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ERRORLESS DISCRIMINATION ESTABLISHED BY DIFFERENTIAL AUTOSHAPING[1]

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In Experiment I, pigeons exposed to a differential autoshaping procedure pecked a key in the presence of the stimulus associated with reinforcement but did not peck, or pecked infrequently, in the presence of the stimulus associated with nonreinforcement. In Experiment II, pigeons were exposed to a differential autoshaping procedure in which one stimulus was associated with reinforcement and two stimuli were associated with nonreinforcement. The birds initially responded in the presence of one stimulus associated with nonreinforcement but never responded in the presence of the second stimulus associated with nonreinforcement. They were subsequently exposed to an autoshaping procedure in which reinforcement followed both these stimuli. The number of stimulus-reinforcement pairings required to establish pecking in the presence of the stimulus during which responses had not previously occurred suggested that such stimuli are inhibitory. These findings have implications for autoshaping, errorless discrimination, inhibition, and theories of discrimination byproducts.

Stimuli often do not control responding unless differentially associated with reinforcement. Jenkins and Harrison (1960), for example, found that a tone controlled pigeons' key pecking so that pecking depended upon the presence of the tone only after exposure to a differential reinforcement or discrimination procedure in which key pecking in the presence, but not the absence, of the tone was reinforced. Discrimination training such as arranged by Jenkins and Harrison typically results in numerous responses ("errors") in the presence of the stimulus associated with nonreinforcement (S−). Responses in the presence of S− cease to occur only after extended training. Terrace (*e.g.*, 1963) has clearly shown that errors are not a necessary outcome of discrimination training, and that whether or not errors occur depends primarily upon how the discrimination training procedure is arranged. He found that pigeons make no or very few errors when acquiring a wavelength discrimination if the S− is introduced soon after pecking in the presence of the stimulus associated with reinforcement (S+) is established (by reinforcing successive approximations to pecking), and if S− is introduced gradually, both in intensity and duration, over a period of time.

The present research was undertaken to determine if Brown and Jenkins' (1968) autoshaping procedure would result in errorless discrimination. Brown and Jenkins arranged a trial procedure for different groups of pigeons. For one group of pigeons, trials consisted of an 8-sec illumination of the response key followed immediately by a 4-sec, response-independent reinforcement. The response key was not illuminated and reinforcement was not available during the intertrial interval. A second group of pigeons received trials similar to the first group, except that key illumination was not followed by reinforcement. All subjects in the first, but none in the second group, pecked the illuminated key. We thought it possible that if both types of trials were arranged for individual subjects, an errorless discrimination might result. Since exposure to the differential autoshaping procedure in which illumination of a response key by one (S+) but not a second (S−) stimulus was followed by reinforcement

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did result in an errorless discrimination, a result that has been independently found by Schwartz (1973) and Wessells (1973), additional procedures were included to determine the role of autoshaping of responding to S+ in the establishment of the errorless discrimination.

EXPERIMENT I

Method

Subjects

Sixteen adult, experimentally naive, King pigeons obtained locally and from the Palmetto Pigeon Plant, Sumter, South Carolina served. Before the experiment began, access to the normal diet of Purina mixed grain was restricted until the birds reached approximately 80% of their free-feeding weights. The birds were subsequently maintained at this weight by mixed grain obtained during experimental sessions and postsession feeding. Water and grit were always available in the home cage.

Apparatus

A Tech Serv, Inc. chamber for pigeons served as the experimental space. A clear plastic response key that required a force of about 0.2 N to operate was mounted on one wall of the chamber directly in front of a Series 10 Industrial Electronics Engineers' stimulus display cell and directly above a Gerbrands grain feeder. The display cell transilluminated the response key with either a 2.5-cm by 0.32-cm white line in different orientations or different colored light. The display cell and a 7-W lamp that illuminated the grain in the feeder tray during feeder operations were the only sources of illumination in the chamber. Extraneous sounds were attenuated by the chamber, the chamber air blower, and approximately 70-dB masking noise present in the chamber. Solid-state logic circuits were used to arrange experimental events and operate recording counters.

Procedure

Once the pigeons had reached approximately 80% of their free-feeding weights they were trained to approach rapidly and eat from the grain feeder. This training took the following general form. First, the lighted feeder tray was held in the up position until the subject had approached and eaten for several seconds. The tray was then lowered and the feeder light turned off. The lighted tray was raised again and left in this position until the subject again approached and ate. The amount of time the subject was allowed to eat on this presentation was less than on the first presentation. The amount of eating time allowed was gradually reduced to 5 sec over several presentations. This training continued until the latency to eat after tray presentation was less than about 1 sec. The stimulus display cell was off during this training phase. All feeder operations occurred independently of the subject's behavior.

After feeder training, six pigeons, numbered S1 to S6, were exposed to differential autoshaping procedures. Bird S1 received 12 sessions, each of which consisted of 25 S+ trials and 25 S− trials. During S+ trials, the response key was transilluminated by red light. The red light was turned off when a peck occurred or after 5 sec if a peck had not occurred before that time. Initially, red-light offset was immediately followed by reinforcement (5 sec of access to the feeder) regardless of whether a peck had occurred in the presence of the red light. After the bird had pecked during five consecutive red-light trials, reinforcement was contingent upon a key peck occurring before the trial automatically terminated after 5 sec. During the 25 S− trials, the response key was transilluminated by green light. The green light was turned off whenever a peck occurred or after a period of time if no peck occurred. These trials were never followed by reinforcement. Initially, the duration of green-light trials was 250 msec if no peck occurred. At the same time that reinforcement on S+ trials was made response-contingent, the duration of S− trials gradually lengthened. This was accomplished by increasing trial duration in steps of 75 to 100 msec over 50 consecutive trials until the green-light trials were 5 sec in duration if no peck occurred. The procedure for the remaining trials was unchanged. The procedure for this subject was designated as an A-EP-RG, where A indicates that responding on S+ trials was established by autoshaping, EP indicates that the S− trials were introduced early (*i.e.*, during first session) and were later progressively increased in duration, and RG indicates that the S+ and S− trial stimuli were red and green respectively. The procedure for Subjects

S2 to S5 differed from that arranged for S1 only with respect to (a) the stimulus present on S− trials, and (b) the manner in which S− trials were introduced. A white vertical line, rather than green light, served as the S− trial stimulus for Subjects S2 and S3. The procedure for these birds was designated as A-EP-RL. The procedure for S4, S5, and S6, designated as A-EFD-RG (Subject S4) and A-EFD-RL (Subjects S5 and S6), was similar to that used for S1, S2, and S3 except that S− trials were introduced at their full duration (5 sec), rather than being progressively increased to this duration.

Since few errors were made by Subjects S1 to S6, additional subjects were studied to determine the role played by autoshaping of S+ responding in the establishment of the errorless discrimination. Subjects S7 to S12 were exposed to a procedure similar to that received by S4, S5, and S6 except that S− trials were not introduced until after responding on S+ trials had been autoshaped. For these subjects, S− trials were introduced at their full duration after the subjects had received between 10 and 24 sessions in which only S+ trials were presented. The procedure for these subjects was designated as A-LFD-RG (Subjects S7, S8, and S9) and A-LFD-RL (Subjects S10, S11, and S12) where L indicates that the S− (either green light or vertical line) was introduced late. The procedure for the remaining four subjects (S13, S14, S15, and S16) differed with respect to how pecking on S+ trials was established. Before the start of the experiment, key pecking in the presence of S+ was established by the method of reinforcing successive approximations. After the subjects had received 50 reinforcements, a trial procedure was introduced that was similar to that arranged for Subjects S4, S5, and S6, except that reinforcement on S+ trials was always response contingent. This procedure was designated as SA-EFD-RG (for Subjects S13 and S14) and SA-EFD-RL (for Subjects S15 and S16), where SA denotes that pecking during S+ was established by reinforcement of successive approximations.

The S+ and S− trials occurred in an irregular order within each session. During intertrial intervals the response key was not transilluminated, the chamber was dark, and key pecking had no scheduled consequences. Intertrial intervals were 30 sec in duration. Sessions were conducted daily.

Results

Table 1 shows the number of S+ and S− trials each pigeon received, the number of S+ and S− trials on which a peck occurred, and the S+ trial on which reinforcement was made response contingent. The latter served as the criterion of when key pecking had been autoshaped. The number of trials-to-criterion

Table 1

Summary of Results—Experiment I

		S+ Only Sessions			*S+-S− Sessions: S+ Trials*			*S+-S− Sessions: S− Trials*	
Subject	*Condition*	*No. of Trials*	*No. of Responses*	*Criterion Trial*	*No. of Trials*	*No. of Responses*	*Criterion Trial*	*No. of Trials*	*No. of Responses*
S1	A-EP-RG	—	—	—	300	249	21	300	2
S2	A-EP-RL	—	—	—	275	189	62	275	0
S3	A-EP-RL	—	—	—	350	254	84	350	1
S4	A-EFD-RG	—	—	—	275	238	35	275	0
S5	A-EFD-RL	—	—	—	275	250	20	275	4
S6	A-EFD-RL	—	—	—	275	233	42	275	0
S7	A-LFD-RG	525	477	42	250	250	—	250	0
S8	A-LFD-RG	600	473	116	250	250	—	250	0
S9	A-LFD-RG	500	487	15	250	250	—	250	1
S10	A-LFD-RL	250	236	16	250	249	—	250	0
S11	A-LFD-RL	500	490	8	250	245	—	250	0
S12	A-LFD-RL	500	485	7	250	249	—	250	0
S13	SA-EFD-RG	—	—	—	250	249	—	250	36
S14	SA-EFD-RG	—	—	—	250	248	—	250	32
S15	SA-EFD-RL	—	—	—	250	242	—	250	35
S16	SA-EFD-RL	—	—	—	250	247	—	250	16

ranged from seven to 116. The average subject reached criterion in 39 trials. With occasional exceptions, the subjects pecked on all S+ trials after reaching criterion.

Of the six subjects (S1 to S6) exposed to the differential autoshaping procedure, three never pecked on an S− trial. The other three made between one and four errors. All subjects in the differential autoshaping conditions would be classified as having acquired an errorless discrimination according to Terrace's (1972) criterion of 25 or fewer S− responses.

Of the six subjects in the A-LFD-RG and A-LFD-RL conditions, five never pecked on S− trials. Subject S9 pecked on one S− trial. All four subjects that acquired key pecking by the successive approximation procedure before being exposed to the S+ and S− trials made errors. The number of errors made by these subjects (range 16 to 36), while small in absolute terms, is four and more times as many as made by any subject in the autoshaping conditions.

With one exception, all errors made by the pigeons in all conditions occurred within the first five sessions (125 S− trials). Subject S3's one error was made during the fourteenth session.

Discussion

The present results, together with the results of Schwartz (1973) and Wessells (1973), demonstrate that differential autoshaping may engender errorless discrimination. Wessells (1973, phase 1) exposed nine pigeons to a trial procedure similar to the A-EFD-RL condition of the present experiment, except that (a) S+ was green, (b) S+ and S− were not turned off by key pecks but rather remained on for 6 sec, (c) intertrial intervals were variable rather than fixed, and (d) the chamber was constantly illuminated by a houselight. Wessells' subjects made between four and 16 errors in 80 or 200 S− trials. Schwartz (1973, procedure I) exposed three pigeons to a procedure in which the response key was transilluminated alternately by green (S+) or red (S−) for 30-sec periods. Response-independent food was presented once every 33 sec on the average during S+ but not during S−. While key pecking developed and persisted during S+, very few pecks occurred during S−.

The present results also show that the manner in which pecking the key on S+ trials is established is an important determinant of whether or not errors occur on S− trials. Subjects trained to peck during S+ by the method of reinforcing successive approximations made more errors than subjects whose pecking was autoshaped. Subjects that acquired pecking by autoshaping made no or few errors when exposed to conditions that might be reasonably expected to result in errors—the late introduction of S− at full duration.

Since autoshaping procedures are formally identical to classical conditioning procedures and since there is some evidence (*cf.* Jenkins and Moore, 1973) that the conditioning process in autoshaping is the same as in classical conditioning, one could consider errorless differential autoshaping an instance of errorless differential classical conditioning. As such, this finding is somewhat of a novelty, since previous attempts to establish errorless differential classical conditioning have failed (*e.g.*, Coleman, Newman, and Moore, 1965).

Differential autoshaping does not invariably lead to errorless discrimination. Errorless discrimination was not found by either Gamzu and Schwartz (procedure I, 1973), who used a procedure nearly identical to that of Schwartz (1973), or by Wasserman, Franklin, and Hearst (Experiment III, *in press*), who used a trial procedure similar to the A-EFD conditions of the present experiment except that (a) trials were 10 sec in duration, (b) trials occurred on two keys rather than on one, (c) S+ and S− were either white key *versus* black vertical line on white or black vertical line on white *versus* black 45-degree line on white, (d) intertrial intervals were variable and averaged 40 sec, and (e) the chamber was constantly illuminated by a houselight. The factor(s) responsible for the discrepancy between these results and those of the present experiment, of Schwartz (1973), and of Wessells (1973) are, at present, unknown.

EXPERIMENT II

A basic question raised by the phenomenon of errorless discrimination is whether an errorless S− differs in any fundamental way from an S− during which errors had occurred but ceased. Previous research (for example, Kodera and Rilling, 1973; Lyons, 1969; Rilling and Caplan, 1973; Rilling, Kramer, and Richards, 1973; Terrace, 1972; Wildemann and Holland, 1973) has shown that there are both apparent similarities and differences between S−s learned with and without errors. The present experiment investigated this question.

Since differences between stimuli may be manifested in different rates of acquisition of responding during the stimuli (Hearst, 1972) we examined the acquisition of autoshaped responding to S− stimuli in which errors had or had not occurred. The results of a pilot experiment suggested that acquisition of autoshaped responding to an errorless S− is slower than the acquisition of autoshaped responding to an S− learned with errors. In the pilot experiment, four pigeons (S4, S7, S8, and S9) that had made no or very few errors and four pigeons (S13, S14, S15, and S16) that had made errors in Experiment I served. No pigeon had made an error during the last 125 S− trials of Experiment I. All birds received autoshaping trials during which the former S− was presented for 5 sec and followed by response-independent reinforcement. If a key peck occurred while the keylight was on, the light was turned off and reinforcement followed. Trials occurred once every 30 sec. Twenty-five trials occurred during each session. Sessions continued until a subject had pecked on five consecutive trials. Subjects that had made no or few errors required a considerably larger number of autoshaping trials to reach criterion than did subjects that had made errors: S4-221, S7-269, S8-308, S9-407, S13-49, S14-99, S15-85, and S16-55 autoshaping trials. While these results suggest that an errorless S− is more resistant to autoshaping than an S− learned with errors, this conclusion is based on a between-subjects comparison. The present experiment permitted a within-subject comparison.

METHOD

Subjects

Two adult, experimentally naive, King pigeons were reduced to approximately 80% of their free-feeding weights before the start of experimentation.

Apparatus

The apparatus was the same as in Experiment I.

Procedure

Following training to approach rapidly and eat from the grain feeder, the pigeons were exposed to a differential autoshaping procedure similar to that arranged in Experiment I but with two S−s. The two subjects, S17 and S18, received 22 and 30 sessions respectively. During the first session, 50 trials were arranged. During 25 trials, the response key was transilluminated by a white vertical (0°) line. These trials lasted until a peck occurred or for a maximum of 5 sec and were followed immediately by reinforcement. During the other 25 trials, the response key was transilluminated by green light. These trials ended once a peck had occurred or after 5 sec had elapsed with no peck and were not followed by reinforcement. The two types of trials occurred in an irregular order within the session. Trials occurred once every 30 sec. During the intertrial interval, the response key was not transilluminated, the chamber was dark, and key pecking had no scheduled consequences. The second session was similar to the first except that the green light was replaced by a horizontal (90°) white line. The remaining odd-numbered sessions were like the first; the remaining even-numbered like the second. Once a subject had pecked during five consecutive 0° line trials, reinforcement on succeeding 0° line trials was response contingent.

During the next phase of the experiment, the subjects received autoshaping trials during which the 90° S− was presented for 5 sec and followed by response-independent reinforcement. If a key peck occurred while the keylight was on, the light was turned off and reinforcement followed. Trials occurred once every 30 sec. Twenty-five trials occurred during each session. Sessions continued until a subject had pecked on five consecutive trials. Similar trials with the green-light S− were next arranged.

RESULTS

Figure 1 shows the number of trials on which a peck occurred during the first 22 (S17) or 30 (S18) sessions of the experiment. Responding to S+ (0°) was autoshaped in both subjects: S17 reached criterion on the sixty-fourth S+ trial, S18 on the one hundred fifteenth trial. Both subjects responded on 90° S− trials during the initial sessions. No errors occurred during the last 125 90° S− trials. In total, S17 responded on 90° S− trials 76 times and S18 109 times. Neither pigeon responded on any green (G) S− trials.

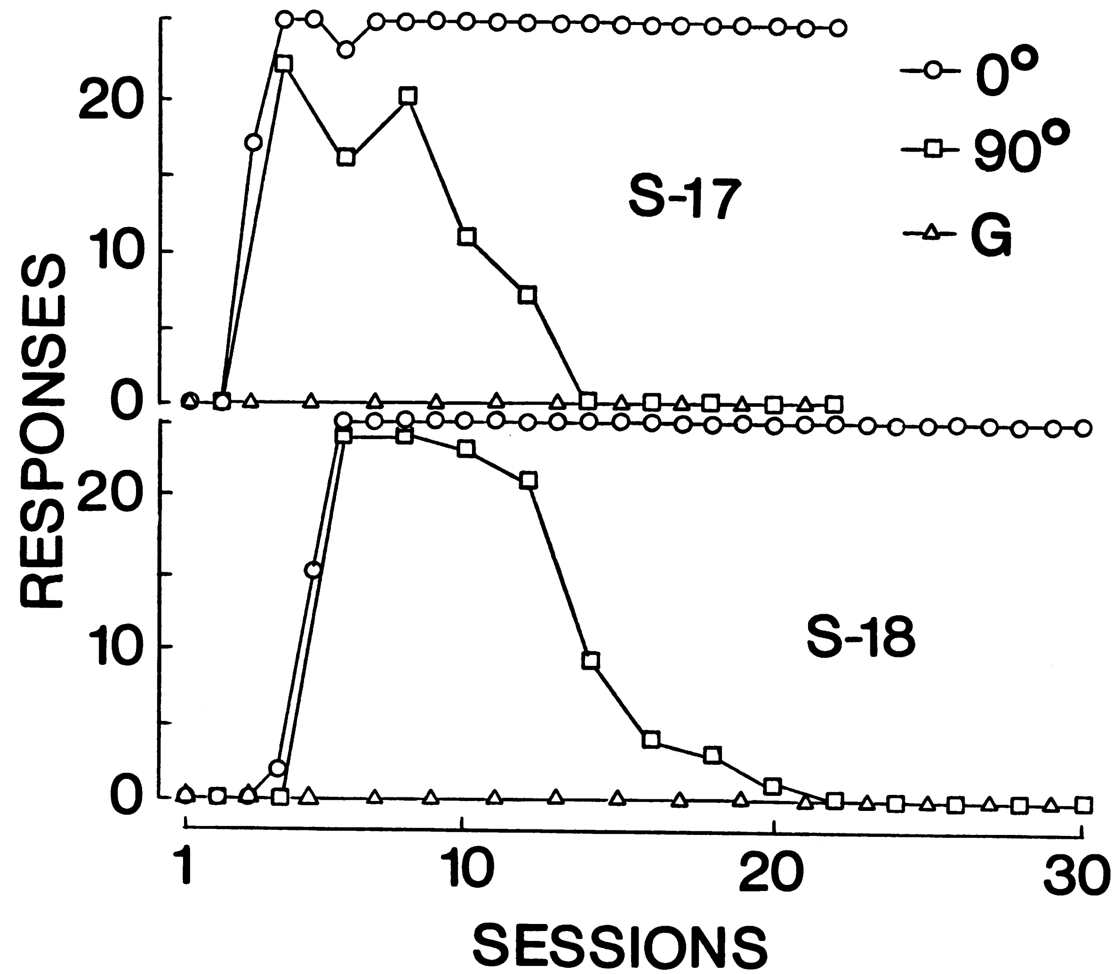

Fig. 1. Number of S+ (0°) and S— (90° and G) trials on which a key-peck response occurred. Twenty-five S+ and 25 S— trials occurred during each session. During even-numbered sessions, S— was a 90° line; during odd-numbered sessions, S— was a green (G) light.

Figure 2 shows the results of the phase of the experiment in which the rate of acquisition of autoshaped responding to the former errorless (G) and errorful (90°) S— was examined. The figure shows the number of autoshaping trials required to produce responding on five consecutive trials and the trial on which the first peck occurred. Both subjects first responded and reached the criterion of responding on five consecutive trials sooner to the S— learned with errors than to the errorless S—.

Discussion

The results of this experiment show, first, that it is possible to establish within-subject errorful and errorless discrimination by differential autoshaping and, second, that an errorless S— is more resistant to autoshaping than an errorful S—. If one considers the number of autoshaping trials necessary to establish pecking to S+ in the first part of the experiment as indicative of the number of stimulus-reinforcement pairings needed to establish responding to a neutral stimulus, then the fact that more autoshaping trials were required to establish pecking to the errorless S— could be taken as evidence that the errorless S— in the present experiment was an *inhibitory stimulus* (*cf.* Hearst, 1972; Hearst, Besley, and Farthing, 1970). Such a conclusion is bolstered by Wessells' (1973) results. In one part of his experiment, he compared speed of autoshaping to an errorless S— and to a novel, presumably neu-

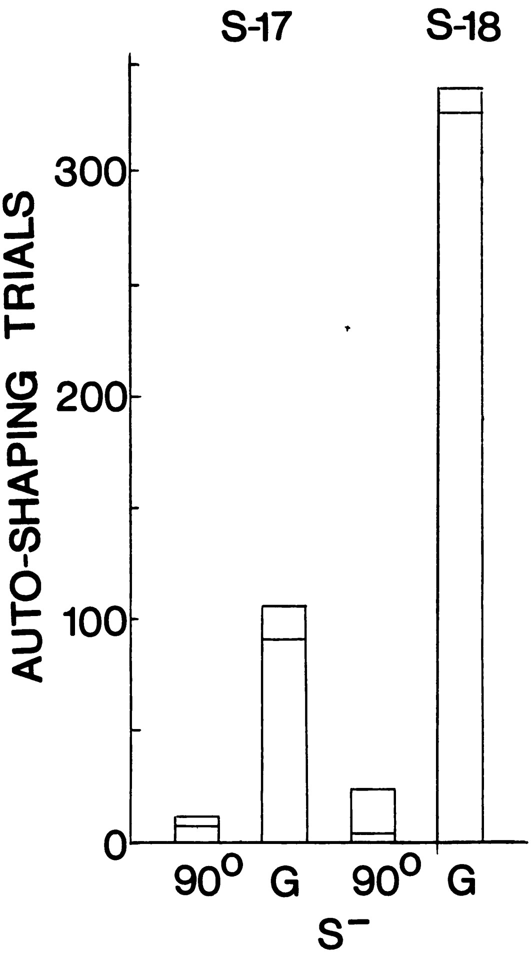

Fig. 2. Number of autoshaping trials until criterion of pecking on five consecutive former errorful S− (90°) and errorless S− (G) trials was reached. The horizontal line on each bar represents the autoshaping trial on which the first peck occurred.

tral, stimulus. He found that more autoshaping trials were needed to establish pecking to the errorless S−. Since errorful S−s are often regarded as being inhibitory (Hearst *et al.*, 1970) the present finding that more errorless S− reinforcement pairings than errorful S− reinforcement pairings were needed to establish pecking is also consistent with the notion that the errorless S− is an inhibitory stimulus.

While these findings suggest that the errorless S− is inhibitory, it could be argued (*cf.* Hearst, 1972) that the resistance-to-autoshaping procedure assays attention or stimulus salience, rather than inhibition, and that the slow autoshaping of responding to the errorless S− was due to inattention to this stimulus or to a decrease in the salience of this stimulus. This possibility would seem to be ruled out by Wessells' (1973) results. If the errorless S− is not attended to, responding to S+ should not be affected if the errorless S− is superimposed on S+. Wessells performed this test and found that superimposing the errorless S− on S+ completely suppressed S+ responding.

GENERAL DISCUSSION

It is not yet clear how both our results and those of Wessells (1973), which suggest that an errorless S− is inhibitory, bear on Terrace's (1966, 1972) conclusion that an errorless S− is neutral. Conceivably, possible differences between errorless discriminations produced by differential autoshaping and Terrace's (1963) procedures could account for the different conclusions about the nature of errorless S−s. However, Terrace's conclusion about the nature of errorless S−s was based on the results of a test for inhibition—the generalization test procedure of Jenkins (1965)—that has been criticized by Hearst *et al.* (1970) as indicating neither the presence nor the absence of inhibition in an unambiguous manner. Note also that three other recent experiments (Hearst *et al.*, 1970; Johnson, cited by Hearst, 1972; Lyons, 1969) in which errorless discrimination was established by procedures other than differential autoshaping, including procedures similar to those used by Terrace, are also consistent with the conclusion that errorless S−s are inhibitory.

Also not clear at present is how the finding that an errorless S− is inhibitory bears on Terrace's (1972) theory of discrimination byproducts. Terrace holds that byproducts such as behavioral contrast (Reynolds, 1961), peak shift (Hanson, 1959), and S− aversiveness (Azrin, Hutchinson, and Hake, 1966; Rilling, Askew, Ahlskog, and Kramer, 1969), which accompany errorful discrimination, are due to the alternation of an S+ with an inhibitory S−. While Terrace has failed to observe these byproducts during errorless discrimination, others have reported that such byproducts do occur during errorless discrimination (Kodera and Rilling, 1973; Rilling and Caplan, 1973; Rilling, Kramer, and Richards, 1973; Wildemann and Holland, 1973). If it is true that both errorful and errorless S−s are inhibitory and that these byproducts occur during both errorful and errorless discrimination, Terrace's hypothesis about the determinants of discrimination byproducts may be correct.

While exactly how inhibitory stimuli exert their effects is not understood (*cf.* Hearst, 1972), a recurrent theme in discussions of inhibitory stimuli is that such stimuli control responses that compete with or are antagonistic with S+ responding. The finding that an errorless S− is inhibitory would appear to rule out one possible reason for the development of such responses—namely that the antagonistic responses develop as a result of the negative reinforcement associated with the cessation of nonreinforced responding. Another possible reason for the development of antagonistic responses that is not inconsistent with the existence of inhibitory errorless S−s is suggested by a recent result reported by Wasserman, Franklin, and Hearst (*in press*). They found, using a differential autoshaping procedure, that pigeons approach and peck an S+ but actively withdraw from an S−. This conditioned withdrawal from the S− could conceivably occur independently of whether or not pecks to S− (errors) occurred and could thus account for the inhibitory nature of both errorful and errorless S−s.

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