Addition versus deletion as a signal

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Subjects typically show superior discriminative performance when a distinguishing feature appears on reinforced rather than nonreinforced trials. The phenomenon is usually attributed to the relative predictiveness of the reinforcer by different stimulus elements. However, stimulus addition may be more effective than stimulus deletion as a signal. By removing the standard intertrial intervals, we made addition and deletion equally predictive of the reinforcer in four operant experiments involving between- and within-subject comparisons. Pigeons consistently performed better on operant discriminations when the addition rather than deletion of an auditory or visual stimulus served as the cue for food. This general finding persisted despite manipulation of the relative duration and localizability of the signal. Thus mere presence as opposed to absence plays a role in the feature-positive superiority, an outcome that may reflect a fundamental, biologically based difference between addition and deletion as effective signals of reinforcement.

In a typical experiment on the feature-positive effect, the subjects receive two kinds of brief trials: one (S+) followed by a reinforcer and the other (S−) followed by nothing. The S+ and S− share a common element—say the illumination of a green light on a pigeon's response key—but a second element, which is the distinguishing feature—say a small white square on the key—is present during one type of trial and absent during the other. Neither the common nor the distinguishing feature appears between trials (the intertrial interval, ITI).

Subjects perform considerably better when the feature is present on positive trials (FP) than on negative trials (FN). This result occurs over a wide range of settings involving different species, reinforcers (USs), and stimulus modalities. Often there is little or no evidence of any FN learning, especially when the feature is not very salient (see Hearst, 1978, 1984; Jenkins & Sainsbury, 1969, 1970; Newman, Wolff, & Hearst, 1980). Beyond the intrinsic interest of the FP superiority, analysis of the two discrimination arrangements is potentially valuable for understanding several general issues in discrimination learning (see also Holland, 1985). The set of experiments to be reported here mainly addresses two such issues: (1) the predictiveness of different stimulus elements with respect to some outcome, and (2) the effectiveness of presence and absence as positive signals.

Prior explanations of the unexpected asymmetry between FP and FN discrimination performance have stressed the role of differential predictiveness (see, for example, Hearst & Jenkins, 1974; Staddon, 1983). For standard FP subjects, the distinguishing feature is the best positive predictor of food in the situation, whereas for FN subjects the common element is. If the subjects mainly notice and respond to elements that they learn are the most reliable predictors of the US, they will perform better on FP discriminations. In that arrangement the best predictor of the US is present only on S+ trials, whereas in the FN case the best predictor is present on both S+ and S− trials. Hearst and Jenkins's description in terms of such "signtracking" was rephrased by Staddon as a special case of hill-climbing: "going for the thing that best predicts reward" (1983, p. 314).

However, a neglected issue involves the possibility that the mere presence of a stimulus may generally be a more effective positive signal than its absence. Unfortunately, almost all demonstrations of the feature-positive effect have confounded the influence of presence or absence with differences in reinforcer predictiveness during discrimination training. In the FP and FN arrangements with ITIs, present stimuli predict the reinforcer better than absent stimuli, because both the distinguishing and the common elements are absent during ITIs, when no reinforcers occur. Our goal was to hold equal the predictiveness of feature presence versus feature absence on various operant discrimination procedures and to determine whether differences in performance would still emerge. Wolff (1983) devised and examined several methods relevant to this overall goal, within the context of Pavlovian (autoshaping) discriminations in pigeons.

One of Wolff's methods involved the complete elimination of ITIs from the standard FP and FN procedures. Translated into operant terminology, this scheme entailed the establishment of simple two-component multiple schedules. On such schedules, the common element (e.g., a green key) would always be present during experimental sessions, but for one group of pigeons the *addition* of an otherwise absent feature (e.g., a white square) would signal the availability or delivery of a US, whereas for

another group, the *deletion* of an otherwise present feature (the square) would signal the US. In Wolff's autoshaping discriminations, addition proved a more effective CS than deletion; but he used a small number of birds, and the results were not statistically conclusive. ·

Interestingly, the question of addition as opposed to deletion is of historical significance for learning theory, via a route seemingly unrelated to work on the feature-positive effect. Hull's (1949) concept of stimulus intensity dynamism implied that presentations of stimuli should normally serve as better positive cues than removals of stimuli. Pertinent research by Kamin (1965; see also Gormezano, 1972; Mackintosh, 1974, pp. 41–45; Welker & Wheatley, 1977) revealed that in a mirror-image ("upsidedown") comparison, the presentation of a noise before shock yielded significantly better fear conditioning in rats than did the removal of the same noise. Kamin suggested that stimulus onsets (or increases in intensity) may evoke considerably greater and longer lasting neural activity than stimulus terminations (or decreases in intensity), and that they thus serve better as delay and trace CSs (but cf. Levis, 1971, who assessed conflicting results in the animal and human literature comparing onset and offset and discussed their relevance to Hull's approach). Work on detection and identification of stimulus changes in sensory-perceptual or memory research with human subjects (e.g., Agostinelli, Sherman, Fazio, & Hearst, 1986; Kemp, 1985; Pezdek et al., 1988; Schulman, 1971) has also produced superior performance for additions than for deletions under many but not all experimental conditions.

The present studies examine whether operant discrimination performance depends on the nature of the S+, that is, on the appearance as opposed to the disappearance of some visual or auditory stimulus. To analyze the generality of any obtained differences, the trial duration and relative proportion of the session devoted to the S+ were varied in one experiment, and the diffuseness of the signal was varied across different experiments. We also examined some complex discriminations in which individual subjects received two kinds of signals for food within each session: either presentations of a tone or light (additions), or removals of a tone or light (deletions). Besides providing more data on the effectiveness of additions as opposed to deletions as positive signals during training, these complex discriminations allowed us to test for possible summation of S+s, by means of a comparison of responding to combinations of S+s with responding to the original training S+s themselves. Weiss (1972) has reviewed and contributed to the relatively small amount of research in which stimulus compounding of onsets is compared with that of offsets, and we hoped to look further at the issue of whether summation is equivalent for S+ combinations involving additions as opposed to deletions.

The multiple schedules used during our discrimination training arrangements equated the predictiveness of presence and absence with respect to the reinforcer. If no differences between the addition and deletion treatments should appear on these schedules, strong support would accrue for the view that predictiveness is the overriding factor producing the usual FP–FN asymmetry. On the other hand, a consistent superiority for addition over deletion on multiple schedules would suggest a fundamental, perhaps biologically based dichotomy between presence and absence of stimuli as effective signals for the occurrence of reinforcing events. Such a factor would then be implicated in the feature-positive effect, presumably in conjunction with the effects of reinforcer predictiveness.

EXPERIMENT 1

In our first experiment, standard visual stimuli from FP and FN research were employed: localized cues appearing on the bird's response key. On S+ trials, a white square either appeared at the center of a continuously green field (addition group) or disappeared from that location (deletion group). The groups were further subdivided so that the S+ either occupied a small proportion of the session or was in force during half the session; the S+ was more predictive of food in the former case. A few more subjects were included in the latter arrangement because of its rarity in the context of feature experiments and because of our presumption that discriminative performance would be generally worse, and group differences harder to detect, than in the former case.

Method

Subjects. Thirty-four experimentally naive adult female White Carneaux pigeons served as the subjects. The birds were individually housed under constant illumination, with water always available. They were maintained at 75% (plus or minus 20 g) of their free-feeding weights, and they had been deprived of food for approximately 23 h before the experimental sessions, which occurred daily, began.

Apparatus. Two standard three-key pigeon boxes served as the test chambers (one a Grason-Stadler Model 1184JA-1 and the other a Lehigh Valley Electronics Model 1519). Only the center key, 2.5 cm in diameter and 25 cm above the floor, was used; the two side keys were covered with black tape and remained inoperative. An Industrial Electronics Engineers in-line projector illuminated the response key with two possible kinds of displays: a homogeneous green field, or a green field with a small (0.2-cm) white square at its center. The green fields on the two displays were equal in brightness. A force of approximately .122 N against the key activated a microswitch behind it and was recorded as a peck.

Mixed grain was available to birds for 3 sec whenever a tray was lit and raised inside a food aperture (6.3 cm square) located 14 cm under the key. A photocell circuit detected entries of a pigeon's head into the aperture when food was accessible. Periodic observation of the birds revealed that the number of photocell interruptions reliably matched the number of food presentations during which a subject actually ate.

A houselight (1820 bulb) was centered 6.3 cm above the key and was shielded to reflect white light diffusely toward the ceiling. A ventilation fan in the boxes and loudspeakers inside and outside the

boxes emitted continuous white noise that masked external sounds. Electromechanical equipment in an adjacent room controlled the presentation of stimuli and the counting of keypecks and magazine entries.

Procedure. All 34 birds received the same preliminary treatment, which lasted 11 sessions, before they were placed on either an addition or deletion discrimination. Three days of feeder training were conducted with the houselight on and the keylight off. The birds obtained about 25 aperiodic grain presentations during each session, which were delivered within a span of approximately 15 min on the second and third days.

On the fourth and fifth days the keylight was turned on, and keypecking was manually shaped while the white square appeared and disappeared irregularly on the green background; the square was present for about half the session. Session 5 lasted only about 15 min for the birds that had clearly acquired the keypecking response. The experimenter tried to ensure that approximately the same number of feedings occurred during the presence and the absence of the square on the key. Somewhat longer sessions were arranged for the birds whose keypecking was still sporadic.

Sessions 6-11 were designed to maintain operant keypecking on progressively leaner variable interval (VI) schedules. The birds were initially placed in a dark box, but shortly afterwards the houselight and keylight came on. The square might be present or absent on the key at the start of a session, but each session involved approximately equal exposure to the two stimulus conditions, with an equivalent number of reinforcers delivered in both conditions. By Session 8, the subjects were ready for an automated schedule that programmed each stimulus display to last 24, 48, or 72 sec. Throughout the 20-min session, 10 3-sec reinforcers were available for pecking during each of the two kinds of displays. The same conditions held during Sessions 9 and 10, but a different sequence of stimulus durations was in force each day. Session 11 lasted 30 min but was otherwise the same as Sessions 8-10 (VI 1 min).

After completion of Session 11, the subjects were divided into four groups matched as closely as possible for mean keypecking rates. There were ns of 7 in each of the two groups (addition or deletion) designated for transfer to the short S+ condition, and ns of 10 in each of the two groups (addition or deletion) to be placed in the equal S+ condition. There had been no significant preference for responding to the presence or absence of the square during the preliminary training phase in any of the four groups.

Then discrimination training began; it lasted 20 days for all subjects. Each session, 30 min long, was conceptualized for programming purposes as comprising 150 12-sec intervals or units. Every session began with illumination of the houselight and green keylight, both of which remained on until the end of the session.

In the short S+ condition all 30 positive trials were scheduled to last for 12 sec plus a response. The S+ was either the appearance or the disappearance of the white square on the green key, for addition or deletion birds, respectively, and these trials occurred at the same points during sessions for the addition and deletion subjects. The first keypeck after the 12 sec had elapsed produced a 3-sec grain delivery, with the restriction that this response must occur within 6 sec after the opportunity for food became available (the appropriate S+ display remained on the key until the 6 sec were up or the food presentation terminated). However, on most S+ trials during the discrimination phase, a response occurred that activated the food magazine within a fraction of a second after the minimum 12-sec period.

The 30 S— trials that intervened between S+ trials were 24, 48, or 72 sec long, with each of these three intervals equally represented throughout a session. Thus the 30-min sessions contained four S— units for every S+ unit, yielding a total of approximately 6 min of S+ and 24 min of S—. By responding optimally, the subjects earned 30 reinforcers during a session. Several different arrangements of S+ and S— trials, all conforming to the constraints above, were con-

structed and used in a mixed order from day to day. To permit calculation of discrimination ratios, the total number of keypecks during the 12-sec S— periods immediately preceding S+s was compared with the total number of keypecks during the first 12 sec of S+s.

The equal S+ condition was arranged to parallel the short S+ condition as closely as possible. The S+ and S— periods could each last 24, 48, or 72 sec, and one of every four 12-sec S+ units was programmed so that the first peck after its completion would be reinforced. The times at which reinforcers became available corresponded for the short and equal conditions on a given experimental day; but a few different sequences of S+ and S— durations were composed, and one sequence was randomly selected for use on a particular day. Unlike in the short condition, reinforcers could occur in the midst of an S+, following any 12-sec unit of it; and more than one reinforcer might be possible during the 48- or 72-sec S+s. Reinforcers became available during or at the scheduled end of an S+ for 6 sec, the same period as for the short group.

Each 30-min equal S+ discrimination session contained one S+ unit for every S— unit, producing a total of approximately 15 min of S+ and 15 min of S— per session. As in the short condition, optimal responding earned birds 30 reinforcers during a session. To permit calculation of discrimination ratios, the total number of keypecks during S— periods was compared with the total number of pecks during S+ periods, not counting pecks during the 6-sec limited hold periods when reinforcement was available in S+.

Results and Discussion

Figure 1 displays performance over all training sessions for the square-addition and square-deletion subjects in the two S+ conditions. Daily discrimination ratios were calculated by dividing the total number of keypecks during the S+ by the total number of pecks during both the S+ and a comparable S— period (as defined above). Thus a ratio of .50 indicates no difference in responding for the S+ and S— periods, whereas a ratio of 1.00 represents a perfect discrimination.

All the groups improved over the 20 training sessions, but in both the short and equal conditions, an S+ involving the addition of a feature on the key yielded better performance than an S+ involving the deletion of that same feature. Every one of the 7 addition birds in the short S+ group achieved a discrimination ratio of at least .90 by the 4th day of training, as compared with only one of the 7 deletion birds; over the entire training phase, group differences in number of days until this criterion was reached differed significantly [$t(12) = 2.85, p < .02$]. Similarly, 7 addition birds in the equal S+ group reached the .90 criterion by the 10th day of training, as compared with only 2 deletion birds; group mean differences in sessions to reach this criterion were statistically significant here too [$t(18) = 2.49, p < .03$].

Analyses of variance of all the daily discrimination ratios in this experiment revealed that over the 20 training sessions, the main effects of addition versus deletion, short versus equal, and sessions were statistically significant [$F(1,30) = 16.14, F(1,30) = 20.55,$ and $F(19,570) = 61.56$, respectively; $p < .001$ in all cases]. The only significant interaction was between addition–deletion and sessions [$F(19,570) = 3.29, p < .001$].

Because one could argue that the preceding differences might arise from or be related to the fact that the S+ for
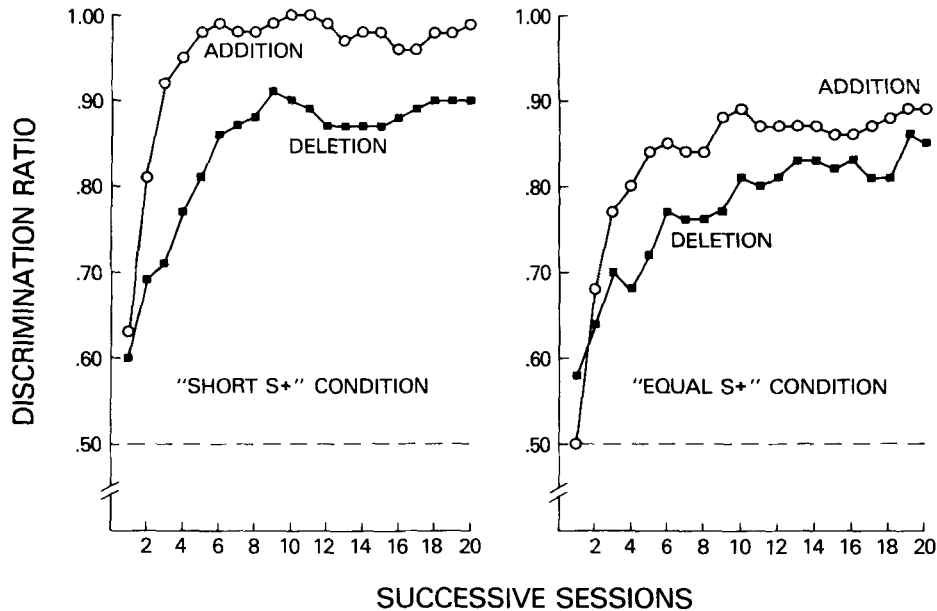
Figure 1. Mean discrimination ratios for addition and deletion subjects trained under either the short S+ or equal S+ condition of Experiment 1. The stimulus added or deleted was a white square on the response key.

the addition birds contained a definite feature to peck at (the small white square, perhaps resembling a piece of grain), whereas the S+ for the deletion birds did not contain such a target, the absolute daily number of responses to the S+ was compared for the two groups over the 20 training days. However, in both the short and equal S+ conditions, the somewhat greater amount of S+ responding in the addition group did not prove statistically significant [$F(1,12) = .083$, and $F(1,18) = 1.44$, for the short and equal birds, respectively]. Thus, differential performance in the two conditions was not attributable to some bias toward pecking rapidly at small objects, a conclusion that receives further support from our failure to observe differences in pecking in response to the forthcoming S+ and S− during the VI pretraining phase that preceded discrimination training. As will be seen, the results of Experiment 2, which employed an auditory feature not located on the response key, also contradict the "feature as target" explanation.

In Experiment 1, the subjects for which the addition of a visual feature served as the signal of food availability performed considerably better than the subjects for which the deletion of that same feature served as the positive signal. The short condition produced reliably better discrimination ratios than the equal condition—a finding that conforms with interpretations of stimulus control in terms of the overall predictiveness of the S+ (Hearst & Jenkins, 1974), or with more explicit approaches like scalar expectancy theory (see, for example, Gibbon & Balsam, 1981). However, because the discrimination ratios in the two conditions could not be calculated with the same time periods as a base, that aspect of the results is not stressed or pursued here.

EXPERIMENT 2

Our next experiment began with a direct attempt to assess the generality of the superiority of addition over deletion obtained in Experiment 1. Instead of a visual stimulus localized on the response key, a diffuse auditory cue (a 732-Hz tone) served as the element that was removed or added as a signal of food (see also the logic underlying Experiment 5 in Hearst, 1987, for a similar justification). The short S+ arrangement in Experiment 1 was used in this and our subsequent experiments, because it had produced very good discriminative performance.

Furthermore, after behavior on their original auditory discrimination was stable, most of the subjects were placed on a double discrimination. For half the birds, the addition of a either a diffuse ceiling light or the 732-Hz tone signaled the imminent availability of food; for the other half, the removal of either the light or the tone signaled the imminent availability of food. Besides indicating whether the addition of the diffuse light was a more effective signal than its deletion—another test of the generality of our prior results—this new procedure allowed us to meaningfully compare responding to combinations of additions or deletions in final test sessions. Would the novel combination of two deletion S+s yield more responses than either S+ alone, as has often been found for combinations of addition S+s (see Kehoe & Gormezano, 1980; Weiss, 1972)?

Method

Subjects. Twenty-four experimentally naive pigeons of the same type as in Experiment 1 were used. Their general maintenance and deprivation conditions matched those in the earlier study.

Apparatus. The two chambers from Experiment 1 served here, with some modifications. As before, only the center key was available to peck, but now it was always illuminated with a solid green light during keypecking sessions. Several new stimuli that could be added or removed were introduced in Experiment 2. One was a 732-Hz, 82-dB (SPL) tone, emitted from a speaker mounted behind the wall containing the key and food magazine; the addition or deletion of this tone provided the only stimulus change to be discriminated in the first part of Experiment 2. Another new stimulus was a 14-18 pps, 82-dB (SPL) clicker from the same speaker. In addition, a diffuse ceiling light (28ESB bulb, fitted with a colored cap) was centered at the top of the chamber, above a translucent plastic panel that covered the entire chamber and stood at a level just below the houselight. This ceiling light was red, at an intensity of 5.0 lx, during the first part of Experiment 2, but it was later changed to a blue color, at an intensity of 2.2 lx, during the double-discrimination phase. In the early training stages of this experiment, in which only tone addition or deletion served as the S+, the clicker, red ceiling light, and standard houselight always remained on while the subjects were in the chambers.

Procedure. Each bird received two or three sessions of feeder training with the keylight off and all the other auditory and visual stimuli continuously on. After a few manually controlled food presentations on the 1st day, the birds were given 30 automatically programmed 4-5 sec grain deliveries on each day of feeder training. During the next three or four sessions the green keylight was turned on and the subjects were trained to peck it, first on a continuous reinforcement (CRF) schedule and then on a rich schedule that became progressively leaner. After Day 7, the food delivery time was reduced to 3 sec for all birds, and over the course of 7-8 sessions, they were gradually transferred from a VI 30-sec to a VI 1-min schedule, on which they remained for 3-4 sessions until the discrimination training began.

During the preliminary shaping and VI training, the houselight, clicker, and ceiling light were already on when the subjects were placed in the box, and the tone was either absent or present, depending on whether the bird had been preassigned to the addition or deletion group, respectively; the future S— condition for that bird was in force when it was put in the box. The keylight was turned on soon afterwards. Sessions involved equivalent numbers of reinforcers during periods when the tone was present or absent. This auditory stimulus appeared and disappeared irregularly, but it was on for approximately half of each session, which lasted until 30 food deliveries had been obtained. Throughout the shaping and VI training phase no consistent differences appeared between keypecks during the presence and keypecks during the absence of the tone. By the end of this training, all the birds responded steadily during the sessions.

Discrimination training then began; it lasted 20 days for every subject. These sessions, which were approximately 30 min long, corresponded closely to the short S+ condition of Experiment 1. The 12 birds in the addition group were always placed in and removed from the chambers when the clicker, red ceiling light, and houselight were on, but the tone was off (i.e., an S— period); the 12 birds in the deletion group were always placed in and removed from the chamber when the clicker, red ceiling light, houselight, and tone were on (their S— period). Soon after a subject's placement in the box, the keylight was illuminated with green, and S+ periods were interspersed with S— periods. The 30 daily S+ periods (tone on for addition, tone off for deletion) were scheduled to last for 12 sec plus a response, which produced a 3-sec grain delivery. On most S+ trials during the experiment, the reinforcer was triggered within a second or two after food became available for a peck. At the end of each session the keylight went out.

The 30 S— trials that separated the S+ trials ranged from 24-72 sec long, in multiples of 12 sec. As in the short S+ condition of Experiment 1, the calculation of discrimination ratios involved a comparison of the total number of responses during the first 12 sec of the S+ with the total number of responses during the immediately preceding 12 sec of the S—.

After the 20 discrimination-training sessions, which involved either tone addition or tone deletion for the 24 birds, a variety of procedures were tested, in different subgroups: removal of food after either S+ or S— (extinction); placement on a discrimination involving the addition or deletion of a dim blue ceiling light (pilot work with other birds had indicated that an analogous discrimination with the bright red light was too easy, and a clicker discrimination too hard, for both the addition and the deletion subjects); institution of Pavlovian rather than operant contingencies. This series of manipulations was too unsystematic to justify discussion in this report, but the work did give us information about how to set up the double-discrimination arrangement that 16 of the birds, which had merely been extinguished for 5 days after original training, experienced in the last phase of the experiment.

After these birds had received 19 more days of exposure to the same simple tone-addition (n = 8) or tone-deletion (n = 8) discriminations on which they had originally been trained (to make sure that their performance regained or bettered its earlier levels), the ceiling light was changed from red to blue, and two types of trials could occur for each group of birds. In the addition group, half of the 30 daily S+ trials involved the addition of the tone, as before, but the other 15 trials involved the addition of the blue ceiling light. In the deletion group, half of the 30 daily S+ trials involved the deletion of the tone, as before, but the other 15 trials involved the deletion of the blue ceiling light. No more than 2 consecutive trials of either type could occur and sequences of the different kinds of trials were changed from day to day. Sessions for the addition birds always began with the ceiling light and tone off, whereas for the deletion birds, both of these stimuli were on when they were placed in the experimental boxes.

All the other details of the procedure were the same as before (e.g., the houselight and clicker were always on while the birds were in the chambers). The responding during the 12-sec periods of the S— preceding each S+ was separately recorded for the auditory and visual signals, to provide a baseline for calculating the discrimination ratios for each kind of cue.

The birds remained in their assigned double discrimination for 28 sessions. Then the experiment concluded with a series of 5 compound-and-element test sessions, interspersed with sessions on the regular double discrimination. During the first 2 such test days, the subjects initially received 6 reinforced warmup trials, exactly as during the immediately prior double-discrimination training sessions. Then stimulus tests were given in the absence of any further reinforcement. Testing consisted of 27 trials, nine presentations of three kinds of stimuli: the subject's former light and tone S+s, and the (novel) combination of those S+s. All the test trials lasted 12 sec, separated by the usual S—s, and the different stimuli were presented in a mixed order with the constraint that no trial type could occur more than twice in a row. The birds returned to their double discrimination, with reinforcement available after S+s, for 6 sessions between Tests 1 and 2. After those 2 tests there were 9 more days on the regular double discrimination. The final 3 test sessions, given on successive days, did not include a 6-trial warmup but began immediately with tests of the three trial types in extinction. Different sequences of the three kinds of trials occurred on the 5 test days. A printout counter recorded the number of keypecks for every trial on each test day.

Results and Discussion

Performance over all the original training sessions is shown for the tone-addition and tone-deletion subjects in Figure 2. As in Experiment 1, an S+ that involved the addition of an otherwise continuously absent feature
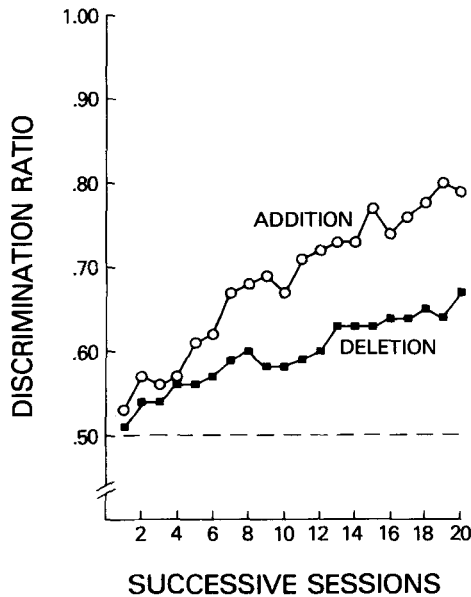
Figure 2. Mean discrimination ratios for addition and deletion subjects during single S+ training in Experiment 2. The stimulus added or deleted was a 732-Hz tone.

produced performance superior to that of an S+ that involved the deletion of the same but otherwise continuously present feature. Analyses of variance based on all the daily discrimination ratios disclosed that the main effects of addition versus deletion and sessions were statistically significant [$F(1,22)$ = 6.85, p < .02, and $F(19,418)$ = 26.19, p < .001, respectively], as was the interaction between them [$F(19,418)$ = 3.36, p < .001].

The discrimination ratios were generally lower in this experiment with its auditory feature than they were in Experiment 1 with its visual feature. This outcome could be due to differences in the salience, spatial location, or localizability of the two types of features—which naturally would be difficult to equate for a fair comparison—or the result could be related to the typically greater control exerted over the appetitive behavior of pigeons by visual as opposed to auditory cues (see, for example, LoLordo, 1979). Nevertheless, the major finding of both experiments was the same; addition of a feature served as a more effective S+ than deletion of that feature.

In Experiment 2, the feature was not located on the response key, and absolute response rates were, if anything, higher during the tone-deletion S+ than during the tone-addition S+, which was the opposite of the tendency in Experiment 1. However, as in Experiment 1, the pecking rates in response to the addition S+ as opposed to those in response to the deletion S+ did not differ significantly—neither during the 20 discrimination sessions [$F(1,22)$ = 1.83, p > .10], nor with these different stimulus conditions during the prediscrimination phase of the experiment. The superiority of addition over dele-

tion occurred despite all the differences between Experiments 1 and 2 that we have mentioned.

The second part of Experiment 2 involved training on the double (visual–auditory) discrimination and then tests including trials with the original S+s and their (novel) combination. After brief exposure to an extinction procedure, 16 birds were returned to the arrangement that provided the data in Figure 2—so as to recheck performance on their respective auditory discriminations prior to placement on the double discrimination. Over the last 7 days of this reacquisition phase, the performance was even better than during the last few sessions depicted in Figure 2. The discrimination ratios of the addition group averaged .91 during this period, those of the deletion group .71. An overall analysis of variance indicated that this difference was statistically significant [$F(1,14)$ = 7.14, p < .025]. Performance over these final 7 days did not differ significantly from session to session [$F(6,84)$ = 1.74], suggesting that asymptotic discriminative behavior had been reached. An analysis of simple main effects showed a significant superiority of addition over deletion (ps < .05) on each of the 7 days. Thus the main finding gleaned from Figure 2 (the superiority of addition over deletion) was replicated during continued exposure of the birds to those procedures.

The last seven sessions on the double discrimination yielded mean discrimination ratios of .82 and .79 for tone addition and light addition, respectively, in the addition group, and .72 and .62 for tone deletion and light deletion, respectively, in the deletion group. An overall analysis of variance performed on the individual mean ratios for these seven sessions revealed a significant superiority for addition over deletion [$F(1,14)$ = 4.70, p < .05], and for tone change over light change [$F(1,14)$ = 19.10, p < .001]. The interaction between these two factors was also significant [$F(1,14)$ = 4.60, p < .05]. However—surprisingly—an analysis of simple main effects revealed that the addition versus deletion effect was significant only for the light change condition [$F(1,28)$ = 6.85, p < .025]. The greatly worsened auditory-discrimination performance of 2 or 3 birds in the addition group, compared to prior levels described above for earlier phases of the experiment, contributed to the lack of a significant difference for the tone change case [$F(1,28)$ = 2.54, p > .10]. Still, the difference between tone addition and deletion was in the same direction as in all the other (statistically significant) comparisons of this kind made in Experiment 2.

In order to decide whether behavioral summation occurred when two S+s, either additions or deletions, were combined for the first time during the final days of the experiment, we compared total responding to the combination of these two elements with responding to the "stronger" single element (tone change or light change)—that is, the component that evoked the greater responding of the two. This criterion conforms to Weiss's

(1972) definition of additive summation, in terms of greater response to a stimulus compound than to either individual component.

Data for all five summation tests were merged for ease of analysis. Given the above criterion, 6 of the 8 birds in the addition group but only 3 of 8 in the deletion group displayed additive summation; in the former group there were means of 245.8 responses to the combination of S+s and 201.5 responses to the stronger S+ alone, whereas in the latter group the respective means were 546.5 and 556.6. The stronger element was the tone change for 13 of the 16 birds. However, statistical tests did not convince us that additive summation had occurred, especially in the deletion group. In the overall analysis, the main effect of compound–element did not achieve an acceptable level of significance [$F(1,14) = 1.61, p > .20$], although the interaction between addition–deletion and compound–element approached such a level [$F(1,14) = 4.08$, with p approximately .07]. It is at least suggestive that an analysis of simple main effects indicated significantly more responding to the compound than to the stronger element in the addition group [$F(1,14) = 5.41, p < .05$] (but not in the deletion group, where $F = .28$).

Thus Experiment 2 showed, with one exception in terms of achieving an acceptable level of statistical significance, that addition produces better performance than deletion with two kinds of relatively diffuse stimuli (sound and diffuse illumination). However, evidence of additive summation after double-discrimination training was not very powerful. While providing some additional data on training with a single S+, our next two experiments concentrated on the double-discrimination procedure and the possibility of replicating the addition versus deletion effect within that paradigm, as well as that of obtaining behavioral summation effects in responses to S+ combinations following such training.

EXPERIMENT 3

Our first two experiments provided strong evidence of superior discrimination performance by birds when the S+s consisted of the addition rather than the deletion of a stimulus. This outcome held, despite the use of S+s involving different sensory modalities, trial durations, and relative localizabilities. The overall design of Experiment 3 paralleled the single- and double-discrimination paradigm to which most of the Experiment 2 birds had been exposed. The major difference between the two experiments was that the birds in Experiment 3 were given their original single S+ training with a signal consisting of either the addition or deletion of the blue ceiling light, instead of the auditory training initially given in Experiment 2.

The new subjects were subsequently placed on the same double discrimination as in the prior experiment, with either two kinds of stimulus addition (presentations of tone or ceiling light) signaling the availability of food, or two kinds of stimulus deletion (removals of tone or ceiling

light) acting as the food signals. We hoped that the statistically significant performance difference favoring addition over deletion for the blue light in the double discrimination of Experiment 2 would also appear during original training, and that double-discrimination training would reveal unequivocal differences along the same lines for both the visual and auditory stimulus changes. Finally, by employing more birds in each subgroup, we wanted to increase the likelihood of observing convincing summation effects when either addition or deletion S+s are combined for the first time.

Method

Subjects. Twenty-four experimentally naive pigeons of the same kind as in the prior experiments were the subjects. All maintenance and deprivation conditions matched those in the earlier work.

Apparatus. The two chambers employed in Experiments 1 and 2 were used without modification. The 14–18 pps clicker and the houselight remained on throughout the time that the birds stayed in the chambers. The 732-Hz, 82-dB tone was also on continuously until the double-discrimination training phase began. When illuminated, the ceiling light was always blue at an intensity of 2.2 lx, and its addition or deletion provided the stimulus change to be discriminated in the first part of this experiment.

Procedure. Feeder training, shaping, and VI training proceeded as in Experiment 2, except that the blue ceiling light served the role assigned to the tone in the prior experiment. For example, shaping and VI training sessions started with the light either absent or present, depending on whether a bird had been preassigned to the addition or deletion group, respectively. Then the light appeared and disappeared irregularly, but was on for approximately half the session. Equivalent numbers of food deliveries were arranged to occur during each of the two light conditions. By the end of VI training all birds responded steadily during the sessions, and there were no consistent differences between the numbers of keypecks made during the presence and those made during the absence of the light.

Discrimination training then began; it lasted 23 days for all birds. The procedural details matched those for the single S+ training in Experiment 2, except that the ceiling light was substituted for the tone. There were 12 birds in the light addition group and 12 birds in the light deletion group.

After this discrimination phase was complete, all the subjects received 5 sessions of extinction (which will not be discussed in this report) and then were returned to their original light discrimination for 11 more sessions. After these sessions, the double discriminations were introduced, exactly as in Experiment 2. The former light addition subjects experienced 15 daily S+ trials of light addition and 15 daily S+ trials of tone addition, whereas the former light deletion subjects experienced 15 trials of light deletion and 15 trials of tone deletion. Exposure to this procedure lasted 19 sessions. Then the experiment concluded with five compound-and-element test days, separated by intervening sessions on the regular double discrimination, and conducted the same way as in Experiment 2.

Results and Discussion

Figure 3 displays mean performance over all the original training sessions for the light-addition and light-deletion subjects. Although the mean discrimination ratios of the addition group were higher than those of the deletion group during every session after the first three or four, an overall analysis of variance of the data in Figure 3 did not reveal a significant superiority of addi-
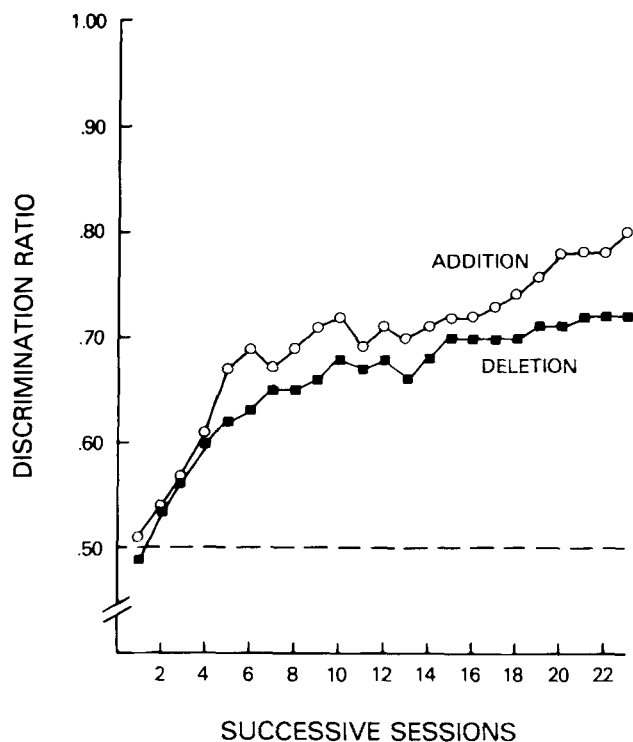
Figure 3. Mean discrimination ratios for addition and deletion subjects during single S+ training in Experiment 3. The stimulus added or deleted was a blue ceiling light.

tion over deletion ($F < 1.00$). The effect of sessions was statistically significant [$F(22,484) = 20.28, p < .001$], but the interaction between addition–deletion and sessions was not ($F < 1.00$).

Likewise, over the final 7 days of retraining before the double-discrimination procedure was introduced (shown in the first panel of Figure 4), the mean discrimination ratio for the addition birds was .80 and for the deletion birds .72; but, once again, this difference did not achieve an acceptable level of statistical significance [$F(1,20) = 1.31$] (two birds in the addition group suffered an apparatus failure during this period and were not included in the analysis). Discriminative behavior was stable over these seven sessions, as indicated by an insignificant sessions effect ($F < 1.00$).

The main section of Figure 4 displays changes in mean discrimination ratios during the double-discrimination phase. Performance initially worsened on the discrimination that had been exclusively in force during single S+ training (either light addition or light deletion), but by the end of double-discrimination training the performance had regained its earlier levels. The last seven sessions of the double discrimination produced mean ratios of .85 and .81 for tone addition and light addition, respectively, in the addition group, and .73 and .70 for tone deletion and light deletion, respectively, in the deletion group.

An overall analysis of variance comprising the individual mean ratios over these last 7 days revealed a signifi-

cant superiority for addition over deletion [$F(1,22) = 5.15, p < .05$], and for tone change over light change [$F(1,22) = 15.55, p < .001$]. The interaction between these factors was insignificant ($F < 1.00$). Analysis of simple main effects showed that addition was better than deletion for both the tone change and light change conditions [$F(1,44) = 5.51, p < .025$, and $F(1,44) = 4.59, p < .05$, respectively]. The within-subject superiority of tone change over light change was also statistically reliable in both the addition group and the deletion group [$F(1,22) = 10.71, p < .01$, and $F(1,22) = 5.31, p < .05$, respectively].

These results essentially replicate those obtained during asymptotic performance on the double discrimination in Experiment 2, except that the superiority of tone addition over tone deletion achieved an acceptable level of statistical significance in the double discrimination of Experiment 3—as it did in all other comparisons of this kind calculated for single S+ training in Experiment 2. Note that although the superiority of light addition over light deletion suggested in Figure 3 and the first panel of Figure 4 did not attain statistical significance within the condition involving a single S+, the effect achieved significance within the context of the double-discrimination arrangement in both Experiments 2 and 3.

As in Experiment 2, our decision about the existence of additive summation was based on a comparison of total keypecks in response to the simultaneous combination of both S+s with total keypecks in response to the S+ (tone change or light change) that evoked the greater number of responses. Data for the five test sessions were combined in the analysis. All 12 of the addition birds responded more to combinations of the light and tone than to the stronger of those two elements, with means of 453.7 pecks and 371.3 pecks, respectively. Seven of the 12 deletion birds responded more to the joint deletion of light and tone than to the deletion of either one alone, with means of 331.8 pecks and 282.3 pecks, respectively. An overall analysis of variance revealed significantly more responding during compound than element trials [$F(1,22) = 16.84, p < .001$], and an analysis of simple main effects indicated further that this difference was significant for both the addition and deletion groups [$F(1,22) = 13.14, p < .005$, and $F(1,22) = 4.75, p < .05$, respectively]. It is interesting that, once again, the stronger element was the tone change in 10 of the 12 addition birds and 10 of the 12 deletion birds.

The results of Experiment 3 generally support the conclusions from the first two experiments. Although the addition as opposed to the deletion of the ceiling-light illumination suggested the usual superiority for addition in Figure 3 and in the first panel of Figure 4, this trend was not statistically reliable during such single S+ training; the effect did prove reliable, however, within the context of the double discrimination. The superiority of tone addition over tone deletion, shown in Experiment 2, was substantiated again with the double-discrimination procedure of Experiment 3. There was striking and highly sig-
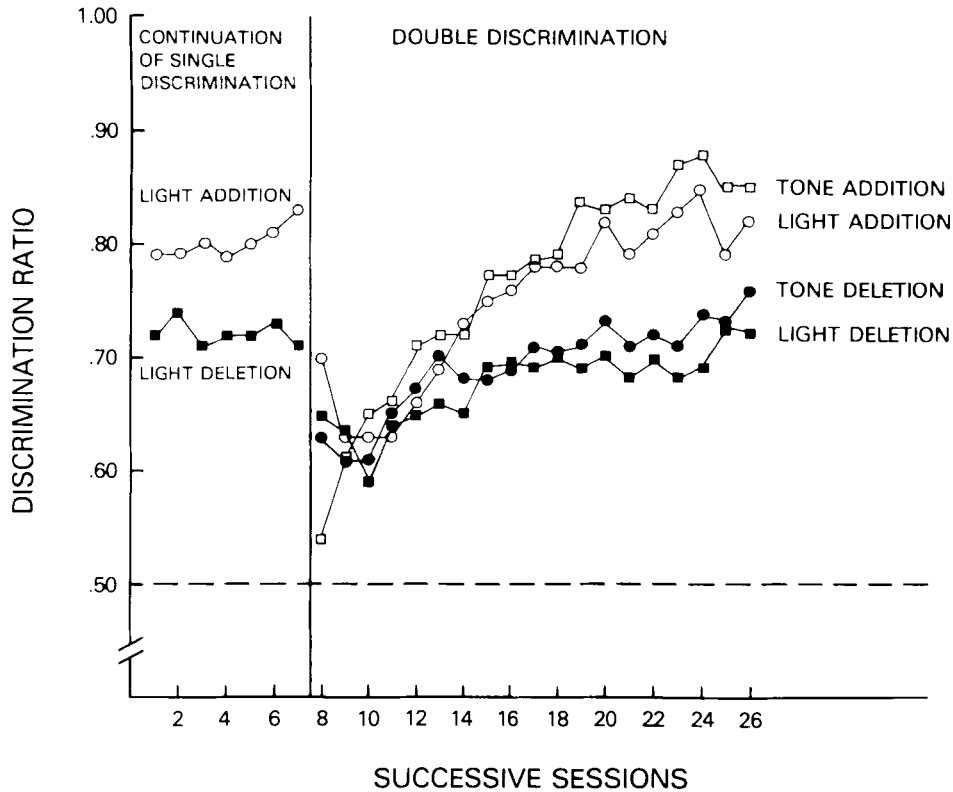
Figure 4. Mean discrimination ratios during the final seven sessions on a continuation of the single S+ training displayed in Figure 3, followed by sessions on the double discrimination in Experiment 3. The stimuli added or deleted during the latter phase were either the 732-Hz tone or the blue ceiling light.

nificant evidence of additive summation to S+ combinations in the addition group, and a statistically reliable indication of this phenomenon in the deletion group.

EXPERIMENT 4

Our final experiment focused on the double-discrimination procedure in an attempt to compare addition and deletion conditions within individual subjects; Experiments 1–3 had involved the exposure of the birds to only one or the other condition, and the evidence for a superiority of addition over deletion was based solely on between-group comparisons. Experiment 4 began with the placement of the subjects directly in our standard double discrimination, with either tone addition or light addition as S+s (addition group), or tone deletion or light deletion as S+s (deletion group). The subjects were left on the discrimination longer than in Experiments 2 and 3, and then they were given our usual tests for possible summation in response to their combined S+s. Subsequently, the birds in the addition group were switched to the deletion condition and vice versa. After extended exposure to their new double discrimination, all the birds once again received standard tests for summation of S+s. Would

auditory and visual discriminative performance worsen permanently when addition birds were switched to the deletion condition, and improve when deletion birds were switched to the addition condition, as the data of Experiments 1–3 seemed to predict?

Method

Subjects. Twenty-two experimentally naive pigeons of the same kind and maintained in the same way as in Experiments 1–3 served as the subjects.

Apparatus. The experimental chambers were the ones used in all the prior work. The specifications of the visual and auditory stimuli matched those in effect during the double discrimination of Experiment 2 and the various discriminations of Experiment 3.

Procedure. Feeder training, shaping, and VI training were carried out according to the same general method as that employed in Experiments 2 and 3, except that the birds ($n = 11$) to be placed on the addition double discrimination in the first major phase of the experiment always began their keypeck training sessions with both the ceiling light and tone off, and the birds ($n = 11$) to be placed on the deletion double discrimination always began their preliminary training sessions with both the ceiling light and tone on. These early sessions consisted of the irregular presentation and removal of both these stimuli, and, as in the previous work, the experimenter tried to ensure that approximately the same number of food deliveries occurred during each of the possible stimulus

conditions. By the end of the VI training, all the birds responded steadily throughout the sessions and there were no consistent differences between keypecking rates during the presence and keypecking rates during the absence of the light and tone.

Then the birds were placed directly in their assigned double discrimination. The addition group remained on this procedure for 34 days; the deletion group did so for 50 days. Extra time was given the latter birds because we thought that their visual and auditory discriminations might still improve; the ratios they had achieved by Day 34 were generally not as good as those attained on the same double discrimination in Experiments 2 and 3. However, the discriminations did not improve over the additional 16 sessions, and this is why we have not included data for the extra sessions in Figure 5.

After this double-discrimination phase, the subjects received summation tests just as in Experiments 2 and 3 except that (due to an experimenter error) the birds were not given the standard second test that included a brief warmup with reinforcement. Instead, after the 1st summation test day, they were placed again on their double discrimination for 6-11 sessions and then given the usual final 3 tests without reinforcement. Thus they received 4, rather than 5, summation test sessions.

Upon completion of the summation tests, the birds returned to their original double discrimination for 6 more sessions before being switched to the opposite double discrimination (addition was switched to deletion; deletion was switched to addition), on which they remained for 50 sessions. The experiment concluded with another series of summation tests, scheduled the same way as in Experiments 2 and 3.

Results and Discussion

Figure 5 summarizes the performance of the birds on the first double discrimination to which they were exposed. After half of the 34 sessions, the mean ratios for both tone addition and light addition were consistently higher than for tone deletion and light deletion, an outcome that confirmed the findings of Experiments 2 and 3—but in this case with subjects that had received no prior single S+ training. Over the last 7 sessions in the figure (Days 28-34), the mean ratio for tone addition was .80 and for tone deletion .63; similarly, the mean ratio for light addition was .76 and for light deletion .59.

An overall analysis performed on individual-subject means over these last seven sessions disclosed that the superioity of addition over deletion was statistically significant [$F(1,20) = 15.17, p < .001$], as was the superiority of tone change performance over light change performance [$F(1,20) = 10.63, p < .005$]. The interaction between addition-deletion and light change-tone change was not significant ($F = .01$). Analysis of simple main effects indicated that the superiority of addition over deletion was significant for both the tone change and light change conditions [$F(1,40) = 14.37$, and $F(1,40) = 13.92$, respectively, with $p < .001$ in both cases]. Tone discrimination performance was superior to light discrimination
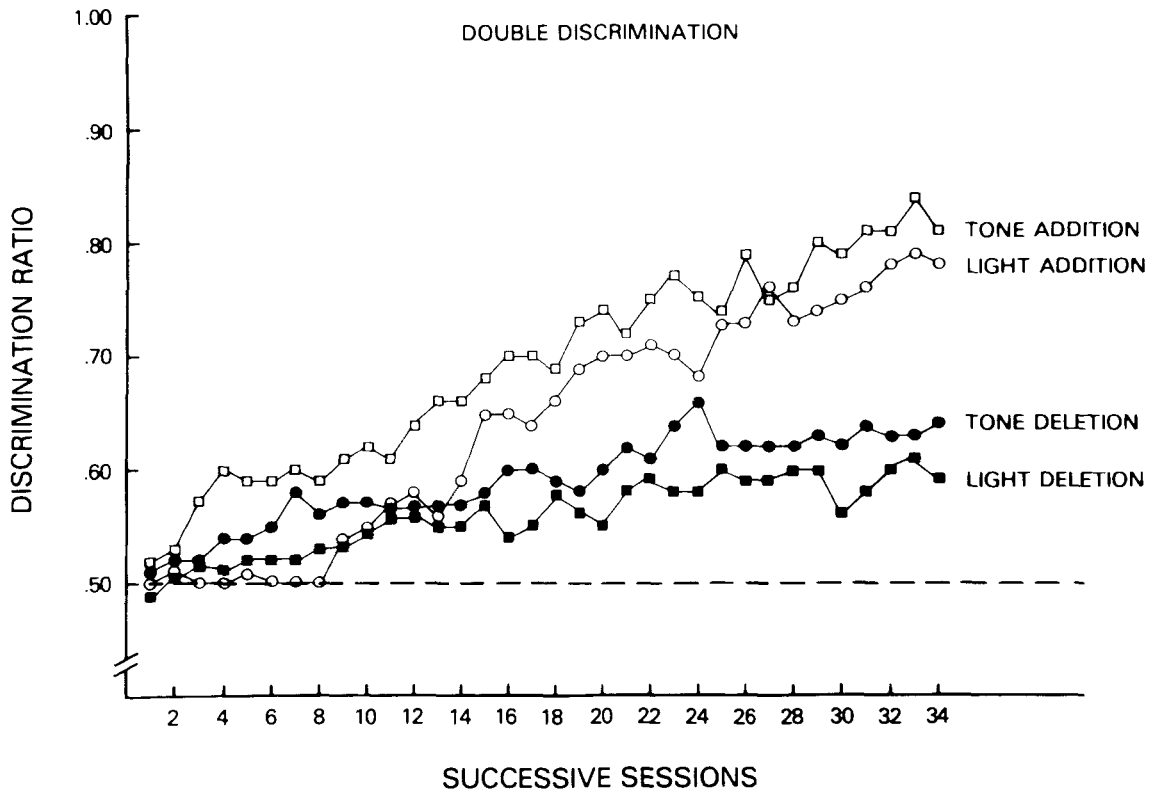

Figure 5. Mean discrimination ratios during the first 34 sessions of Experiment 4, in which subjects were trained with a double-discrimination procedure from the start. The stimuli added or deleted were either the 732-Hz tone or the blue ceiling light.

performance in the addition group and the deletion group [$F(1,20) = 5.69$, and $F(1,20) = 4.94$, respectively, with $p < .05$ in both cases].

When switched to the opposite double discrimination after intervening summation tests, 9 of the 11 birds transferred from tone addition and light addition to tone deletion and light deletion worsened in performance in response to both the auditory and visual S+s; the mean discrimination ratios over the last 7 days for the new discrimination (Sessions 44–50 of that phase) were .72 for tone deletion and .67 for light deletion. On the other hand, the performance of 10 of the 11 birds switched from deletion to addition improved for both the auditory and visual S+s; the mean ratios over the last 7 days on their new discrimination were .73 for tone addition and .71 for light addition.

An overall analysis with one between-subjects factor (order: addition first or deletion first), and two within-subjects factors (addition–deletion and tone change–light change) was carried out on the individual mean discrimination ratios over the final seven sessions of the original and reversed double discriminations. The analysis confirmed the statistical reliability of all the statements in the preceding paragraph, and corroborated relevant conclusions from Experiments 2 and 3. The main effect of order was not itself statistically significant [$F(1,20) = .13$], but the superiority of addition over deletion was highly significant [$F(1,20) = 9.33$, $p < .01$], as well as the superiority of tone change over light change [$F(1,20) = 15.86$, $p < .001$]. The only significant interaction occurred between order and addition–deletion [$F(1,20) = 5.13$, $p < .05$]. A further analysis of simple main effects revealed, among other less interesting comparisons, that the superiority of addition over deletion was significant for both tone change and light change [$F(1,22) = 16.21$ and 19.33, respectively, with $p < .001$ in both cases]. The tone change–light change effect was significant for both addition and deletion [$F(1,38) = 14.64$ and 23.82, respectively, with $p < .001$].

Unfortunately, the combined data for the four summation tests given after training on the original double discrimination revealed no clear evidence for summation in either the addition or deletion groups. Only 6 of the 11 addition birds made more keypecks in response to the novel combination of S+s than to the element (the tone, in all cases) evoking the greater number of pecks, whereas 8 of the 11 deletion birds pecked more in response to the combination of their individual S+s than to the "stronger" S+ (the deletion of the tone, in 10 of the 11 cases). An overall analysis yielded no significant differences between responses to compound and responses to element [$F(1,20) = .53$], and no significant interaction between addition–deletion and compound-element [$F(1,20) = 2.32$].

When the summation tests following the completion of the switch to the new double discrimination were analyzed, the same conclusions emerged. Only 7 of the 11 new addition birds displayed additive summation, and only 3 of the 11 new deletion birds. Statistical tests disclosed no significant differences of any relevance to the issue of summation, and details of these analyses do not merit any space here. Perhaps the only interesting finding was the fact that 6 of the 7 birds exhibiting summation in the new addition group had also showed summation in the first half of the experiment, on the deletion procedure.

In view of the fact that 18 of 20 addition subjects (and 10 of 20 deletion subjects) exhibited summation in response to combinations of S+s when the data of Experiments 2 and 3 are merged, one can only speculate about factors responsible for the lack of an effect in the present experiment. There is some evidence (admittedly controversial: see Baker, 1968; Forbes & Holland, 1985; Kehoe, 1986; Razran, 1971) that overtraining with respect to a compound stimulus produces decreased responding to its separate components in experiments whose designs are the converse of the present studies (of course we trained with components and then tested with their compound). It may be relevant, then, that the birds in Experiment 4 received 34–50 sessions of training on their respective double discriminations, whereas the birds in Experiments 2 and 3 received 28 and 19 sessions, respectively. And the biggest summation effects were observed in Experiment 3, which involved the smallest number of training sessions.

In all other respects, however, Experiment 4 confirmed and extended the results of Experiments 1–3. The addition of a stimulus produced a significantly more effective signal than did deletion, for both auditory and visual changes, and the discrimination ratios of the individual birds that were switched from one type of stimulus change to the other in Experiment 4 improved or worsened, respectively, depending on whether they were transferred to an addition or deletion double discrimination.

GENERAL DISCUSSION

Unlike conventional comparisons of feature-positive and feature-negative discriminations, the present series of experiments focused on the general possibility that mere presentation as opposed to removal of a stimulus might be differentially effective as a signal for food. This goal necessitated equating the positive predictiveness of the presence as opposed to the absence of some environmental feature in different experimental phases or groups of subjects, which was accomplished here by the complete elimination of standard ITIs between the S+ and the S−. We observed consistently better discrimination performance when the addition rather than the deletion of a stimulus served as the S+. This conclusion held, despite the manipulation of the relative duration of the S+, the sensory modality and localizability of the S+, and the use of within-subject as opposed to between-group designs. These manipulations did affect the overall accuracy of discriminative performance and the extent and reliability of the superiority of addition over deletion, but an advantage favoring addition appeared in every comparison made in our four experiments.

This outcome suggests that explanations of the feature-positive effect, and perhaps some general theories of simple learning, have concentrated too much on the role of the relative predictiveness of the distinguishing and common elements, and that they have neglected confounded differences in the signaling capacity or potential associative control possessed by physical presence as opposed to absence. Our results certainly do not deny an important role for stimulus–reinforcer predictiveness in the feature-positive effect; the short S+ condition of Experiment 1 yielded better performance than the equal S+ condition, and the discrimination ratios based on stimulus deletion far exceeded those normally obtained on standard feature-negative discriminations with the same distinctive element and interspersed ITIs (see Hearst, 1987; Morris, 1976). But the removal of differences in stimulus–reinforcer predictiveness by means of multiple schedules of the kind used here did not abolish relevant group differences, contrary to what Hearst and Jenkins (1974) implied in their sign-tracking analysis and to what Staddon (1983, chap. 11) surmised on the basis of postulating stronger competing activities in the S– when ITIs are omitted. Mere addition as opposed to deletion seems to act in conjunction with other factors, including stimulus–reinforcer predictiveness, in producing the feature-positive effect, which is apparently a more complex phenomenon than was originally thought.

The strength of our conclusions about the superiority of addition over deletion as a signal requires some qualification, however. It seems probable that the finding would not necessarily hold for extreme values of stimulation; studies employing either very intense onsets and offsets, or very faint ones, might well not yield the general results reported here. For example, our pilot work with a bright red ceiling light produced very rapid discrimination learning under both conditions. On the other hand, discrimination learning might be too hard for both groups if the stimulus change that served as a signal were weak in some absolute sense or if it represented only a small deviation from continuous background levels (see Mackintosh, 1974, pp. 41-45, for a relevant discussion of stimulus intensity dynamism and sensory adaptation effects).

Of course it is possible to view addition as opposed to deletion as one means of varying stimulus "salience," an important parameter in various models of learning and performance. Additions may generally be considered more salient than deletions, which also seems to be the case for sudden as opposed to gradual onsets and moving as opposed to stationary stimuli.

The introduction to this report, as well as Newman et al.'s (1980) discussion of pertinent work with human beings, mentioned the possibility of a fundamental, biologically based difference between stimulus presence and absence as effective signals. In natural environments, appetitive and aversive events of inherent importance for survival characteristically involve the appearance of some object or organism, not its disappearance. Consequently, as a few authors have suggested, additions or onsets may

generally produce greater and more persistent neural response and lead to increases in activity, alertness, or arousal, whereas removals of stimulation may naturally lead to relaxation and decreased activity. This evolution-based hypothesis is clearly open to explicit experimental test, through physiological and behavioral measurement of innate (unconditioned) responses to onsets as opposed to offsets. The link with our research involves the supposition that such an inborn bias extends to signals as well as to biologically significant events themselves. In this connection, it is interesting that the feature-positive effect has been demonstrated in chicks as young as 1 to 4 days old—organisms that presumably have not yet had the opportunity to learn much about the properties of stimulus–reinforcer relations outside the confines of their egg (Miller, McDougall, & Zolman, 1988).

However, we ought to mention that our multiple-schedule procedure may not completely equate the relative predictiveness of addition as opposed to deletion for the different stimuli we used. If one includes the nonsession time of the day (in which all relevant stimuli are absent), the presentation of a stimulus during the session is differentially more predictive than its removal. "Absence" is a predictor conditional on the subject's being in the experimental situation. Discrimination tasks that entail 24-h daily sessions may provide a way of evaluating this possible complication.

Differences between asymptotic discriminative performance for visual and for auditory stimuli appeared in our series of experiments, and yet they were not highlighted in our description of the work. The findings merit some comment. The best discrimination ratios occurred when the S+ involved a stimulus projected directly on the response key (Experiment 1), but in the double discriminations of Experiments 2-4, changes in a diffuse auditory signal were consistently more effective as S+s than changes in a diffuse visual signal. The latter result is apparently inconsistent with LoLordo's (e.g., 1979) conclusion that visual stimuli exert more control than auditory stimuli over a pigeon's appetitive behavior. However, even disregarding the obvious complications that arise from an inability to equate the intensity, localizability, etc., of stimuli from different modalities, we can note our incidental observations that birds often moved toward the ceiling light S+, which would presumably interfere with their ability to peck the key and would thereby produce lower discrimination ratios. The intrusion of such sign-tracking behavior is a complexity that must be taken into account in making decisions about relative control by stimuli from different modalities.

It would be only an academic exercise to speculate extensively about possible reasons why we sometimes observed and at other times failed to observe additive summation when the subjects were presented for the first time with combinations of the single S+s in force during their prior double-discrimination training. Simplistic application of the notion of generalization decrement (see Kehoe & Gormezano, 1980) implies that subjects should not

respond more to an unfamiliar stimulus than to stimuli that have long served as S+s; but many birds in Experiments 2 and 3 (18 of the 20 addition and 10 of the 20 deletion subjects) actually did so, and a reasonable number of birds in Experiment 4 did so too. However, overall statistical support for the existence of additive summation was completely lacking in Experiment 4. Weiss (1972) has reviewed the literature on the topic, which includes a variety of settings where summation occurred in response to addition S+s.

Weiss's own work suggested that compounding of two deletion S+s is as effective as compounding of two addition S+s in yielding summation. He had predicted this outcome on the basis of a composite-dimension analysis, which assumes symmetrical interactions between the S— stimulus (no tone and no light versus tone and light, for the presence and absence S+s, respectively) and the S+ stimuli themselves. This elegant account handled his results nicely and has worthwhile implications for understanding peak shift, stimulus intensity dynamism, and response inhibition; nevertheless, predictions from the approach did not receive consistent support in our work. We have suggested, however, that the likelihood and magnitude of additive summation may be negatively related to the amount of prior training given both the individual elements in a double-discrimination situation—a simple empirical statement that fits the pattern of our results. Unfortunately, this assertion or conclusion does not follow directly from any currently popular theory of discrimination learning, although the general outcome is reminiscent of classic results on the effects of overtraining with respect to various discrimination-transfer phenomena (Mackintosh, 1974, chap. 10).

At any rate, the present findings indicate the deficiency of any explanation of the feature-positive superiority that does not go beyond the relative predictiveness of various elements and that fails to include some provision for the differential effectiveness of addition and deletion as signals. In combination with other results mentioned in Hearst (1984), the experiments reported here generally suggest that behavioral control by stimulus absence may require a somewhat different treatment than for stimulus presence.

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