compared at the two different amounts of training.

Results and Discussion

During the training phase, all 28 birds learned to peck the vertical-line stimulus that preceded illumination of the magazine light, with food available in the magazine on 50% of the trials. In the 2-day training group, the total number of pecks to this forward stimulus ranged from 10 to 1,614 over the 2 days; in the 20-day training group, the total number of pecks to the stimulus ranged from 201 to 2,345 over the last 2 days of their training period. Of course, these total numbers of pecks to the forward stimulus over the last 2 days of training differed significantly between the 2- and 20-day groups ($p < .01$ for both the B+ and the B- treatments), but the more important point was that within each amount-of-training condition there was no significant difference on this measure between the B+ and the B- subgroups ($F_s < 1.00$).

As in Experiment 1, response levels to the backward stimulus itself were very low during training in all four groups. Within the 2-day condition, 5 of the 7 birds in the B+ group and 6 of the 7 in the B- group made fewer than three total pecks to the red stimulus. Within the 20-day condition, 6 of the 7 birds in the B+ group and all 7 birds in the B- group made fewer than three total pecks over the last 15 days of training. Therefore, keypecking measures during the training phase yielded no evidence of backward conditioning to the red stimulus in any of the four groups, the same conclusion reached in Experiment 1 after 7 days of training.

Nevertheless, performance during the transfer phase revealed definite effects dependent upon the type and amount of backward training given earlier. In Figure 2, the results of the transfer phase, in which the red stimulus now preceded magazine illuminations, are summarized. As in Experiment 1, the most pronounced group differences occurred on the first day of the new phase, with the B+ groups pecking on more trials than did their B- counterparts. A repeated-measures ANOVA of all the data constituting Figure 2 yielded a significant effect of type of prior backward training (positive vs. negative) [$F(1,22) = 11.67, p < .005$] and of amount of prior training (2 vs. 20 days) [$F(1,22) = 4.58, p < .05$]. The interaction between these factors reached a p of approximately .12. The effect of sessions was reliable [$F(4,88) = 67.79, p < .001$], as was the interaction between type of prior training and sessions [$F(4,88) = 5.97, p < .001$] and between amount of prior training and sessions [$F(4,88) = 5.01, p < .001$].

Figure 2. Mean number of trials with a peck to the red keylight when it preceded magazine illuminations for all subjects during the final 5-day test phase of Experiment 2. Two of the four groups had previously received backward-positive (B+) training, for either 2 or 20 days; the other two groups had previously received backward-negative (B-) training for either 2 or 20 days.

However, it is worth pointing out that further tests of the B+ versus B- difference indicated significance only for the 20-day training condition [$F(1,22) = 12.80, p < .005$]; the B+ superiority in the 2-day group attained an $F(1,22)$ of 1.57. Furthermore, the effect of amount of prior training yielded significance only in the B- group [$F(1,22) = 7.15, p < .025$]; the F was less than 1.00 for the B+ birds.

Thus, changes in the positive conditionability of a backward stimulus were apparently an inverse function of the amount of prior training in only the B- group. Although the 7-day training groups included in Experiment 1 had been run months earlier and thus cannot be directly compared to the 2- and 20-day groups constituting Experiment 2, it is noteworthy that the 7-day B- group of Figure 1 would fall between the 2- and the 20-day groups of Figure 2 with respect to the number of trials with a peck on Day 1. On the other hand, the 7-day B+ group in Figure 1 performed slightly better than the 2-day group in Figure 2. This observation fits the conclusion that the positive conditionability of a B- stimulus decreases monotonically with increases in the amount of prior training, whereas the effectiveness of a B+ stimulus does not change in any clear-cut way as the amount of prior training increases—at least up to the 20 days included in the present work. There was no convincing evidence that the B+ stimulus was more or less excitatory after 2 or 20 days than after 7 days, contrary to previous reports that its effectiveness and valence should be a definite function of the amount of backward training.

The mean total trials before the first peck to the red stimulus in the transfer phase were calculated, and these data indicated conclusions similar to those from the measures plotted in Figure 2. The B+ birds averaged 14.1 and 17.3 trials to their first peck, respectively, for the 2- and 20-day conditions; the B- birds averaged 28.4 and 55.0 trials to their first peck, respectively. An overall ANOVA of these data yielded a significant effect of B+ versus B- pretraining [$F(1,24) = 12.26, p < .005$] and an effect approaching significance (p approximately .06) for amount of prior training [$F(1,24) = 4.00$]. Although the interaction between type and amount of prior training did not reach an acceptable level of statistical significance (p approximately .13), it is interesting that further analysis of the B+ versus B- difference yielded $p < .05$ only after 20 days of prior training [$F(1,24) = 12.89, p < .005$], and the effect of amount of prior training yielded $p < .05$ for only the B- group [$F(1,24) = 6.40, p < .025$].

The mean total number of pecks to the red stimulus on Day 1 of the transfer phase was 233.7 and 165.1, respectively, for the 2- and 20-day B+ groups, and 77.9 and 34.3 pecks, respectively, for the 2- and 20-day B- groups. However, only the effect of B+ versus B- training was statistically significant for this measure [$F(1,24) = 7.51, p < .025$].

The results of this experiment indicate that the highly significant B+ versus B- difference shown after 7 days

of backward training in Experiment 1 is maintained even after 20 days of such training. The B+ stimulus apparently remains excitatory, and the B- stimulus becomes, if anything, even more inhibitory.

EXPERIMENT 3

In the training phase of Experiments 1 and 2, a stimulus preceded all illuminations of the food magazine. Because this forward stimulus came to evoke keypecking, and because it was closely associated in time with the backward stimulus that followed 50% of the illuminations in all groups except the B⁰ group, its inclusion in the procedure might have been crucial for producing the group differences found during the transfer phase in those two experiments. Furthermore, several investigators (e.g., Dolan et al., 1985; Williams & Overmier, 1988) who have examined the role of surprise and signaling within the framework of certain contemporary theories of Pavlovian conditioning have found important differences between arrangements involving signaled versus unsignaled USs. In Experiment 3, B+ and B- groups trained with and without a CS preceding magazine illuminations were compared. The comparison that included a forward CS provided a direct replication of the effects obtained in Experiment 1 for 7 days of training.

Method

Twenty-four experimentally naive pigeons were placed on either a B+ or a B- procedure during the session after magazine training ended. Half of the birds in each of these conditions ($n=6$) received the standard 7-day training of Experiment 1, including presentations of a 6-sec white line on the key prior to magazine illuminations, 50% of which were accompanied by grain availability. The other half of the birds in each condition ($n=6$) received 7 days of unsignaled magazine illuminations, 50% of which were accompanied by grain availability. One B- bird in the group without a forward stimulus during the training phase failed to eat at all on the first day of that phase; it was eliminated from the experiment but was not replaced by another subject.

After the 7-day training phase, each subject was exposed to a standard 5-day test phase, as in Experiments 1 and 2, with the formerly backward red keylight preceding all magazine illuminations.

Results and Discussion

All 12 birds that were trained with the forward stimulus learned to peck at it. As in Experiment 1, there was no statistically significant difference between the B+ and the B- groups in terms of total pecks to that stimulus over the 7-day training phase [$F(1,11) < 1.00$; these total responses ranged from 1,929 to 6,634 pecks among the 12 subjects].

Also as in Experiments 1 and 2, the number of pecks to the backward stimulus was low in all four groups of Experiment 3. In the groups that had a forward stimulus during training, 4 of the 6 B+ birds and 5 of the 6 B- birds made fewer than eight total pecks to the red stimulus during the training phase. In the groups without a forward stimulus, 5 of the 6 B+ birds and all 5 B- birds made either 0, 1, or 2 total pecks to the red stimulus dur-

ing training. Mean differences among the four groups in total pecks to that stimulus were not statistically significant; an analysis of the overall effect of B+ versus B- training yielded $F < 1.00$, and an analysis of the overall effect of forward versus no forward stimulus yielded $F(1,19) = 2.58, p > .10$.

Thus, even though one might expect some (however slight) generalization of responding from acquisition of pecking at the vertical line (forward stimulus) to pecking at the backward stimulus in the training phase, birds with a forward stimulus did not respond significantly more often to the red stimulus than did birds that had no stimulus preceding magazine illuminations. The training phase of Experiment 3 provided no evidence of backward conditioning to the red stimulus in any of the groups, corroborating the results obtained in Experiments 1 and 2.

Despite the lack of differences among the four groups in their pecking at the backward stimulus during the training phase, clear-cut differences emerged during the transfer phase, in which the red stimulus now preceded all magazine illuminations. In Figure 3, the data for the same measure plotted in Figures 1 and 2 are summarized. The large difference in Figure 3 favoring B+ over B- birds when training had included a forward stimulus for both groups replicates the basic result obtained in Experiment 1. When no forward stimulus had been present during training, pecking at the red stimulus in both the B+ and the B- groups started more slowly than when the forward stimulus had been included; however, overall acquisition levels for the B+ group were still greatly superior.

Figure 3. Mean number of trials with a peck to the red keylight when it preceded magazine illuminations for all subjects during the final 5-day test phase of Experiment 3. Two of the four groups had previously received backward-positive (B+) training, with or without a signal preceding magazine illuminations ("forward CS"; FCS); the other two groups had previously received backward-negative (B-) training with or without the same signal.

A repeated-measures analysis of the data constituting Figure 3 revealed significant overall effects of B+ versus B- training [$F(1,19) = 15.12, p < .001$], of forward versus no forward stimulus training [$F(1,19) = 8.98, p < .01$], and of sessions [$F(4,76) = 59.91, p < .001$]. There was a significant interaction between forward versus no forward stimulus training and sessions [$F(4,76) = 3.18, p < .025$], but none of the other interactions approached statistical significance. The fact that the type of backward training did not interact significantly with the signaling condition ($p > .20$) indicates that the B+ versus B- effect occurred reliably in both the signaled and the unsignaled conditions.

Measures of the mean total trials before the first peck to the red stimulus during the transfer phase supported the conclusions drawn from the trials-with-a-peck measure in Figure 3. The B+ birds with forward stimulus training averaged 15.8 trials to their first peck; their B- counterparts averaged 43.2 trials; without forward stimulus training, the B+ birds averaged 44.7 trials and the B- birds averaged 97.8 trials. The overall effects of B+ versus B- training and of forward versus no forward stimulus training were statistically significant [$F(1,19) = 7.15$, and 7.69 , respectively, $p < .025$]. The general conclusions mentioned above and their statistical reliability would not change if the total number of daily pecks to the red stimulus over the transfer phase were used as an index instead of the other two measures discussed above. Paralleling the results for the trials-with-a-peck measure, the interaction between B+ versus B- training and forward versus no forward stimulus training did not approach significance for the trials-to-the-first-peck and total-pecks measures ($p > .20$ in both cases).

Although the lack of a signal preceding magazine illuminations during original training led to a retardation of acquisition during the subsequent transfer phase, there was still a clear difference favoring B+ over B- birds when the formerly backward stimulus was made a signal for magazine illuminations. The presence of a forward stimulus during original training is therefore not critical for producing the B+ versus B- effects obtained in Experiments 1 and 2. It is likely that generalization of prior learning to peck a keylight signaling food is mainly responsible for the quicker acquisition of pecking during the transfer phase in birds pretrained with a forward stimulus. This supposition could be easily tested by use of an auditory or diffuse visual forward stimulus that does not evoke pecking during original training.

EXPERIMENT 4

The final experiment was mainly an attempt to demonstrate in a different way the effects obtained in the earlier experiments. As in the new groups of subjects included in Experiment 3, no forward stimulus was employed during original training in Experiment 4. However, a control treatment mirroring the backward-nondifferential (B^N)

arrangement of Experiment 1 was added to determine whether the B+ and the B- groups differed not only from each other, but also from some presumably intermediate baseline; if so, one would have more justification for describing the B+ procedure as producing positive effects and the B- procedure as producing negative effects. A final feature of Experiment 4 was the inclusion of backward stimuli after every magazine illumination during the training phase. Instead of an arrangement in which half of the training trials were followed by a red stimulus and the other half by nothing (Experiments 1-3), a green stimulus was presented after the trials on which the red-backward stimulus was not scheduled. The possibility of a "backward color discrimination" might increase the sensitivity of our procedure for detecting group differences.

Method

After standard magazine training, 36 experimentally naive pigeons were randomly assigned to one of three types of backward-discrimination treatments ($ns = 12$). This 7-day training phase consisted of 52 daily trials, 26 involving 3-sec illumination of the magazine with available grain and 26 involving 3-sec magazine illuminations only. No stimuli preceded these 52 magazine illuminations, but half of them were followed by a 6-sec red keylight and half by a 6-sec green keylight.

The consistent group (defined in relation to the color correlations that would hold in the forthcoming transfer phase of the experiment) received red-light presentations immediately after each food delivery and green-light presentations immediately after each magazine illumination without food. The inconsistent group received the green lights after food and the red lights after no-food events. The nondifferential (uncorrelated) group received red or green lights randomly, each after half of the food and half of the no-food events. In all other respects, the training phase followed the parallel procedures of Experiments 1-3, in which only one color (red) was presented as a backward stimulus.

During the first session of the 5-day transfer phase, the birds were initially given 10 warmup trials (5 with food, 5 without food) on the same procedure that they had experienced during training. For all 36 birds, the remainder of Session 1 and all of Sessions 2-5 contained 52 trials in which 6-sec red keylights (CS+) preceded food and 6-sec green key lights (CS-) preceded no food in the illuminated magazine. The first two daily trials were composed of either a CS+ followed by a CS- or a CS- followed by a CS+, on a random basis from subject to subject and day to day. No more than two consecutive trials of the same type were possible within the entire set of 52-trial programming sequences that varied from day to day.

The total number of CS+ and CS- pecks was recorded daily on electromechanical counters during the transfer phase. The number of trials to the first peck in CS+ and the total number of CS+ trials with a peck during Sessions 1 and 2 were derived from trial-by-trial printout counter records that could later be analyzed by a computer. Because data for Sessions 1 and 2 of the transfer phase were most revealing in Experiments 1-3, analysis of the results for Experiment 4 will be confined to performance during those two sessions.

Results and Discussion

The 36 subjects hardly responded to the red and green backward stimuli during the training phase of the experi-

ment; only 2 birds made more than four total pecks to both stimuli combined over the 7 days. As in the three prior experiments, there was virtually no evidence of backward conditioning, from measures of pecks to the red and green stimuli, during the original training phase.

However, consistent with Experiments 1–3, the transfer data presented a picture different from the training phase. All of the standard measures collected in Figure 4 converged on the same general conclusion as before, namely, that the subjects had learned something about relationships between the backward stimuli and food versus no food in the training phase of the experiment, regardless of their failure to respond to those stimuli at that time. The mean number of trials with a peck to the red key (CS+) during Sessions 1 and 2 of the transfer phase was highest for the group that had received the red stimulus only after positive trials in the prior phase, lowest for the group that had received the red stimulus only after negative trials, and at an intermediate value for the group that had been exposed to no correlation between colors and food. The difference among treatments was highly reliable [$F(2,33) = 8.07, p < .005$]. Individual comparisons (Isd technique) revealed that the mean difference between the consistent and the inconsistent groups was significant at $p < .001$, whereas the consistent–nondifferential and inconsistent–nondifferential differences both achieved a p of approximately .05 [$t(33) = 2.02$ and 2.00 , respectively].

The second measure in Figure 4—total trials to the first peck in CS+—showed that the birds in the consistent group began to peck the CS+ sooner than did the birds in the other two groups, with the inconsistent group performing the worst of the three. An ANOVA indicated that the treatment differences were significant [$F(2,33) =$

$7.97, p < .005$]. Individual (Isd) comparisons indicated that the consistent group pecked reliably sooner to the CS+ than did either the nondifferential or the inconsistent groups ($p < .05$ and $.001$, respectively). However, the difference between the latter two groups did not achieve an acceptable level of significance [$t(33) = 1.86$]. Perhaps worth noting is the fact that during the transfer phase, 11 of the 12 consistent birds made their very first peck to the CS+, as did all 12 in the nondifferential group, but only 8 of the 12 in the inconsistent group.

The final measure in Figure 4 provides additional support for the conclusions already reached. The birds in the consistent group made the most pecks to the CS+ on Transfer Days 1 and 2, with the nondifferential group again intermediate and the inconsistent group lowest. The overall analysis yielded a reliable treatment effect [$F(2,33) = 3.81, p < .05$], but Isd tests indicated that only the difference between the consistent and the inconsistent birds was statistically significant [$t(33) = 2.75, p < .01$].

The total number of responses to the CS– (green key-light) during Sessions 1 and 2 was also subjected to statistical analysis, but no significant differences appeared between the treatment groups [$F(2,33) < 1.00$]. Based solely on the effects of the stimulus–food correlations during the earlier training phase, the prediction would have been that fewer CS– responses should occur in the consistent group than in the two other groups. However, a complication arises because the birds in this group started pecking the CS+ sooner than did the birds in the other groups, and one might then expect some initial stimulus generalization of pecking from CS+ to CS–, thus counteracting the effects of the correlations that held during the training phase.

Figure 4. Three measures of acquisition performance to the red CS+ when it preceded food for all subjects over the first two sessions of the final 5-day test phase of Experiment 4. During original training, the red keylight had followed food in the consistent (B⁺) group, no food in the inconsistent (B⁻) group, or half the food trials and half the no-food trials in the nondifferential (B^N) group. A green keylight had followed the other half of the trials during training and then preceded the no-food trials during the subsequent test phase.

The results of this experiment confirm the main results of the previous work, despite a few procedural changes, including the use of two colors as backward stimuli. The B+ (consistent) subjects pecked sooner and more often to the CS+ than did the B- (inconsistent) subjects during the transfer phase. The control (B^N; nondifferential) birds displayed an intermediate level of transfer performance, often significantly different from either or both the B+ and the B- birds. These group differences suggest that, at least under the conditions of our four studies, stimuli that follow the presentation of food become excitatory and stimuli that follow the absence of food become inhibitory.

GENERAL DISCUSSION

The basic arrangement used in these experiments produced definite evidence for the establishment of both positive and negative backward associations in pigeons. A keylight stimulus that had only followed brief periods of available food proved much easier to convert into an effective signal preceding food delivery than did the same stimulus when it had only followed brief periods of unavailable food. Control groups given either no previous backward stimulus presentations, or presentations that had randomly followed food and no-food trials, performed at an intermediate level during the final transfer phase. The backward-positive stimulus retained an approximately equivalent effect regardless of whether it had received 2, 7, or 20 days of such training, whereas the backward-negative stimulus seemed to retard forward conditioning more as the number of days of B- training increased. Substantial differences between these two main groups occurred whether or not another visual signal had preceded all trials during original training, although the conversion of a backward stimulus into an effective forward stimulus was more rapid when the signal had been included. A procedure on which a keylight of one color followed food trials and a keylight of another color followed no-food trials yielded results that confirm the findings obtained when only a single type of trial was followed by a backward stimulus. It is noteworthy that in all four experiments, significant and consistent differences in transfer performance between the backward-positive and the backward-negative birds were revealed, even though pecking to the backward stimulus was near zero during original training in all groups.

Previous research mentioned earlier in this report and in various chapters of Miller and Spear's (1985) volume has generally suggested that backward excitatory conditioning is weak, nonexistent, or, at best, relatively impermanent, lasting as long as the US is still "surprising" (Wagner & Terry, 1975; see Wagner & Larew, 1985, for a more sophisticated analysis based on Wagner's SOP model) or until subjects learn that the backward stimulus signals a comparatively long US-free interval. Then the stimulus usually displays inhibitory powers, which could also arise from other sources (see LoLordo & Fairless,

1985, pp. 4-14). Even those writers (e.g., Spetch et al., 1981) who argue for the robustness of excitatory backward conditioning stress that the strongest evidence for it comes from situations involving a small number of US-CS pairings and the application of noxious USs.

The present research revealed positive and negative backward conditioning that persisted over many sessions and depended on the use of an appetitive US—the delivery of grain to a hungry pigeon. The critical group differences could not be due to what happened immediately after the backward stimuli were presented during training because all groups (B+, B-, and B^N) that received the backward stimulus were equated in terms of the delay and the type of events that followed it. The degree of overall contextual excitation was presumably equated for all conditions, as well, whether such excitation was assumed to be relatively low (in the cases in which the USs were signaled) or high (in the cases in which the USs were unsignaled). In the face of such details, the main question to be addressed here is why the present work was consistently successful in obtaining evidence for excitatory and inhibitory associations that could only arise from a backward relationship between a CS and some other event—the presence versus the absence of food.

Several features of our procedure seem crucial in this respect and differ from the details of arrangements used in prior research on the topic. First, a schedule of partial reinforcement was in force throughout the present work; 50% of the magazine illuminations were accompanied by accessible food and 50% were not. Second, and as a potential consequence of the first point, the backward stimuli occurred in the context of associated differential reinforcement; the B+ stimulus always followed food delivery and was never presented after magazine illuminations without food, whereas the B- stimulus occurred according to the opposite rule. Because many studies of forward conditioning (see Mackintosh, 1974, chaps. 9 and 10) have shown greater stimulus control following differential training than following nondifferential training (in which, say, pairings of the stimulus and the reinforcer occur on all trials in the experiment), it does not seem unreasonable to suggest that the same principle might govern the formation, strength, and permanence of backward associations. Third, as defined in our experiments, the absence of food is a specific, discrete event; it is not the occurrence of "nothing," but the illumination of the magazine without accessible food. Therefore, a pairing of two events is possible and the establishment of an inhibitory backward association may thereby be encouraged in the B- case.

These apparently novel aspects of our arrangements relate to issues and concepts that frequently arise in theoretical discussions of excitation, inhibition, and backward conditioning. For example, because of the partial reinforcement schedule in the present experiments, the US remained relatively unpredictable or surprising, regardless of whether or not a signal preceded magazine illuminations. Wagner and Terry (1975; but see Gordon,

McGinnis, & Weaver, 1985) have provided evidence that backward excitatory conditioning is most likely to occur with surprising USs, and they suggested that the transitory nature of such backward conditioning may be due to the disappearance of this surprisingness as conditioning trials progress on standard procedures, which have involved US delivery on every trial.

One deficiency in the present series of experiments, particularly with respect to the conclusion that inhibitory learning occurred to the B⁻ stimulus, lies in our failure to include postacquisition summation tests to assay the facilitatory, suppressive, or neutral effects of the target stimuli. The final transfer phase in all of the present experiments was, of course, an example of a retardation-of-learning test and, to the extent that the B⁺ group learned faster than the control groups, and the B⁻ group slower, it may be permissible to describe the former effects as excitatory and the latter as inhibitory. However, most contemporary researchers who study conditioned excitation, facilitation, and inhibition believe that the summation test, either alone or in combination with the retardation test, provides the most direct and unambiguous way to assess these effects (for justifications, see Hearst, 1972; Miller & Spear, 1985). By arranging comparisons of performance during combinations of the red keylight stimulus and some other established visual or auditory CS⁺, with performance during the visual or auditory CS⁺ alone, one could implement summation tests after training phases conducted as in the present work.

Besides the issue of the missing summation tests, there are some other obstacles that would have to be surmounted before one could draw strong conclusions about the formation of excitatory and inhibitory associations in the present studies. Control groups that receive only magazine training prior to being placed on the transfer conditions in the different experiments would help to assess the excitatory versus inhibitory nature of the associations established in our B⁺ and B⁻ phases; if B⁻ subjects acquire keypecking to the red light slower than these original-learning controls, and B⁺ subjects faster, there would be additional reason to assume the establishment of conditioned excitors and inhibitors (besides the evidence from our B⁰ group, which in Experiment 1 provided a counterpart to an original-learning condition and also controlled for possible effects of including a vertical-line forward stimulus in the procedure). Variations of Rescorla's (1967) truly random control, in which red keylights, food presence, and food absence are presented randomly and not in constant conjunction with one another during the training phase, would help the analysis as well.

If one conceptualizes the magazine illuminations as CSs in our work, the B⁺ procedures without a forward CS might be said to mirror AX⁺, A⁻ training, and the B⁻ procedures A⁺, AX⁻ training, in standard use for establishing conditioned excitors and inhibitors. However, my view is that the magazine light is different from conventional CSs because it is located in the same place as food and it informs the subject whether or not grain is

available *before* X is presented. Nevertheless, another worthwhile comparison group would eliminate the magazine illuminations without food in the B⁻ condition, to determine whether the red keylight would become equally inhibitory (because of the ITI it initiates) even if it did not follow the specific "absence of food." One could argue that the presumed inhibitory effects in the present research are not necessarily backward in the B⁻ groups, and that B⁺ and B^N subjects show quicker acquisition because of differential excitatory backward conditioning added on to such inhibitory forward effects.

Furthermore, a skeptic might claim that some of the differences observed during the transfer phases of the present experiments may reflect differential degrees of habituation or attention to the red keylight used as the backward stimulus, and not conditioned excitation and inhibition to that stimulus. For example, habituation to the B⁺ stimulus might be minimal after original training because the birds in that group were still eating during presentation of that stimulus and had failed to pay much attention to it. Therefore, in the transfer phase, the B⁺ stimulus (now occurring when the birds are not eating) would be better attended to and would condition faster than the B⁻ stimulus. However, this alternative explanation seems far-fetched because the B⁰ birds in Experiment 1 had never seen the red keylight before, and yet they conditioned more slowly than the B⁺ birds. Moreover, it seems hardly likely that the B⁺ subjects in Experiments 1-3 did not notice a stimulus that lasted 6 sec on a key where their forward CS was presented and pecked at. Finally, there appears no good reason why mere habituation to the B⁻ stimulus should be extremely high after original training as compared, say, to the B^N stimulus.

Perhaps the major contribution of the experiments described in the present report lies not so much in their specific theoretical implications but in their successful development of a particular technique for studying positive and negative associations that arise from correlations of a backward stimulus with the presence or absence of a US. Partial reinforcement and the use of a magazine-light "event" for presence versus absence seem to be important aspects of the procedure. Future elaboration of the technique, along with isolation of its crucial features for producing various effects, may help us decide whether the functional similarity of forward and backward associations is as great as is suggested here.

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