

# Transfer testing after serial feature-ambiguous discrimination in Pavlovian keypeck conditioning

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Four experiments were performed to explore modulatory transfer after serial feature-ambiguous (F-A) discrimination ( $X \rightarrow A+$ ,  $A-$ ,  $X \rightarrow B-$ ,  $B+$ ) in Pavlovian keypeck conditioning (autoshaping) with pigeons. Diffuse features were used in the first three experiments, and no modulatory transfer was found: (1) There was no modulatory transfer between two concurrently trained F-A tasks; (2) modulatory transfer to conditioned and then extinguished stimuli was not observed; and (3) responding to the targets (A and B) after their contingencies were reversed was not affected by presentation of their original feature stimulus (X). Transfer between two serial F-A tasks was obtained in the last experiment, in which keylights were used as features, but other evidence indicated that this was due to stimulus generalization between the features. Together, the results strongly suggest that specific target-food occasion setting or configural learning is the underlying mechanism of F-A discrimination.

A large number of studies examining Pavlovian conditioned modulation have been conducted with serial feature-positive (F-P) and feature-negative (F-N) discrimination tasks (see Holland, 1992; Swartzentruber, 1995, for reviews). In the serial F-P task ( $X \rightarrow A+$ ,  $A-$ ), where an unconditioned stimulus (US) follows a target stimulus (A) only when A is preceded by a feature stimulus (X), X facilitates responding to A. On the other hand, in the serial F-N task ( $X \rightarrow A-$ ,  $A+$ ), where the US follows A only when A is presented alone, X inhibits responding to A. In these tasks, one stimulus (X) modulates responding to another stimulus (A).

According to Holland (1983, 1985), conditioned responses (CRs) to a conditioned stimulus (CS) can be controlled or modulated by an "occasion setter," which operates on specific CS-US linkages. Thus, X sets a positive occasion for an A-US link in the F-P task and a negative occasion for it in the F-N task. On the other hand, Rescorla (1985) argued that X in F-P and F-N tasks changes the activation threshold of US representations so that A evokes strong CRs in the F-P task and weak CRs in the F-N task (see also Rescorla, 1979). Thus, the underlying mechanisms of conditioned modulation pro-

posed by the two hypotheses differ, though both of these hypotheses claim hierarchical event learning in the sense that a stimulus controls CRs via a linkage of another stimulus and a US.

One way to differentiate between these two hypotheses is to combine serial F-P and F-N tasks with one feature stimulus (X) and two target stimuli (A and B) to make a serial feature-ambiguous (F-A) task ( $X \rightarrow A+$ ,  $A-$ ,  $X \rightarrow B-$ ,  $B+$ ). Mastery of this task is impossible by the US-threshold mechanism proposed by Rescorla (1985), because X cannot both lower and raise the threshold of a US representation at the same time. The specific occasion-setting hypothesis claimed by Holland (1983, 1985), however, allows for the mastery of this task, because X acts positively on the A-US linkage and negatively on the B-US linkage.

Some studies have demonstrated mastery of serial F-A tasks. Nakajima (1992, 1994) and Rescorla (1993) showed that pigeons can learn an F-A task in Pavlovian keypeck conditioning (autoshaping; cf. Bottjer & Hearst, 1979; Looney, Cohen, Brady, & Cohen, 1977; Rescorla, Grau, & Durlach, 1985). In addition, Holland (1991) and Holland and Reeve (1991) have demonstrated mastery of serial F-A tasks by rats in an instrumental conditional discrimination. Thus, the specific CS-US occasion-setting hypothesis (Holland, 1983, 1985) seems to accommodate the data better than the US-threshold changing hypothesis (Rescorla, 1979, 1985).

However, one aspect of these studies is not accountable by the specific CS-US occasion-setting hypothesis. The occasion-setting mechanism does not allow a feature of an F-A task to have a transfer effect on targets that have not been trained with that feature stimulus, because occasion setting depends on specific CS-US linkages. But Holland (1991) demonstrated transfer between two concurrently trained serial F-A tasks: A feature of one task

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controlled responding to the targets of the other task in transfer testing. Moreover, the same study, as well as Rescorla (1993, Experiment 4), demonstrated mutual transfer between a serial F-A task and a serial F-P or F-N task: A feature of an F-A task facilitated CRs to a target of an F-P task and inhibited CRs to a target of an F-N task, and a feature of the F-P task facilitated CRs to a target trained in the F-P subtask of the F-A task while a feature of the F-N task decreased CRs to a target trained in the F-N subtask. Finally, Holland and Reeve (1991) showed that a feature of a serial F-A task increased responding to a separately reinforced and then extinguished stimulus.

Nevertheless, transfer of modulation in serial F-A discriminations does have some specificity. For example, a feature of a serial F-A task does not affect responding to a continuously reinforced stimulus (Holland & Reeve, 1991) or to a partially reinforced stimulus (Holland, 1991). Because a feature stimulus of an F-A task affects targets trained in another F-A task, targets of F-P and F-N tasks, and a reinforced and then extinguished target, one might also suppose that it would work as an "inverter" for current patterns of responding to target stimuli that have any ambiguous history of reinforcement and extinction: it would increase CRs elicited by a currently weak excitator and decrease CRs elicited by a currently strong excitator. However, Holland (1991) revealed that reversal training of the targets of a serial F-A task did not invert the effect of the original features on those targets: Reinforcement of A and extinction of B after  $X \rightarrow A^+$ ,  $A^-$ ,  $X \rightarrow B^-$ ,  $B^+$  training neither caused X to decrease responding to A, nor X to increase responding to B. Indeed, X still increased responding to A and decreased responding to B, despite the fact that A alone evoked more responding than B alone. Thus, the inverter account seems inadequate at least in his experiment (see also Nakajima, 1994).

Studies of modulatory transfer by a feature of serial F-A discrimination clearly challenge the specific occasion-setting hypothesis. In spite of this theoretical importance, few studies have examined modulatory transfer of serial F-A discriminations. Two of them (Holland, 1991; Holland & Reeve, 1991) used an instrumental preparation. The remaining study conducted by Rescorla (1993, Experiment 4) used Pavlovian keypeck conditioning, but this experiment had no controls for nonmodulatory factors such as stimulus generalization between feature stimuli, external inhibition, and disinhibition. The purpose of the present experiments was to explore modulatory transfer in a serial F-A discrimination in a Pavlovian preparation that controls for the effects of nonmodulatory factors.

## EXPERIMENT 1

The primary purpose of this experiment was to test the possibility that reversing the targets' associations with the US would change the direction of the effects of conditioned modulation in a serial F-A discrimination. As described above, this topic was examined in an instrumental preparation by Holland (1991), with negative re-

sults. The same issue was pursued in the present experiment in a Pavlovian rather than instrumental preparation. Pigeons were trained on a serial F-A task with a concurrent pseudomodulator treatment ( $X \rightarrow A^+$ ,  $A^-$ ,  $X \rightarrow B^-$ ,  $B^+$ ;  $P \rightarrow E^+$ ,  $E^-$ ,  $P \rightarrow E^-$ ,  $E^+$ ). After acquisition of the F-A task, the reinforcement contingencies of the targets of the true modulator (X) were reversed ( $A^+$ ,  $B^-$ ), and the modulatory effects of X and the pseudomodulator (P) on CRs to these stimuli were then examined. After the first test, the original contingencies were restored and then the effects of X and P were tested again.

The second purpose of Experiment 1 was to explore transfer of control of X over separately trained stimuli with ambiguous history of reinforcement and extinction. Thus, in the third test of this experiment, two new stimuli were used as targets of X and P. Prior to the test, both new stimuli were reinforced first ( $C^+$ ,  $D^+$ ), then the birds received discrimination training ( $C^-$ ,  $D^+$ ), and finally the discrimination contingency was reversed ( $C^+$ ,  $D^-$ ) in order to provide the stimuli with ambiguous histories of reinforcement and extinction. The three-stage treatment was intended to give C a history of extinction *after* reinforcement, which would make C more sensitive to transfer control by X (Holland & Reeve, 1991; cf. Swartzentruber & Rescorla, 1994).

## Method

### Subjects

Sixteen female White Carneaux pigeons were maintained at 80% of their free-feeding body weights. Although they had histories of Pavlovian keypeck conditioning, the feature and target stimuli used in this experiment were novel for them. The birds were housed in pairs in a colony room on a 16:8-h light:dark cycle. Experimental sessions were conducted during the light period.

### Apparatus

Eight identical chambers, measuring  $27 \times 27 \times 35$  cm, were used for training and testing. The ceiling and three walls of each chamber were clear acrylic, and the floor was metal mesh. The fourth wall was metal and was used as a front panel, the center of which had two openings. One was a  $5 \times 5$  cm food magazine opening located 5 cm above the floor and through which it was possible to access a hopper containing mixed grain. The hopper was lighted by a 6-W bulb inside the magazine when food was available. A clear acrylic key was attached to the other opening, measuring  $10 \times 8$  cm, which was located 8 cm above the magazine. Pecks to the key were detected by a switch behind the key. Visual target stimuli were presented on the key by a 5-in. Magnavox TV located 1 cm behind the key. The top or bottom portion of the key was visually blocked by a black strip for counterbalancing the stimuli across the chambers. The chambers were individually enclosed in sound- and light-attenuating shells, with ventilation fans providing background noise of 62 dB (re  $20 \mu\text{N/m}^2$ ). A 6-W white bulb on the right wall of each shell served as a houselight, and it was illuminated at all times except during the operation of the food hopper. All events were controlled and recorded by computers located in an adjacent room.

### Stimuli

The TV projected each of five different target stimuli on the center of the visible portion of the key: a white five-pointed star in an imaginary  $26 \times 21$  mm rectangular square space; a red X shape consisting of two  $5 \times 24$  mm rectangles crossing at their midpoints; a blue ring pattern consisting of three 2-mm line con-

Table 1  
Outline of the Procedure in Experiment 1

F-A Discrimination	Target Reversal	Test 1	Target Re-Reversal	Test 2	New Target Training			Test 3
					I	II	III	
X→A+, A-, X→B-, B+	A+, B-	X→A-, A-, X→B-, B-	A-, B+	Same as in Test 1	C+, D+	C-, D+	C+, D-	X→C-, C-, X→D-, D-
P→E+, E-, P→E-, E+		P→A-, P→B-						P→C-, P→D-

Note—Stimuli X (a modulator) and P (a pseudomodulator) were 15-sec diffuse feature stimuli. A, B, C, D, and E were 5-sec target keylights. An arrow (→) indicates serial compounding in which the feature preceded the target by 10 sec. Plus (+) and minus (-) symbols indicate reinforcement and nonreinforcement, respectively.

centric circles with 19-, 13-, and 7-mm diameters; a green inverted equilateral triangle of 22-mm sides; and a purple vertical rectangle of 5 × 22 mm. The background of the TV was black.

Two diffuse stimuli were used as features: an 80-dB white noise presented by a speaker on the right wall of each shell and a flashing of the houselight at a rate of 1/sec.

### Procedure

In all the experiments reported here, sessions were scheduled on successive days, 7 days a week, at about the same time each day. Because the birds were accustomed to the chambers and the hoppers, magazine training was not necessary. The initial four sessions were used to lower the rate of responding to the target stimuli. Each of three targets to be used in the following F-A task (the white star, the red cross, and the blue ring pattern) was presented 12 times for 5 sec in a quasi-random order without food reinforcement. The average intertrial interval (ITI), defined as the time from the onset of a trial to the next trial, was 60 sec throughout this experiment. Table 1 shows the design of Experiment 1.

**F-A discrimination.** For 30 sessions, the birds were trained in a serial F-A task and a pseudomodulation task. One of the diffuse features, the noise or the flashing light, was used as a conditioned modulator (X) for the keylight targets—the white star and the red cross (A and B). The other feature was used as a pseudomodulator (P) and was trained with the blue ring pattern (E). Each session consisted of six trials each of the following eight trial types: Feature X along with A followed by food (X→A+); Target A alone with no food (A-); Feature X along with B, but no food (X→B-); Target B alone followed by food (B+); Feature P along with E followed by food (P→E+); Target E alone with no food (E-); Feature P along with E, but no food (P→E-); Target E alone followed by food (E+). The feature stimuli were 15 sec long and the targets were 5 sec long. On the compound trials, the features started 10 sec prior to target onset, resulting in a 5-sec overlap. Food presentation was 5 sec, and it occurred immediately after target offset on reinforced trials. All eight trial types were mixed in each block, and two different training sequences were made of six blocks, with the restrictions that the maximum number of successive reinforced or nonreinforced trials was three throughout a given sequence, and that the same trial type did not come in succession in the sequence. One of these sequences was quasi-randomly chosen for each session. The identities of X and P were counterbalanced across the birds. The same was true for A and B.

**Target reversal.** The reinforcement contingencies of A-alone and B-alone trials were reversed for three sessions. Each session consisted of 24 trials each of A+ and B-. Throughout this and the following experiments, Fellows (1967) series were used to make a quasi-random trial order for the reversal training of A and B.

**Test 1.** Effects of the modulator and the pseudomodulator were tested for two sessions. Each session began with 18 trials each of A+ and B-, and they were followed by nonreinforced test trials in two sequences of either [X→A, A, P→A, X→B, B, P→B], [P→A, A, X→A, P→B, B, X→B], [X→B, B, P→B, X→A, A, P→A], or [P→B, B, X→B, P→A, A, X→A], counterbalanced across birds. That is, each of the six test trial types was presented a total of four times in this phase.

**Target re-reversal.** The reinforcement contingencies of A-alone and B-alone trials were changed again to make them identical to those in the original F-A task. In each of five sessions, 24 trials each of A- and B+ were scheduled.

**Test 2.** The same procedure as that of Test 1 was employed, except that the sessions began with 18 trials each of A- and B+.

**Retraining of F-A discrimination.** The original training procedure for the F-A discrimination was repeated for 20 sessions in the same way.

**New target training.** New target stimuli, C and D (the green triangle and the purple rectangle, counterbalanced), were introduced and were reinforced 24 trials each for one session. The next three sessions consisted of 24 trials each of C- and D+. The F-A discrimination was then retrained for two sessions, after which the contingencies of C and D were reversed for three sessions (C+, D-).

**Test 3.** This test was identical to Test 1, except that A and B were replaced with C and D, respectively.

### Data Analysis

The rate of pecking to the lit target key was the response measure in this and the following experiments. A Wilcoxon *T* (signed rank) test was conducted for each pair of interest. For simplicity, only statistically reliable ( $\alpha < .05$ , two-tailed) *T* values are reported below. For test trial performance, a set of comparisons was applied to each target stimulus. In general, statistical conclusions were the same, even if the alpha level of .05 was set for the entire set of comparisons for each target by Ryan's (1960) method. For instances in which this was not the case, the conclusion by Ryan's method is also reported.

## Results

### F-A Discrimination

Acquisition of the F-A discrimination is shown in the left-hand portion of Figure 1. Feature X facilitated responding to A and inhibited responding to B, whereas the pseudomodulator had no effect on responding to E. In the last block, responding to A was higher when it was accompanied by X than when it was presented alone [ $T(16) = 2$ ]. Responding to B showed the opposite pattern [ $T(16) = 5$ ]. In addition, the birds pecked less to A than to B when they were presented alone [ $T(16) = 11$ ], but more to A than to B when they were with X [ $T(15) = 1.5$ ]. There was no difference between P→E and E trials.

### Target Reversal and Test 1

Discrimination between A and B was reversed, as is reflected in test performance shown in the top panel of Figure 2: responding was higher on A-alone trials than on B-alone trials [ $T(16) = 1$ ]. More interesting were the comparisons between these trials and compound trials. Neither X nor P had any reliable effect on responding to

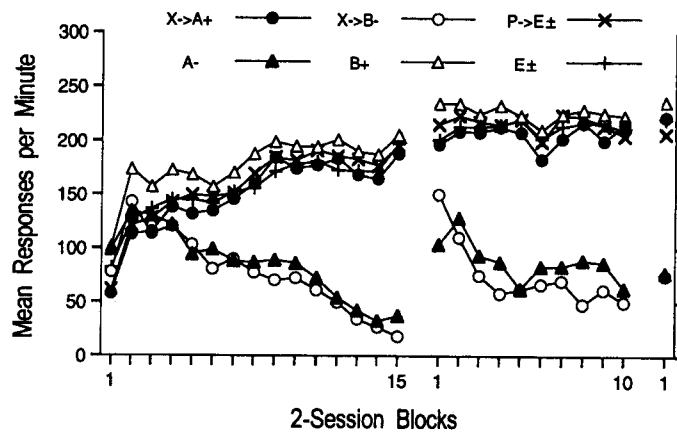


Figure 1. Mean rates of pecks to the target keylights during serial feature-ambiguous discrimination training in Experiment 1. X (a modulator) and P (a pseudomodulator) were diffuse stimuli which preceded the targets (A, B, and E).

A or B. This finding suggests that X did not work as an inverter of patterns of responding to A and B. Indeed, Figure 2 hints that X still tended to increase responding to A and decrease responding to B (cf. Holland, 1991). This suggestion is supported by the fact that the effects of X on A and B were opposite to those of the pseudomodulator that controlled for any nonmodulatory effects of novel stimulus combinations. The differences between  $X \rightarrow A$  and  $P \rightarrow A$  [ $T(16) = 23.5$ ] and  $X \rightarrow B$  and  $P \rightarrow B$  [ $T(9) = 0$ ] were reliable, although Ryan's (1960) method showed that only the latter was reliable on the target-wise alpha level.

### Target Re-Reversal and Test 2

Target re-reversal training was successful, as is reflected in the performances during Test 2 shown in the middle panel of Figure 2. When presented alone, A evoked fewer pecks than did B [ $T(16) = 0$ ]. Modulatory control of X over A and B was clear. The rate of responding was higher on  $X \rightarrow A$  trials than on A or  $P \rightarrow A$  trials [ $T_s(14) = 0$ ], and responding was lower on  $X \rightarrow B$  trials than on B [ $T(15) = 7$ ] or  $P \rightarrow B$  trials [ $T(16) = 18.5$ ]. These results indicate that conditioned modulation survived for the preceding 10 days during which target reversal, Test 1, and target re-reversal treatments were conducted. Thus, the failure of inverting response patterns in Test 1 could not be attributed to interference or forgetting of modulation caused by the preceding target reversal training.

### F-A Retraining

The right-hand portion of Figure 1 shows the birds' performances on F-A retraining sessions prior to new target training. The last unconnected points depict F-A performance embedded in the new target training. On this last block, X modulated responding to A [ $T(15) = 1$ ] and to B [ $T(16) = 0$ ]. Responding was less to A than to B when they were presented alone [ $T(16) = 4$ ], but the opposite pattern was observed when they were accompanied with X [ $T(16) = 3$ ].

### New Target Training and Test 3

All birds showed good discrimination learning with C and D, as is reflected by their final performances in Test 3 shown in the bottom panel of Figure 2. More responding occurred on C-alone trials than on D-alone trials [ $T(16) = 0$ ]. The modulator, X, had no effect on either target. Although the pseudomodulator, P, had a reliable incremental effect on D [ $T(9) = 6$ ], it did not satisfy Ryan's criterion. Thus, contrary to Holland and Reeve's (1991) observation in an instrumental preparation with rats, there was no modulatory transfer to conditioned and then extinguished targets.

### Discussion

This experiment replicated the result of Holland (1991) that a feature of F-A discrimination did not invert current patterns of responding to its targets after targets' contingencies with a US were reversed. It also suggested that modulatory control by a feature of a serial F-A task is more specific in autoshaping than in an instrumental learning study with rats (Holland & Reeve, 1991), because the feature did not affect separately trained and then extinguished targets.

## EXPERIMENT 2

Experiment 2 was designed to explore transfer between concurrently trained serial F-A tasks, which has been reported in another study (Holland, 1991). The possibility that a feature of F-A discrimination would work as an inverter of current patterns of responding to targets after reversal training was also reexamined.

### Method

#### Subjects, Apparatus, and Stimuli

Fifteen new pigeons of the same sex and strain as in Experiment 1 were maintained in the same way. They had histories of Pavlovian keypeck conditioning. The apparatus was the same as

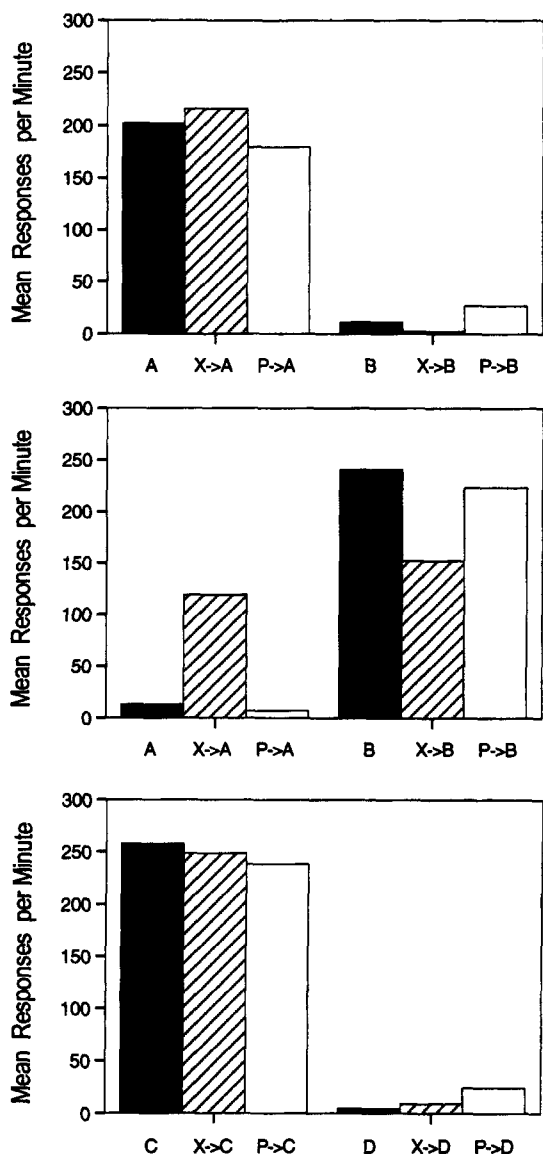


Figure 2. Mean rates of pecks to the target keylights in three tests of Experiment 1. Top panel: test performance after feature-ambiguous discrimination training and target reversal training. Middle panel: test performance after target re-reversal training. Bottom panel: test performance after new target training. An arrow indicates serial compounding in which the feature preceded the target.

in Experiment 1, except for the addition of a 1.8-kHz 80-dB tone from the speaker as another feature stimulus. The feature and target stimuli used in this experiment were novel for the birds.

#### Procedure

The initial four sessions were used to lower the rate of responding to the target stimuli. Each of the five targets (the white star, the red cross, the green triangle, the purple rectangle, and the blue ring pattern) was presented 12 times for 5 sec in a quasi-random order without food reinforcement. The average ITI was 50 sec throughout this experiment. Table 2 shows an outline of the following procedures.

**F-A discrimination.** For 60 sessions, birds were trained in two serial F-A tasks and on a pseudomodulatory task. The flashing light was used as a modulator (X) for the keylight targets, the green triangle and the purple rectangle (A and B). One of the auditory features, the noise or the tone, was used as another modulator (Y) for other targets, the white star and the red cross (C and D). The other auditory feature was used as a pseudomodulator (P), and it was trained with the blue ring pattern (E). The first column of Table 2 shows the 12 trial types used in this phase. Temporal parameters of the features, the targets, and the food US were the same as in Experiment 1. All 12 trial types were mixed in each of six blocks, and two different training sequences were made with the same restrictions as those used in Experiment 1. One of these sequences was quasi-randomly chosen for each session. The identities of Y and P, A and B, and C and D were counterbalanced across the birds.

**Test 1.** The effects of the modulators and the pseudomodulator on responding to Targets A and B were tested for two sessions. Each session began with four blocks of the 12 training trials arranged in a quasi-random order. These were followed by nonreinforced test trials in two sequences of either [Y→A, A, X→A, P→A, P→B, X→B, B, Y→B], [P→A, A, X→A, Y→A, Y→B, X→B, B, P→B], [Y→B, B, X→B, P→B, P→A, X→A, A, Y→A], or [P→B, B, X→B, Y→B, Y→A, X→A, A, P→A], counterbalanced across birds. That is, each of the eight test trial types was presented a total of four times in this phase.

**Target reversal.** The reinforcement contingencies of A-alone and B-alone trials were reversed for two sessions. Each session consisted of 36 trials each of A+ and B-.

**Test 2.** The nonreinforced test procedure used in Test 1 was employed for two sessions, but each session began with 24 trials each of A+ and B-.

**Target re-reversal.** The reinforcement contingencies of A-alone and B-alone trials were changed again to make them identical to those in the original F-A task. In each of three sessions, 36 trials each of A- and B+ were scheduled.

**Test 3.** The same procedure as that used in Test 2 was employed, except that the sessions began with 24 trials each of A- and B+.

#### Data analysis

One bird failed to peck the key in almost all sessions, so its data were excluded from the analyses.

## Results

### F-A discrimination

Figure 3 depicts acquisition of two F-A discriminations. Although acquisition was quicker for the task with the flashing light modulator than for the task with the auditory modulator,<sup>1</sup> both tasks were well mastered by the last block of sessions, in which X increased responding to A but decreased responding to B, and Y increased responding to C but decreased responding to D [ $T_s(14) = 0$ ]. In addition, responding was less to A than to B, more to X→A than to X→B, less to C than to D, and more to Y→C than to Y→D [ $T_s(14) = 0$ ]. The bottom panel of Figure 3 also indicates that the pseudomodulator had no effect on responses to E.

### Test 1

The top panel of Figure 4 presents performance during Test 1. As in the preceding training, responding was less on A-alone trials than on B-alone trials [ $T(14) = 0$ ]. The original modulator (X) of A and B controlled responding

**Table 2**  
**Outline of the Procedures in Experiment 2**

F-A Discrimination	Test 1	Target Reversal	Test 2	Target Re-Reversal	Test 3
X→A+, A-, X→B-, B+	X→A-, A-, X→B-, B-	A+, B-	Same as in Test 1	A-, B+	Same as in Test 1
Y→C+, C-, Y→D-, D+	Y→A-, Y→B-				
P→E+, E-, P→E-, E+	P→A-, P→B-				

Note—Stimuli X, Y (modulators), and P (a pseudomodulator) were 15-sec diffuse feature stimuli. A, B, C, D, and E were 5-sec target keylights. An arrow (→) indicates serial compounding in which the feature preceded the target by 10 sec. Plus (+) and minus (-) symbols indicate reinforcement and nonreinforcement, respectively.

to these targets [ $T_s(14) = 0$ ], and this control was much more than that of the modulator in the other F-A task (Y) or of the pseudomodulator (P) [ $T_s(14) \leq 3$ ]. Although responding to A was slightly increased by Y [ $T(12) = 11.5$ ] and by P [ $T(12) = 14$ ], these differences failed to reach Ryan's (1960) criterion. There were no reliable differences between Y and P in their effects on A or B. Hence, contrary to Holland's (1991) success in instrumental

learning, there was no modulatory transfer between concurrently trained serial F-A tasks in the present setting.

**Target Reversal and Test 2**

Target reversal training was successful, as is reflected in performance during Test 2 shown in the middle panel of Figure 4. When presented alone, A evoked more pecks than did B [ $T(14) = 0$ ]. The effects of all features were

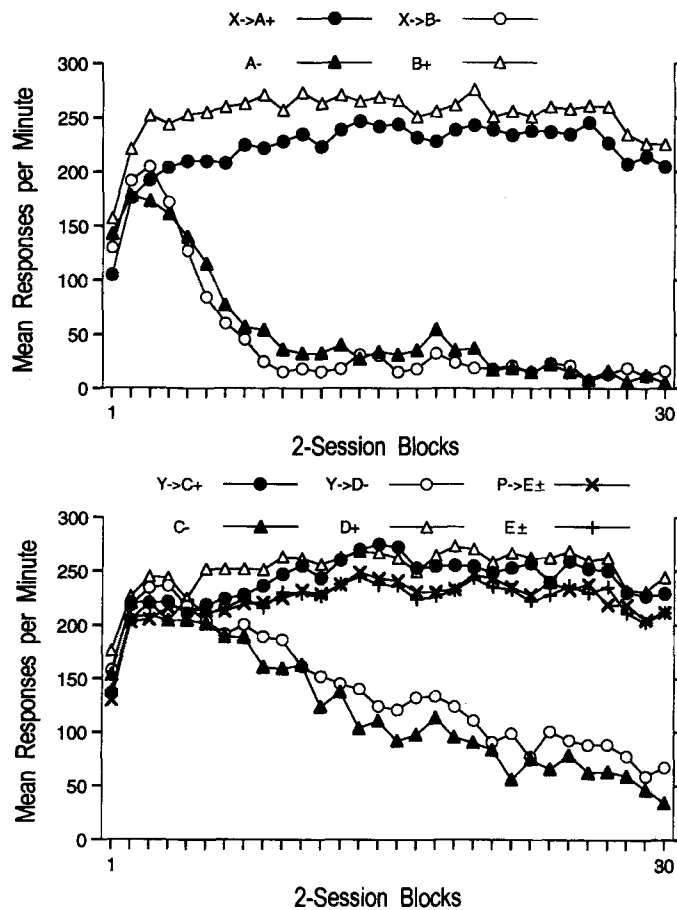


Figure 3. Mean rates of pecks to the target keylights during serial feature-ambiguous discrimination training in Experiment 2. Top panel: X (a modulator) was a flashing light which preceded the targets (A and B). Bottom panel: Y (another modulator) and P (a pseudomodulator) were auditory stimuli which preceded the targets (C, D, and E).

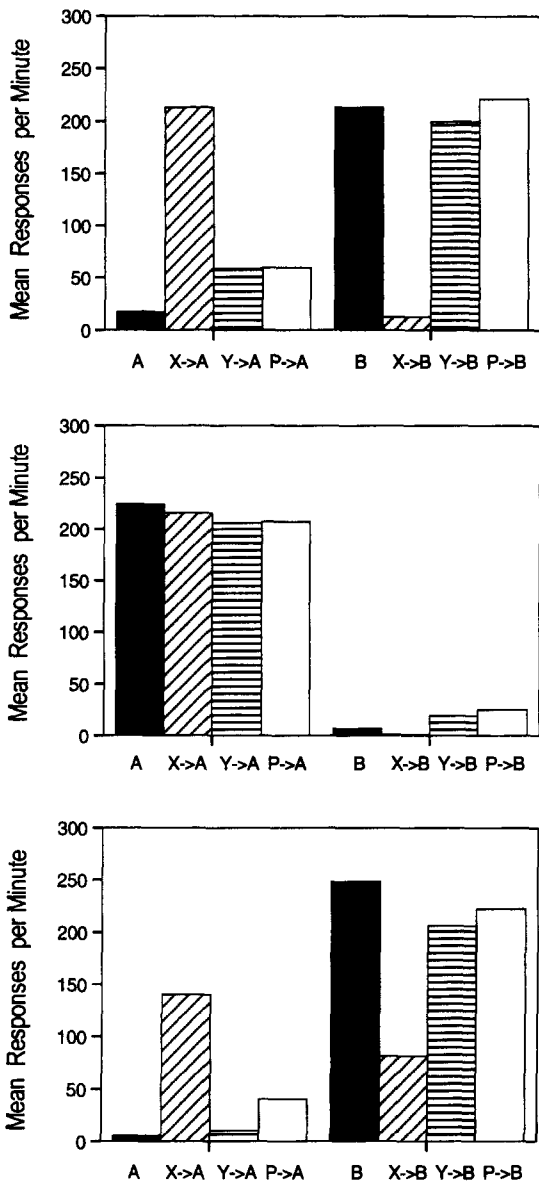


Figure 4. Mean rates of pecks to the target keylights in three tests of Experiment 2. Top panel: test performance after feature-ambiguous (F-A) discrimination training. Middle panel: test performance after target reversal training. Bottom panel: test performance after target re-reversal training. An arrow indicates serial compounding in which the feature preceded the target.

not reliable except for that of P on B [ $T(8) = 2$ ]. However, this difference failed to reach Ryan's (1960) criterion. Thus, this test replicated the results of Experiment 1.

#### Target Re-Reversal and Test 3

All birds pecked less on A-alone trials than on B-alone trials following target re-reversal training, as is reflected in the test performances shown in the bottom panel of Figure 4 [ $T(14) = 0$ ]. Modulatory control of X over A and B was maintained. The rate of responding

was higher on X→A trials than on A-alone, Y→A, or P→A trials [ $Ts(13) = 0$ ], and responding on X→B trials was lower than on B-alone, Y→B, or P→B [ $Ts(14) = 0$ ]. In addition, the pseudomodulator (P) had an incremental effect on A [ $T(9) = 0$ ], and the difference between Y→A and P→A trials was also reliable [ $T(10) = 1$ ]. The effect of P observed here suggests some nonmodulatory effect. In any case, the results of Test 3 replicated the durability of conditioned modulation following reversal and re-reversal observed in Experiment 1.

#### Discussion

This experiment failed to yield modulatory transfer between two serial F-A tasks, contrary to the success in instrumental learning preparations with rats (Holland, 1991). One reason for the failure might have been the pseudomodulation treatment in the F-A discrimination phase. In order to discriminate between the modulatory and pseudomodulatory auditory features, birds might have paid more attention to differences in all features presented, resulting in no transfer between the auditory modulator and the flashing light modulator. By contrast, in Holland's (1991) study, the group of rats trained on two serial F-A tasks did not have concurrent pseudomodulation training. His test of nonmodulatory factors involved another group of rats that received one F-A task and one pseudomodulation task. Because of no reliable effects by the pseudomodulator, Holland concluded that the transfer that he observed in the former group was genuinely indicative of modulatory control.

#### EXPERIMENT 3

In Experiment 3, modulatory transfer between two serial F-A tasks was assessed in the absence of concurrent pseudomodulation training, as in Holland (1991). Non-modulatory factors were assessed by using a third feature, which had not been presented in the F-A discrimination phase.

This experiment also tested modulatory transfer in a savings procedure. After the usual transfer testing and retraining of the two F-A tasks, the targets of one task were paired with a feature of another task to make a new F-A task. Performance in this task was compared with that in a second new F-A task consisting of the same targets and the nonmodulator. Because savings sometimes reveal otherwise undetectable differences among conditions (see, e.g., Holland & Ross, 1983; Zentall & Hogan, 1976), the savings test of Experiment 3 might be a more sensitive test of modulatory transfer.

#### Method

##### Subjects, Apparatus, and Stimuli

Sixteen new pigeons of the same sex and strain as in the preceding experiments were maintained in the same way and were trained and tested in the same apparatus. The feature and target stimuli used in the preceding experiments were employed but were novel to the birds.

Table 3  
Outline of the Procedure in Experiment 3

F-A Discrimination	Test 1	Target Reversal	Test 2	Target Re-Reversal	Test 3	Savings Test
X→A+, A-, X→B-, B+ Y→C+, C-, Y→D-, D+	X→A-, A-, X→B-, B- Y→A-, Y→B- P→A-, P→B-	A+, B-	Same as in Test 1	A-, B+	Same as in Test 1	Y→A+, A-, Y→B-, B+ P→A+, A-, P→B-, B+

Note—Stimuli X, Y (modulators), and P (a false modulator) were 15-sec diffuse feature stimuli. A, B, C, and D were 5-sec target keylights. An arrow (→) indicates serial compounding in which the feature preceded the target by 10 sec. Plus (+) and minus (-) symbols indicate reinforcement and nonreinforcement, respectively.

### Procedure

Preexposure to the target stimuli was conducted for three sessions in the same fashion as in Experiment 2, except that the blue ring pattern was not used in this experiment. On the fourth session, the auditory feature stimuli as well as the target stimuli were presented without reinforcement, 12 times each. This treatment was intended to reduce any neophobic reaction to the auditory features. The average ITI was 50 sec throughout this experiment. Table 3 shows an outline of the following procedures.

**F-A discrimination.** For 30 sessions, birds were trained in two serial F-A tasks. The flashing light was used as a modulator (X) for the keylight targets, the green triangle and the purple rectangle (A and B). One of the auditory features, the noise or the tone, was used as another modulator (Y) for the other targets, the white star and the red cross (C and D). The other auditory feature (P) was not presented in this phase and was spared for use as a false modulator in testing. Temporal parameters of the features, the targets, and the food US were the same as in the preceding experiments. All eight trial types were mixed in each of nine blocks, and two different training sequences were made with the same restrictions used in the previous experiments. One of these sequences was quasi-randomly chosen for each session. The identities of Y and P, A and B, and C and D were counterbalanced across the birds.

**Test 1.** The effects of the modulators and the false modulator on responding to Targets A and B were tested for two sessions. Each session began with seven blocks of the eight training trials arranged in a quasi-random order. These were followed by the nonreinforced test trials used in Experiment 2. That is, each of the eight test trial types was presented four times in total in this phase.

**Target reversal, Test 2, Target re-reversal, and Test 3.** The procedures were the same as those of the corresponding phases of Experiment 2, with the exception that the number of sessions of target re-reversal was two rather than three.

**Retraining of F-A discrimination.** The original training procedure for F-A discrimination was repeated for eight sessions in the same way.

**Savings test.** Both Y and P were used as training features of Targets A and B, which had been trained with X. Each of eight sessions consisted of 18 trials each of A- and B+, and of nine trials each of Y→A+, P→A+, Y→B-, and P→B-.

## Results

### F-A Discrimination

The left-hand portion of Figure 5 shows acquisition of the two F-A discriminations. Although discrimination performance was better in the task with the flashing light modulator than in the task with the auditory modulator, both tasks were well learned by the last block, in which X increased responding to A but decreased it to B, and Y increased responding to C but decreased it to D [ $T_s(16) = 0$ ]. In addition, responding was less to A than to B, more to X→A than to X→B, less to C than to D, and more to Y→C than to Y→D [ $T_s(16) \leq 1$ ].

### Test 1

The top panel of Figure 6 shows that responding was less on A-alone trials than on B-alone trials [ $T(16) = 0$ ]. This panel also indicates that X→A trials evoked more responding than did A-alone, Y→A, or P→A trials [ $T_s(16) \leq 8$ ]. The other comparisons for A yielded no reliable difference. On the other hand, X→B trials evoked less responding than did B-alone, Y→B, or P→B [ $T_s(16) \leq 1$ ], and the rates of responding on the latter three trial types did not differ reliably. Therefore, this test replicated the failure of modulatory transfer between two serial F-A tasks in Experiment 2 and suggests that the underlying mechanism of conditioned modulation is highly specific.

### Target Reversal and Test 2

Target reversal training was successful, as is reflected in performance during Test 2 shown in the middle panel of Figure 6. When presented alone, A evoked much more pecking than did B [ $T(16) = 0$ ]. None of the effects of any feature were reliable for Target B. For Target A, the differences between A-alone and Y→A trials [ $T(15) = 10$ ], between A-alone and P→A trials [ $T(16) = 6.5$ ], between X→A and Y→A trials [ $T(15) = 21.5$ ], and between X→A and P→A trials [ $T(14) = 12.5$ ] were reliable, and all four differences except the third one reached Ryan's (1960) criterion. This pattern suggests that the combinations of the features (Y and P) with A caused external inhibition effects on responding.

### Target Re-Reversal and Test 3

All birds pecked less on A-alone trials than on B-alone trials following target re-reversal training, as is reflected in test performance shown in the bottom panel of Figure 6 [ $T(16) = 0$ ]. Modulatory control of X over A was weak but reliable. The differences between A-alone and X→A trials [ $T(13) = 1.5$ ], between X→A and Y→A trials [ $T(13) = 6$ ], and between X→A and P→A trials [ $T(13) = 0$ ] were reliable. The original modulator (X) also maintained inhibitory control over B [ $T(16) = 9$ ], although Y and P also reduced responding to B [ $T(16) = 26.5$  and  $T(16) = 6$ , respectively]. However, reduction of responding was more when B was accompanied by X than when B was accompanied by the other features: Responding was less on X→A trials than on Y→B trials [ $T(16) = 8$ ] or on P→B trials [ $T(15) = 14$ ]. The decrement of responding to B by Y, the modulator of the other F-A task, should not be considered as evidence of mod-



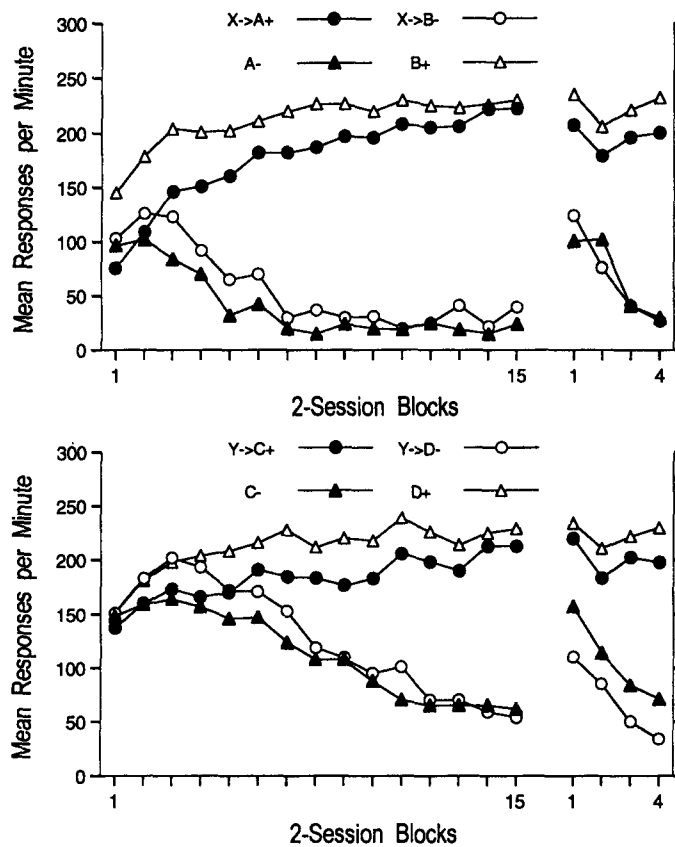


Figure 5. Mean rates of pecks to the target keylights during serial feature-ambiguous discrimination training in Experiment 3. Top panel: X (a modulator) was a flashing light which preceded the targets (A and B). Bottom panel: Y (another modulator) was an auditory stimulus which preceded the targets (C and D).

ulatory transfer between the F-A tasks, because the decrease was numerically *less* than that caused by P, the false modulator. In addition, the difference between the B and Y→B trials failed to reach Ryan's (1960) criterion. A plausible reason for the reduction in responding to B caused by Y and P is external inhibition.

### Retraining of F-A Discrimination

The right-hand portion of Figure 5 shows the course of reacquisition of the F-A tasks. On the last block, modulatory effects of X and Y on their own targets were highly reliable [ $Ts(16) \leq 4$ ]. Responding was less to A than to B, more to X→A than to X→B, less to C than to D, and more to Y→C than to Y→D [ $Ts(16) \leq 2$ ].

### Savings Test

Figure 7 shows performance during the eight-session savings test. The modulator of the other F-A task (Y) was no more effective than the false modulator (P) throughout the test phase: There were no reliable differences between Y→A and P→A trials or between Y→B and P→B trials in any session. In other words, there were

no signs of modulatory transfer between two serial F-A tasks even in the savings test. By the last block, both features controlled responding to A and B [ $Ts(16) \leq 5$ ].

### Discussion

Transfer between two serial F-A tasks was not observed with a design similar to that of Holland (1991), who found transfer in instrumental learning preparations with rats. Furthermore, the unsuccessful transfer was also evident even in a savings test. These results indicate that there is no modulatory transfer between the serial F-A tasks in the preparation used here.

### EXPERIMENT 4

So far, all experiments reported here failed to show any modulatory transfer in Pavlovian keypeck conditioning with pigeons, supporting the specific occasion-setting hypothesis (Holland, 1983, 1985). On the other hand, Rescorla (1993, Experiment 4) found modulatory transfer between an F-A task and an F-P or F-N task after concurrent training of these tasks. Because he did not

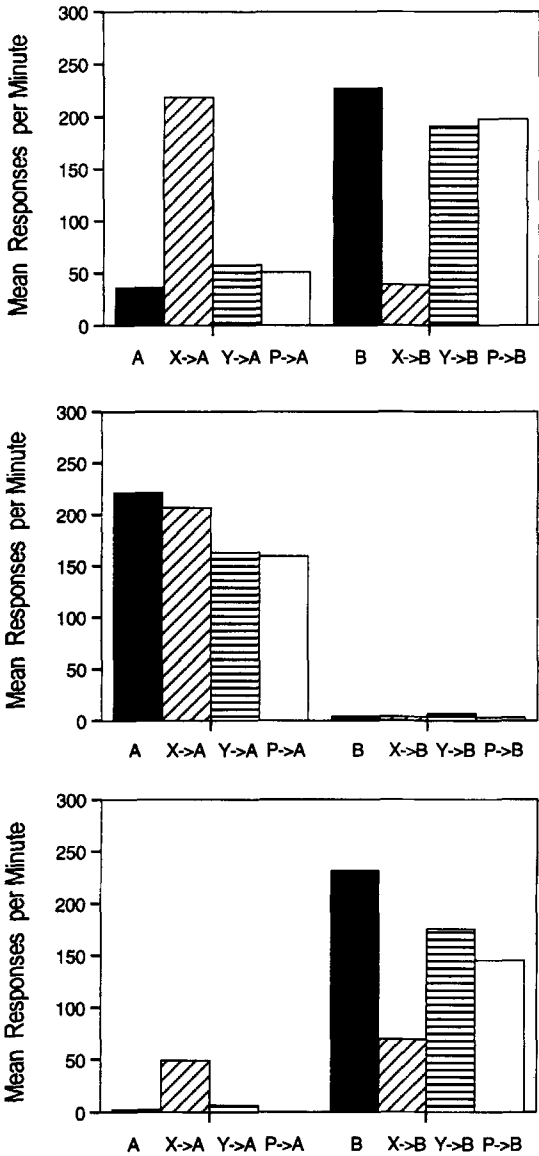


Figure 6. Mean rates of pecks to the target keylights in three tests of Experiment 3. Top panel: test performance after feature-ambiguous (F-A) discrimination training. Middle panel: test performance after targets reversal training. Bottom panel: test performance after target re-reversal training. An arrow indicates serial compounding in which the feature preceded the target.

test the effects of any feature stimuli that had lacked modulatory training, however, his results may not have reflected true modulatory transfer between tasks. This possibility should not be dismissed, because Rescorla used as features keylights that had some perceptual resemblance. Consequently, the transfer across features may have been due to simple stimulus generalization between the features.

Experiment 4 was performed to examine this issue in testing modulatory transfer between two serial F-A tasks. The feature stimuli were the same as those used in Rescorla's experiment, as were the temporal parameters. Non-

modulatory factors were assessed by using another key-light feature that had no history of modulatory training.

**Method**

**Subjects, Apparatus, and Stimuli**

Sixteen pigeons of the same sex and strain as in the preceding experiments were maintained in the same way. They had histories of Pavlovian keypeck conditioning. The same apparatus and the target stimuli were used. The diffuse feature stimuli were replaced with three visual stimuli projected on the key. All of them were circular disks 22 mm in diameter. One stimulus consisted of eight white-and-black sectors, making a pinwheel-like pattern. A second stimulus was white and contained .5-mm-thick parallel black lines spaced 3 mm apart and slanted 135° from the vertical. A third stimulus consisted of alternating 1-mm-thick white and black parallel lines slanted 45° from the vertical. The feature and target stimuli used in this experiment were novel for the birds.

**Procedure**

The initial two sessions were used to lower the rate of responding to the target stimuli. Each of the six stimuli (the white star, the red cross, the green triangle, the purple rectangle, the pinwheel pattern, and the 135° stimulus) were presented 12 times for 5 sec in a quasi-random order without food reinforcement. The 45° stimulus was spared for the later use. The average ITI was 60 sec throughout this experiment.

**F-A discrimination.** For 38 sessions, birds were trained in two F-A tasks. Either the pinwheel pattern or the 135° stimulus was used as a modulator (X) for the green triangle and the purple rectangle (A and B), and the other was used as another modulator (Y) for the white star and the red cross (C and D). The temporal parameters for this experiment differed from those of the preceding experiments but were identical to those used by Rescorla (1993, Experiment 4). On each compound trial, a 5-sec feature started 10 sec before a 5-sec target, with a 5-sec gap between them. This temporal arrangement is necessary to reduce simple excitatory conditioning to the feature. All eight trial types were mixed in each of 12 blocks, and two different training sequences were made with the same restrictions used in the preceding experiments. One of these sequences was quasi-randomly chosen for each session. The identities of X and Y, A and B, and C and D were counter-balanced across the birds.

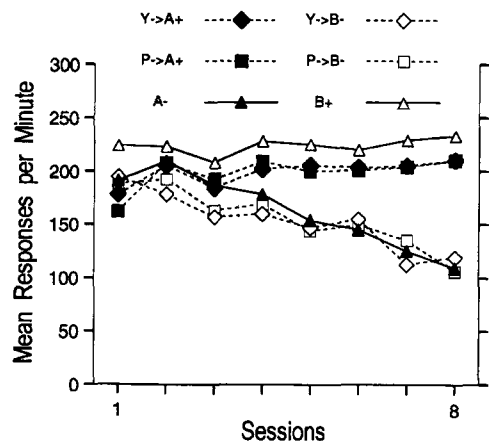


Figure 7. Mean rates of pecks to the target keylights during savings transfer tests with serial feature-ambiguous tasks in Experiment 3. Y had been a modulator for other targets, and P had been a false modulator. Both stimuli used here as modulators which preceded the targets (A and B).

**Introduction of a false modulator.** The same F-A discrimination training was continued for six sessions, but each session also had two trials with the 45° stimulus. This stimulus was presented on the 33rd and 66th trials and was nonreinforced. This treatment was intended to reduce any neophobic reaction in preparation for the forthcoming test, in which it was to be used as a false modulator, P.

**Test 1.** The effects of the modulators and the false modulator on responding to Targets A and B were tested for two sessions. The initial 49 trials were the same as in the last session of the preceding phase: Four trials each of 12 training trials plus one trial with the false modulator arranged in a quasi-random order. These were followed by 16 nonreinforced test trials, 2 trials each of eight test types. The same sequence as in Experiments 2 and 3 was used. That is, each of the eight test trial types was presented four times in total in this phase.

**Target reversal.** The reinforcement contingencies of A-alone and B-alone trials were reversed for two sessions. Each session consisted of 36 trials each of A+ and B-.

**Test 2.** The same procedure as that of Test 1 was employed, except that the sessions began with 24 trials each of A+ and B-.

**Target re-reversal.** The reinforcement contingencies of A-alone and B-alone trials were changed again to make them identical to those in the original F-A task. In each of two sessions, 36 trials each of A- and B+ were scheduled.

**Test 3.** The same procedure as that of Test 2 was employed, except that the sessions began with 24 trials each of A- and B+.

#### Data Analysis

One bird failed to peck the key in almost all sessions, so its data were excluded from the analysis. Since the keylight stimuli were used as features in this experiment, responding to these features was also recorded.

## Results and Discussion

### F-A Discrimination

Figure 8 depicts acquisition of two F-A discriminations. Both tasks were mastered in similar ways. On the last block, X and Y modulated responding to their own targets [ $T_s(15) \leq 1$ ]. In addition, the differential responding between both A and B and C and D was reliable both in target-alone trials and in compound trials [ $T_s(15) \leq 1$ ].

Although the average rates of responding to the features (X, Y, and P) on the last block were 27, 27, and 28 responses per minute (rpm), respectively, the majority of these pecks were from 1 bird whose rates of responding to these features were 362, 376, and 378 rpm, respectively. According to casual observation, this bird also pecked the unlit key vigorously during the delay between X or Y and their targets, and it pecked for several seconds after the offset of P-alone trials.

#### Test 1

The top panel of Figure 9 shows that responding was less on A-alone trials than on B-alone trials [ $T(15) = 0$ ], and that X controlled responding to its original targets, A and B [ $T_s(15) \leq 3$ ]. The most interesting finding, however, is that Y and P also had the same control over these targets [ $T_s(15) \leq 3$ ]. Because there were no differences in modulatory effects among these features, the most likely account of these results is simple stimulus generalization among the features. It is likely that the same factor caused transfer in Rescorla's (1993) experiment.

The average rates of responding to X, Y, and P (and those of the highest responder) were 30 (389), 27 (369), and 29 (362) rpm, respectively.

#### Target Reversal and Test 2

Target reversal training was successful, as is reflected in the performance during Test 2 shown in the middle panel of Figure 9. When presented alone, A evoked much more pecking than did B [ $T(15) = 0$ ]. No feature had any reliable effect on responding to A or B. Thus, the keylight modulators used in this experiment, as well as the diffuse features in the preceding experiments, did not invert the patterns of responding following target reversal.

The average rates of responding to X, Y, and P (and those of the highest responder) were 27 (344), 31 (366), and 35 (440) rpm, respectively.

#### Target Re-Reversal and Test 3

All birds pecked less on A-alone trials than on B-alone trials following target re-reversal training, as is reflected in the test performance shown in the bottom panel of Figure 9 [ $T(15) = 0$ ]. Modulatory control by X over A was weak but reliable [ $T(13) = 7$ ], but so too was that by Y and P [ $T(14) \leq 7$ ]. The effects on B, however, were not.

The results of Test 3 suggest that retention of keylight modulators might be more fragile than that of the diffuse modulators used in the preceding experiments, in which more modulatory control was observed in the corresponding tests.

The average rates of responding to X, Y, and P (and those of the highest responder) were 18 (245), 14 (189), and 20 (260) rpm, respectively. The low rates in comparison with the rates in Tests 1 and 2 also indicates deteriorated stimulus control by the features.

## GENERAL DISCUSSION

Transfer effects on several target stimuli of conditioned modulation by a feature stimulus of serial F-A discrimination were explored in a Pavlovian keypeck preparation. In the first three experiments, diffuse stimuli were used as features. The results of these experiments can be summarized by three points. First, there was no modulatory transfer between two concurrently trained F-A tasks. Second, modulatory transfer to conditioned and then extinguished stimuli was not observed. Third, patterns of responding to targets that received contingency reversal after initial F-A training were not inverted by presentation of their original feature stimuli. These results strongly support the specific occasion-setting hypothesis of Holland (1983, 1985): namely, that a conditioned modulator sets the occasion for specific CS-US linkages.

With keylight stimuli as features, Experiment 4 demonstrated transfer between two F-A tasks, but this finding was ascribed to stimulus generalization because the same effect was obtained with a feature that had no modulatory training history. The results of this experiment

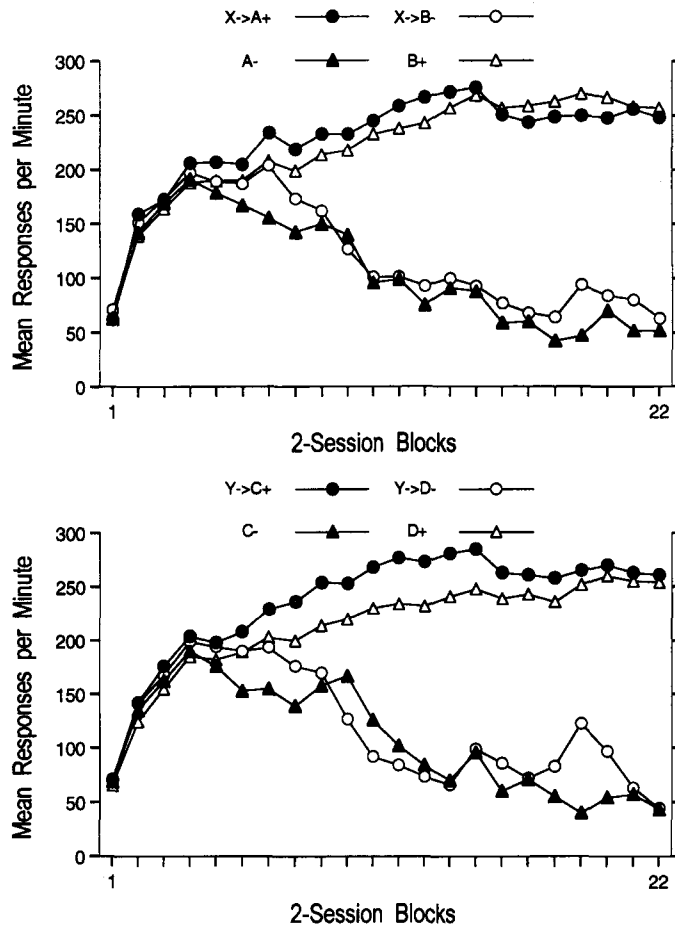


Figure 8. Mean rates of pecks to the target keylights during serial feature-ambiguous discrimination training in Experiment 4. Top panel: X (a modulator) was a keylight pattern which preceded the targets (A and B). Bottom panel: Y (another modulator) was a different keylight pattern which preceded the targets (C and D).

suggest that the mutual modulatory transfer reported between F-A and F-P or F-N discriminations (Rescorla, 1991) was also probably due to stimulus generalization among feature stimuli. All of these features were circular white-and-black patterns projected on the same position of the key. Thus, their physical similarity would permit stimulus generalization (see Parker, Serdikoff, Kaminski, and Critchfield, 1991, for generalization of feature stimulus control; see also Bowers & Richards, 1986).

Conditioned modulation is usually treated as hierarchical event learning, and in this paper it has been supposed that a serial F-A task is mastered in this way. However, the F-A task is solvable by configural learning in which each stimulus compound functions as a unitary stimulus (cf. Kehoe & Gormezano, 1980). Thus, the F-A task may be mastered by learning that XA and B signal reinforcement and that A and XB signal nonreinforcement.

Nakajima (1992) explored temporal relationships between feature and target stimuli in compound trials of an F-A task in which a diffuse feature and keylight targets were 5-sec long. All 6 pigeons in that study showed better

discrimination performance when the feature and target stimuli were presented serially than when the stimuli were compounded simultaneously. This finding appears to be unfavorable for the configural account of F-A discrimination, because configuration seems more likely in the simultaneous stimulus compound than in the serial one (Hull, 1943). But if the birds had limited sources of attention to or limited processing of the stimuli (cf. Riley & Roitblat, 1978), they might not have dealt fully with feature and target stimuli that were presented simultaneously. The serial presentation may have reduced the processing load and made it easy for the birds to integrate the stimuli into a unitary stimulus.<sup>2</sup>

This argument caused the author to run computer simulations of the experiments reported here with a formal model of configural learning (Pearce, 1987, 1994). This model can easily account for acquisition of serial F-A discrimination. Furthermore, it is successful in explaining the general patterns of the test results reported here, given the assumption that salience of feature stimuli is lower than that of target stimuli. For example, if the

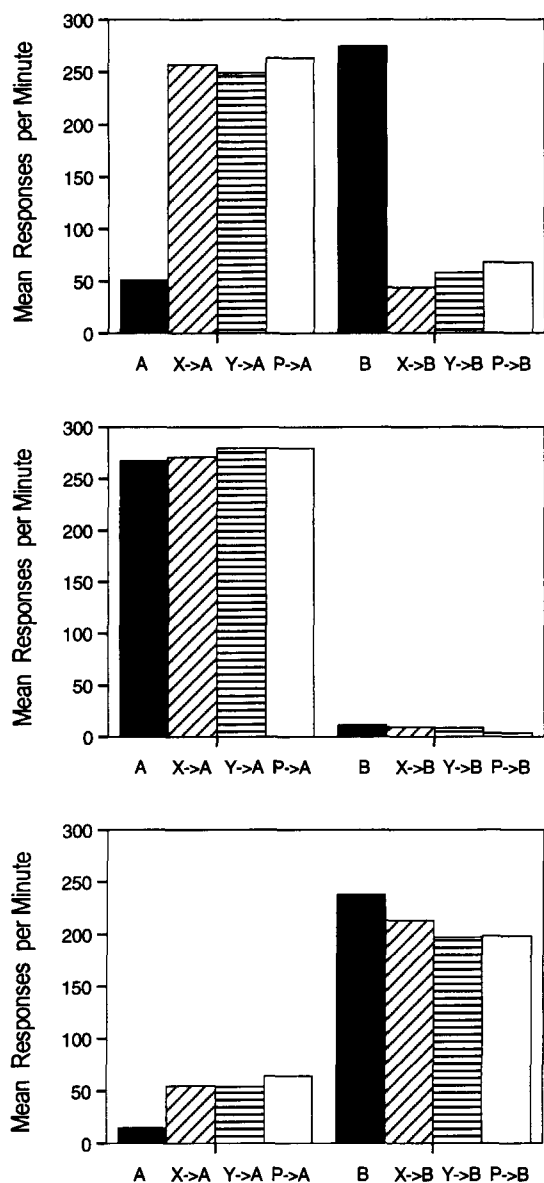


Figure 9. Mean rates of pecks to the target keylights in three tests of Experiment 4. Top panel: test performance after feature-ambiguous (F-A) discrimination training. Middle panel: test performance after target reversal training. Bottom panel: test performance after target re-reversal training. An arrow indicates serial compounding in which the feature preceded the target.

saliency of the features is one fifth that of the targets and if the maximum associative strengths provided by reinforcement and nonreinforcement are 1 and 0, respectively, the associative strengths of A,  $X \rightarrow A$ ,  $Y \rightarrow A$ ,  $P \rightarrow A$ , B,  $X \rightarrow B$ ,  $Y \rightarrow B$ , and  $P \rightarrow B$  trials, respectively, of Experiments 2 and 3 should be 0.0, 1.0, 0.0, 0.0, 1.0, 0.0, 0.8, and 0.8 in Tests 1 and 3, and 1.0, 1.8, 0.8, 0.8, 0.0, -0.8, 0.0, and 0.0 in Test 2. Accordingly, the possibility of configural learning in serial F-A discrimination should not be disregarded.

The present experiments revealed that conditioned modulation is specific to original feature-target combinations and that "transfer" to new combinations may be caused by simple stimulus generalization. The specificity of conditioned modulation in serial F-A discrimination observed here indicates that its underlying mechanism of modulatory control in serial F-A discrimination is either specific CS-US occasion setting (Holland, 1983, 1985) or configural learning (Pearce, 1987, 1994). However, in studies done by Holland (1991; Holland & Reeve, 1991), modulatory control by a feature of F-A discrimination was less specific: It affected responding to targets of concurrently trained F-P, F-N, and F-A tasks and a conditioned and extinguished stimulus. Holland used rats as subjects in instrumental learning, whereas pigeons were employed in the present autoshaping study. Thus, the differences in experimental preparations between his and my studies may underlie the differences in modulatory transfer. There is another intimation of the differences between these preparations. In the rats' instrumental setting, acquisition of serial F-A discrimination was as quick as that of serial positive or negative patterning (Holland & Reeve, 1991). Although corresponding studies in which acquisition of these tasks has been compared in the same experiment have not been published in Pavlovian keypeck conditioning with pigeons, acquisition of serial patterning tasks (see, e.g., Nakajima, 1995; Rescorla, 1991; Robbins, 1990) seems much quicker than that of serial F-A discrimination observed in the present study and in others (Nakajima, 1992, 1994; Rescorla, 1993). The slow learning of a serial F-A task in this preparation may indicate that highly specific modulation needs more training.

Holland (1995) argued that modulatory transfer may be larger in instrumental paradigms than in Pavlovian ones because the four-term contingency [feature-[target-[response-reinforcer]]] arranged in the instrumental paradigm gives animals another possible locus of transfer, "response," which is lacking in the Pavlovian paradigm. That is, modulatory transfer observed in the F-A studies of Holland (1991; Holland & Reeve, 1991) might have been mediated by the common "response" element evoked by original and transfer targets. In addition, species difference might be another factor. The exact underlying mechanism of conditioned modulation might differ between the species, and there is some evidence which hints at it. In rats, hippocampal formation lesions impair acquisition of conditioned modulation but not of simple conditioning (see Schmajuk & Buhusi, 1997, for a review). The literature that deals with the effect of hippocampal lesions on pigeons is scanty, but such lesions impair acquisition of simple Pavlovian keypeck conditioning (Reilly & Good, 1989) but not of conditional discrimination (Good & Macphail, 1994), in which a modulation-like process seems to be operating. Further research with different species as well as with different paradigms will be necessary in order to elucidate the underlying mechanism of serial F-A discrimination.

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## NOTES

1. In all experiments of this study in which diffuse features were used, acquisition of discrimination was the quickest with the flashing light modulator, slower with the noise modulator, and slowest with the tone modulator. Because the auditory stimuli were balanced in each experiment and because they had no differential effects on the general patterns of the test results, analysis of this factor has not been included in this paper.

2. Recently, Wagner and Brandon (1997) proposed a modification of their theory of Pavlovian conditioning (Wagner & Brandon, 1989) in order to deal with stimulus configuration, and in this modified theory, the configuration is more likely in serial stimulus compounding than in simultaneous compounding.

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