The Effects of Total Darkness on Stimulus Control

Schulman
THE EFFECTS OF TOTAL DARKNESS ON STIMULUS CONTROL

by

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THE EFFECTS OF TOTAL DARKNESS ON STIMULUS CONTROL

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This experiment examined auditory stimulus control in a totally darkened as opposed to an illuminated chamber. All subjects (pigeons) were trained to keypeck in the presence of only a dimly lit green keylight, which was faded until responding was reliably occurring in a totally darkened chamber. When behavior stabilized under a Variable Interval (VI) 30 second schedule of reinforcement in a darkened chamber, subjects were divided into two groups for discrimination training. A Multiple VI 30 second Extinction (EXT) schedule was in effect, with 1-minute components separated by 5-second timeouts. The discriminative stimulus correlated with the VI component was a pulsing tone; for the EXT component it was a continuous tone. No tone was present during timeout. One group underwent discrimination training in a darkened chamber, the only illumination being a hopper light during grain presentation. The other group underwent identical discrimination training, except that the chamber was illuminated by the houselight at all times other than grain presentation. Pigeons trained in a darkened chamber showed higher asymptotic levels of auditory stimulus control than those trained in an illuminated chamber. The results suggest that visual stimuli provide concurrent sources of reinforcement which can attenuate the control exerted by auditory stimuli. In a totally darkened chamber these visual stimuli are eliminated.
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Richard E. Schulman
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CHAPTER I

INTRODUCTION

Many experimenters have investigated the behavior of organisms under conditions of total darkness in order to address a host of experimental questions. Some examples to be found in relatively early studies entailed the use of a darkened chamber to assess the onset of light as reinforcement with respect to the behavior of rodents. Kish (1955) compared two groups of mice; one group received a brief onset of light as a consequence for bar touching in a darkened chamber, whereas the other group received an identical brief onset of light on a noncontingent basis in a darkened chamber. In the next phase of the experiment, light onset for both groups was discontinued. The group receiving a brief response-contingent onset of light showed an increase in bar touching relative to baseline (no light onset), and in extinction a decrease in bar touching was observed relative to the light onset condition. The group receiving a brief noncontingent onset of light increased bar touching only slightly relative to baseline, and when light onset was discontinued, the rates of bar touching only slightly declined. Since baseline rates of bar touching were high, Kish concluded that the slight change in bar touching exhibited by the noncontingent group was due to adventitious reinforcement. Kish further concluded that, at least in regard to the behavior of mice under the conditions tested,
light is a source of unconditioned reinforcement. Light as a source of conditioned reinforcement is unlikely because the primarily nocturnal behavior evidenced by mice makes less probable any correlation between light and unconditioned reinforcement. Thus, an environmental stimulus change that for the most part appears unrelated to this species' survival functioned as reinforcement.

Robinson (1957) demonstrated that rats engage in bar pressing when the consequence is illuminating a darkened chamber. However, these rats did not bar press when the consequence was returning the experimental chamber to a darkened condition. Robinson suggested that his results do not support a stimulus change theory to explain the reinforcing effects of light since light offset did not gain control of bar pressing.

Premack, Collier, and Roberts (1957) showed that the consequence of lighting a darkened chamber generated monotonically increasing rates of bar pressing in rats as a function of light deprivation. Since deprivation is related to the value of unconditioned reinforcement, the notion of only a stimulus change to explain the control light exerts over the behavior of a rat was again rendered improbable. Instead, Premack et al. suggested that the effects of light are "better treated as a drive for stimulus change, drive being defined as a functional relation between deprivation for X and responding for X" (p. 411). Thus, the relationship between deprivation and the value of light further qualifies the onset of light as a source of unconditioned reinforcement as opposed to reinforcement resulting only from a stimulus change.
Another experiment by Robinson (1959), similar to his earlier study (1957), yielded an interesting hypothesis concerning the effects of light on the behavior of rats. A stimulus change orientation to the effects of light must include a condition where rats' bar pressing is controlled not only by the onset of light, but by the offset of light as well. Yet the previous experiments indicate that the behavior of the rat is reinforced by the change from dark to light but appears not to be reinforced by the change from light to dark. Robinson hypothesized that scanning heterogeneities in a lighted environment is reinforcing and that this source of reinforcement competes with responding that produces an environment which cannot be scanned. Thus, although the stimulus change from a lighted condition to a darkened condition is reinforcing, the effect of this reinforcement is cancelled because it produces an environment that cannot be scanned.

Although the results of these experiments with rodents provide useful information, their relevance to the behavior of other organisms (e.g., pigeons, humans) is limited by biobehavioral differences between the species. Specifically, it would be inappropriate to extrapolate from experimental results obtained with organisms that behave primarily in a darkened environment to organisms that behave primarily in a lighted environment.

Other experimental investigations have focused on an organism's behavioral performance under conditions of illumination as opposed to conditions of total darkness. Examples may be readily found in the delayed matching to sample literature. D'amato and O'Neill
(1971) trained Capuchin monkeys on a delayed matching to sample task and found that performance was superior when the delay interval was spent in darkness rather than in moderate illumination. Further experimentation identified the dark delay rather than just a change in illumination as the critical variable in generating an enhanced matching performance. Worsham and D'amato (1973) examined the performance of monkeys on a visual delayed matching to sample task as a function of the following sources of interference interpolated during the delay interval, both singly and in combination: ambient illumination, white noise, and recorded monkey vocalizations. A sharp performance decrement was generated by ambient chamber illuminations during the delay interval as opposed to a darkened chamber during the delay interval. Neither white noise nor recorded monkey vocalizations presented during the delay interval had an effect on delayed matching performance. Curiously, some of the data indicated that the presentation of recorded monkey vocalizations during the delay interval attenuated the disruptive effect of delay interval illumination on delayed matching performance.

Results indicating superior performance on delayed matching to sample tasks when a darkened rather than illuminated delay interval is used have also been obtained with pigeons. Grant and Roberts (1976) trained pigeons on a delayed matching to sample task and then examined the separate effects of different interpolated stimuli during the delay interval on matching performance. These interpolated stimuli involved: (a) saliency, (b) similarity, (c) familiarity, (d) complexity, and (e) illumination. The pigeons'
matching to sample behavior evidenced a decrement only when illumination was interpolated during the generally darkened delay interval. Subsequent experiments also revealed a direct relationship between the degree of illumination during the delay interval and matching to sample performance. Experimentation by Maki, Moe, and Bierley (1977) examined the effects of delay interval illumination on pigeons' matching performance—using visual stimuli, number of responses, and occurrence versus nonoccurrence of reinforcement as samples—and found that although a performance decrement was related to the amount of light presented during the delay interval, no relationship was found between delayed matching performance and the point at which light was interpolated into the delay. The results of a delayed matching to sample experiment with pigeons conducted by Roberts and Grant (1978) are in sharp disagreement with this last finding. They varied length of exposure to light as well as point of light interpolation. Not only was matching performance increasingly diminished with greater temporal lengths of light exposure, but light introduced at the end of the delay interval produced a greater decrement in matching performance than did light introduced at the beginning of the delay.

Before reviewing another area of research, a recent study by Tranberg and Rilling (1980) involving pigeons and delayed matching to sample warrants discussion. These experimenters noted that past research has found delay interval illumination responsible for a performance decrement in matching to sample tasks across many species. With respect to this research, they also noted that delayed
matching to sample studies employed a baseline in which the delay interval was darkened prior to experimental manipulation. The independent variable was a change in delay interval illumination. Tranberg and Rilling hypothesized that the subsequent performance decrement in matching to sample was not a function of an illuminated delay interval per se, but rather was a result of employing an illuminated delay interval during testing conditions after utilizing a darkened delay interval during baseline conditions. According to this hypothesis, employing an illuminated delay interval during baseline conditions and then using a darkened delay interval during test conditions should result in a performance decrement in a matching to sample task. Tranberg and Rilling tested this hypothesis and found that performance decrements in matching to sample were a function of a change in delay interval rather than of illumination per se. Thus, although prior research in delayed matching to sample suggests a superior performance under darkened delay conditions, the recent study by Tranberg and Rilling calls into question the role of baseline conditions in generating the results of previous studies.

Experiments involving an organism's responding in a darkened chamber as opposed to responding in a lighted chamber have played a role in addressing issues such as whether differential or nondifferential reinforcement is sufficient for the development of auditory stimulus control. Employing a nondifferential procedure (i.e., a stimulus that differs along a specified dimension from the $S^D$ is not presented during training), Guttman and Kalish (1956) brought the keypecking behavior of pigeons under the control of the wavelength...
of light associated with the keylight. This was evidenced during generalization testing in which the gradient peaked around the training stimulus and decreased sharply around the neighboring stimuli according to their similarity to the training stimulus along the dimension of wavelength.

In 1960, Jenkins and Harrison used a nondifferential procedure similar to that employed by Guttman and Kalish; only instead of bringing keypecking under the control of a visual stimulus, they attempted to bring keypecking under the control of an auditory stimulus. The stimulus dimension along which control was to be exerted was auditory frequency or wavelength. However, generalization testing yielded a flat gradient across all of the auditory wavelength values presented during testing. Jenkins and Harrison argued that their failure to obtain auditory stimulus control with a nondifferential procedure was due to the unlocalized nature of the auditory stimulus as opposed to a visual stimulus located directly on the response key, and in fact, subsequent experimentation (Heinemann and Rudolph, 1963) showed that with a visual stimulus the greater the degree of localization, the greater the degree of stimulus control.

Nevertheless, a much later experiment by Rudolph and Van Houten (1977) demonstrated that despite the unlocalized character of an auditory stimulus, keypecking could be differentially controlled by the dimension of tonal wavelength (frequency). These experimenters posited that, using a nondifferential procedure, Jenkins and Harrison (1960) failed to obtain stimulus control along the dimension of tonal wavelength because the keylight gained control of keypecking
and prevented (or at least eclipsed) control by the auditory stimulus. The phenomenon in which one of two stimuli present gains control of behavior at the expense of the other stimulus is called **overshadowing** (Mackintosh, 1977). (As pointed out by Mackintosh, the results of the 1977 Rudolph and Van Houten experiment may have been due to **masking** rather than overshadowing of the tone by the keylight. It is possible that the keylight—rather than preventing control by the tone—simply masked the control acquired by the tone.)

The nondifferential procedure used by Jenkins and Harrison (1960) ensured a situation in which the auditory stimulus and the keylight shared an equal correlation with reinforcement (grain). During generalization testing, although tonal frequency changed, the keylight remained the same on all stimulus dimensions; since the keylight had already gained control of behavior, it maintained control throughout generalization testing, thus producing a flat gradient across all auditory stimulus values presented.¹ In order to confirm their hypothesis concerning overshadowing (or masking) of tone by keylight in the Jenkins and Harrison (1960) experiment, Rudolph and Van Houten (1977) trained two groups of pigeons: one group was trained to keypeck in the presence of a pure tone; the other group was trained to keypeck in the presence of a pure tone with the experimental chamber

¹A related finding from a pigeon experiment by Lolordo and Furrow (1976) is that in an appetitive situation a visual stimulus will control more behavior than an auditory stimulus. But they also reported that in a shock avoidance situation an auditory stimulus will control more behavior than a visual stimulus; this appears to have survival value in that a greater degree of mobility with respect to location is afforded the organism primarily under auditory stimulus control rather than visual stimulus control.
totally dark. Both groups were then given generalization testing for control by tonal frequency. Only the dark-trained birds produced a steep gradient; the light-trained birds were essentially controlled by the illuminated keylight during generalization testing.

An earlier experiment by Van Houten and Rudolph (1972) involved training pigeons on an airflow discrimination—one group being trained in a totally dark chamber, the other group being trained in the presence of an illuminated response key. The dark-trained subjects came under the control of the airflow discriminative stimuli more quickly than the keylight-trained subjects. Apparently, during variable interval pretraining, the keylight either overshadowed or masked the airflow stimulus so that when airflow discrimination training began, the keylight was already controlling behavior.

The next experiment to be described will take this introduction to its conclusion and to the purpose of the present experiment. In 1974, Robinson and Shelley devised an elegant study to examine the effects of total darkness on schedule control. Groups of pigeons were trained to keypeck on four schedules of reinforcement: (a) fixed ratio, (b) variable ratio, (c) fixed interval, and (d) variable interval. Once stable rates of behavior were occurring under a given schedule of reinforcement, the houselight and the keylight were gradually faded until subjects were responding in a totally darkened experimental chamber. Robinson and Shelley, employing an ABAB procedure, alternated a darkened experimental chamber with an illuminated experimental chamber, pending stable responding within a
condition. The results were that response rates under both ratio
schedules were greater in the darkened chamber, thus increasing the
reinforcement obtained per session time. Under both interval sched-
ules the response rates decreased in the darkened chamber without a
subsequent loss in the obtained reinforcement rates. Robinson and
Shelley concluded that conditions of total darkness enhanced sched-
ule control, and they suggested that extraneous concurrent sources
of reinforcement were reduced under dark conditions, resulting in
greater control by the programmed schedule of reinforcement.

This experiment concerns stimulus control under conditions of
total darkness. With the exception of organisms reared under con-
trolled conditions, experimental subjects bring a history of
differential reinforcement with respect to numerous visual stimuli
to the experimental situation. Behavior, such as scanning a lighted
environment, is intermittently reinforced by these stimuli and the
opportunity for further reinforcement they occasion. It seems like-
ly that it would be extremely difficult to extinguish scanning
behavior without resorting to a darkened environment or a carefully
controlled monochromatic environment. It also seems likely that
some behavior appropriate to nonvisual stimuli might be acquired
more slowly in a lighted environment because an ongoing history of
behavior appropriate to visual stimuli is readily reinforced and
thus may attenuate the control exerted by nonvisual stimuli. In
both Rudolph and Van Houten studies (1972 and 1977) visual stimuli
present during pretraining overshadowed (or at least masked) the
subsequent control by nonvisual stimuli. The purpose of the present experiment was to determine if a pigeon's preexperimental history with respect to visual stimuli is a sufficient condition for reducing the subsequent experimental control exerted by auditory stimuli during discrimination training in a lighted experimental chamber. In contrast to prior studies, the visual stimuli within the experimental chamber were prevented from acquiring control of behavior during the experimental pretraining sessions that preceded auditory discrimination training. This was accomplished by pretraining all subjects in a darkened chamber. With the onset of auditory discrimination training, some subjects performed in a darkened chamber and others performed in a lighted chamber. With regard to the acquisition and asymptotic level of auditory stimulus control, discrepancies evidenced between dark-trained and light-trained subjects were addressed according to a history of reinforcement involving visual stimulus control rather than visual stimulus control acquired during pretraining sessions.
CHAPTER II

METHOD

Subjects

Subjects for this study were six experimentally naive female White Carneau pigeons, approximately 3 years of age and maintained at 80% of their free-feeding weights. Of these subjects, two died during preliminary training; data on these subjects are not presented.

Apparatus

Three identical two-key Lehigh Valley Electronics chambers were utilized for the duration of the experiment, with the exception of the shaping procedure for keypecking and the last 5 sessions of the experiment in which only one experimental chamber was used. All three chambers had Mallory Sonalerts (audible model SC628) mounted in rubber brackets behind the response panel. The chambers were interfaced to a Digital Equipment Corporation PDP-8/l Laboratory computer. Both the interface and the software were made by State Systems, Incorporated. The software was Super Sked (Snapper, van Haaren and Inglis, 1978). The computer arranged all stimuli and recorded the data.
Procedure

Preliminary Training

All subjects were trained to eat grain from the hopper, after which keypeck training began. The right key was covered, and the only illumination in the chamber was provided by a green light located on the left response key. Furthermore, until all subjects were reliably keypecking in total darkness, the walls and ceiling of the experimental chamber were covered with nonreflecting black cardboard (by Stewart Laminating) in order to reduce light reflected from the illuminated response key. The cardboard was covered with clear, nonreflecting tape to prevent the subjects from scraping the black finish. Appropriate apertures in the cardboard were made for the response key, hopper, houselight, and air duct. Following dark training, the cardboard was removed. All subjects received 3 seconds (sec) access to grain contingent upon each keypeck and received 40 reinforcements per session for 3 sessions. Dark training began with the 4th session; keypecking was continuously reinforced (CRF), and the green keylight was gradually faded within the session by means of a hand-operated dimmer switch. Until all subjects were keypecking in total darkness, 40 reinforcements were delivered per session per subject. Within the next 6 sessions, three of the subjects were responding in total darkness for most of the session although not at the outset of the session. The other three subjects required a more gradual fading of the green keylight within the session; if the keylight was dimmed too abruptly, responding ceased.
By the 12th session of dark training, all subjects were reliably keypecking in total darkness from the onset of the session. All subjects remained on a CRF schedule for at least 3 sessions with the chamber totally dark from the onset of the session. Next, all subjects were reinforced on a variable interval (VI) 15 sec schedule of reinforcement for keypecking in total darkness. Interval values were selected from Catania and Reynolds (1968). Each subject received 30 reinforcements per session, each reinforcement consisting of 3 sec access to grain. VI 15 sec training was in effect for 19 sessions, following which VI 30 sec training was begun, and the duration of grain presentation was increased from 3 sec to 4 sec. All subjects remained on the VI 30 sec schedule for 31 sessions of dark responding, with 30 reinforcements delivered per session.

Auditory Discrimination Training

Following the 31 sessions of VI 30 sec training, the subjects were randomly placed in one of two groups with three subjects in each group.

**Group 1 Contingencies.** Group 1 was exposed to a multiple (mult) VI 30 sec extinction (EXT) schedule of reinforcement, with the experimental chamber totally dark at all times except during reinforcement periods when the hopper light was present. At the onset of a session the chamber was dark, and a fixed ratio (FR) 1 keypeck response was required to initiate component presentation. The stimulus correlated with the VI 30 sec component (discriminative stimulus or $S^D$ component)
consisted of a pulsing tone that lasted for the duration of each 1-minute component presentation. The stimulus correlated with the EXT component (or $S^D$ component, $S^D$ being a stimulus in the presence of which responding is not reinforced) consisted of an unbroken tone that lasted for the duration of each 1-minute component presentation. $S^D$ and $S^A$ components alternated randomly, with the stipulation that the same component would not appear more than twice in succession. $S^D$ and $S^A$ components were separated by a 5-sec time-out period during which no tone was present and responding produced no scheduled consequences. When subjects had received 30 presentations of 4 sec access to grain per presentation, the session was terminated.

**Group 2 Contingencies.** The three subjects comprising Group 2 were exposed to the same contingencies as those in Group 1 with the exception that the experimental chamber was illuminated by the house-light during the entire session other than grain deliveries when only the hopper light was present. At the onset of a session the houselight was on, and a FR 1 keypeck response was required to initiate component presentation. For both groups 1 and 2, 31 mult VI EXT sessions were run. Also, for both groups, the last 5 sessions of the mult VI EXT schedule were run in one experimental chamber; thus only one subject was run at a time. This was done to eliminate any possibility of an ongoing tone from one chamber controlling the behavior of a subject in another chamber. On the average, sessions were conducted 5 days per week.
CHAPTER III

RESULTS

The results of this experiment are divided into two main sections. The first section describes the performance of all subjects with respect to acquiring a repertoire appropriate to a totally darkened experimental chamber. The second section entails a description of auditory discrimination training for those subjects responding in a lighted chamber as opposed to those subjects responding in a darkened chamber. The first section deals with dark training even though dark training per se was not the focal point of experimental investigation. However, since the number of reported studies involving dark training for pigeons is relatively scarce, a discussion of the fading procedure and the subsequent performance of the subjects seems warranted.

Preliminary Dark Training and Variable Interval Performance

Dark training consisted of a within session fading of the green keylight while the subjects were on a CRF schedule for keypecking. By the middle of the 6th session of dark training, half of the subjects were reliably responding in a totally darkened chamber. By the 12th session, all subjects were responding in the dark from the session's onset. Up until the 12th session, it was often necessary to increase the intensity of the green keylight during a session.
because a preceding decrease in the intensity of the green keylight disrupted keypecking. Rudolph and Van Houten (1977) reported success in dark training their birds by the 3rd session of CRF training, and by the 7th session of training all their subjects were reliably responding in the dark on a VI 15 sec schedule of reinforcement. The considerably greater training period required for the subjects in this study to acquire behavior appropriate to a darkened chamber can most probably be traced to differences in the experimental equipment. The experimental chamber utilized by Rudolph and Van Houten had three features that were not available to this experimenter. These three features provide an optimal experimental setting for generating and maintaining dark responding in pigeons. They are: (a) an enlarged response key, (b) a recessed response key, and (c) a response key located directly above the hopper. This last feature seems especially convenient for shaping and sustaining keypecking in total darkness. The organism need not depend on lateral movement with regard to control by stimulus location when moving from the hopper to the response key, but rather by remaining in a fixed location has access to both the hopper and the response key.

Following dark training on a CRF schedule, all subjects were placed on a VI 15 sec schedule of reinforcement. This was not accomplished without some difficulty. While all subjects immediately began keypecking once the session began, some of the subjects quickly stopped responding when the first several responses went unreinforced. When, after a long period of time, responding did
not resume, the subject was removed from the experimental chamber and then placed back in the experimental chamber. This was done so that the current stimulus conditions were again similar to the stimulus conditions that prevailed during CRF. The assumption, of course, was that responding initially ceased due to a stimulus change decrement—the conditions associated with nonreinforced responding were too dissimilar to conditions under which behavior was continually reinforced. As already noted, many CRF dark sessions were necessary to shape reliable keypecking in total darkness. Thus, all of the subjects were strongly controlled by continuous reinforcement for keypecking, and some of the subjects failed to quickly come under the control of an intermittent reinforcement schedule at first exposure. However, removing and replacing a nonresponding subject from the darkened experimental chamber did reinstate responding. This procedure was performed once for one subject and twice for another subject, only during the 1st session of VI 15 sec reinforcement. To establish relatively steady rates of behavior, all subjects remained on a VI 15 sec schedule of reinforcement for 19 sessions before being placed on a VI 30 sec schedule of reinforcement.

Problems involving disrupted dark responding did not occur when the subjects went from a VI 15 sec schedule of reinforcement to a VI 30 sec schedule of reinforcement. Initially, however, responding for most subjects was not stable from session to session, and for one subject, across session variability did not substantially diminish. Figure 1 shows the overall response rates across the last 10
Figure 1. Overall response rates per minute across the last 10 sessions of VI 30 sec dark training.
sessions of VI 30 sec dark training for each subject. Bird 2399 sustained exceptionally stable rates of keypecking given the absolute level of responding. Bird 8/60 developed fairly stable rates of behavior although the absolute level of responding remained relatively low. The last 10 sessions of overall VI 30 sec responding for Subject 1634 show that although the absolute rate of keypecking remained relatively low, extremely steady rates of keypecking were generated across the final 5 sessions. Bird 6018 sustained the highest absolute rates of behavior, with moderate across session variability given these high rates.

Figure 2 shows the reinforcement delivery rate for each subject across the last 10 sessions of VI 30 sec dark training. Both Birds 2399 and 8/60 exhibited variability in reinforcement rates although Bird 2399 (like Birds 1634 and 6018) produced more consistent rates of reinforcement during the latter sessions. Bird 6018 consistently sustained high reinforcement rates and, as already noted, generated high, although moderately unstable, overall response rates during VI 30 sec training. Apparently, this subject's somewhat inconsistent rates of behavior across VI 30 sec training sessions did not disrupt consistent reinforcement rates across those sessions. This suggests that despite variable between session response rates, the pattern of VI responding was evenly distributed within a session so as to reliably yield high reinforcement rates across VI 30 sec training sessions. Bird 1634's reinforcement rates are relatively low as are this bird's response rates during the first 5 sessions shown under VI 30 sec training. However, the last 5 sessions for this subject
Figure 2. Reinforcement deliveries per minute for all subjects across the last 10 sessions of VI 30 sec dark training.
are marked by consistently elevated rates of keypecking, as well as by a change in the same direction for reinforcement rates.

**Auditory Discrimination Training in Lighted as Opposed to Darkened Conditions**

Figure 3 shows a discrimination index for both light and dark trained subjects across 30 sessions of auditory discrimination training. The index was calculated by:

\[
\frac{S^D \text{ rates}}{\text{number of } S^D \text{ components}} + \frac{S^A \text{ rates}}{\text{number of } S^A \text{ components}}
\]

As indicated by the data in Figure 3, dark trained subjects 1634 and 6018 came to be controlled by the component-correlated auditory stimuli to a greater extent than light trained subjects 8460 and 2399. But this finding is relevant to asymptotic levels of auditory stimulus control rather than the speed with which behavior came to be differentially controlled by these stimuli. For both light trained birds, the relative level of differential control exerted by the auditory stimuli remained fairly consistent across the 30 discrimination sessions. In fact, for Bird 8460 an acquisition curve is virtually absent. For Bird 2399 a slight curve is evidenced from sessions 6 through 17. The asymptotic levels of auditory stimulus control were quite low—not far above chance for either light trained subject.
Figure 3. Discrimination index for light trained subjects (8460 and 2399) and dark trained subjects (1634 and 6018) across 30 sessions of auditory discrimination training.
SUBJECT No. 2399

SESSIONS

SUBJECT No. 6018

DISCRIMINATION INDEX PERCENT

SUBJECT No. 8460

SUBJECT No. 1634
In contrast, both dark trained subjects generated more typically accelerated acquisition curves, yielding asymptotic levels of differential auditory stimulus control which were well above chance values. A sharp increase in differential stimulus control is suggested for Subject 1634 in going from the 16th to the 17th session where the index shows an increase of 21%. The 20th session yielded an index of 91.9% for Bird 1634 which was the highest score obtained by any subject during discrimination training. Subsequent index scores generated by this bird were not comparable, but rather quickly decreased to more moderate values and stabilized. Bird 6018's index scores show an unstable acquisition curve that spans across sessions 11 to 30 of auditory discrimination training although the absolute value of these scores was moderate relative to those obtained by Bird 1634. Bird 6018's index data reveal two sources of superiority in comparison to the data generated by those subjects trained in a lighted experimental chamber. As already noted, higher absolute scores were obtained by Bird 6018 across the vast majority of discrimination training sessions. Further separating Bird 6018's performance from that of light trained Subjects 8460 and 2399 is the former's relatively expansive acquisition curve, as opposed to the absence of an acquisition curve for Bird 8460 and a slightly inclined acquisition curve of limited across session duration for Bird 2399.

In Figures 4 and 5 the right side (sessions numbered 16 to 45) shows the response rate per minute in both $S^D$ and $S^A$ components of the mult VI 30 sec EXT schedule for each subject across the 30
Figure 4. Response rates per minute during VI 30 sec dark training (Sessions 1 through 15) and $S^D$ and $S^A$ response rates per minute during auditory discrimination training (Sessions 16 through 45) for Subjects 2399 and 1634
The graphs illustrate the response rate over sessions for two subjects.

**Subject No. 2399**
- **VI 30"**
- **MULT VI 30" EXTINCTION**

**Subject No. 1634**
- **VI 30"**
- **MULT VI 30" EXTINCTION**

The graphs show the log response rate on the Y-axis and sessions on the X-axis. The data points are represented by different symbols:
- △ MEDIAN VI 30"
- ○ MEDIAN S^D
- ■ S^A
- □ MEDIAN S^A
Figure 5. Response rates per minute during VI 30 sec dark training (Sessions 1 through 15) and $S^D$ and $S^A$ response rates per minute during auditory discrimination training (Sessions 16 through 45) for Subjects 6018 and 8460.
sessions of auditory discrimination training. This display portrays the separation of \( S^D \) responding from \( S^A \) responding. The median response rate in \( S^D \) and \( S^A \) for the last 15 sessions of discrimination (sessions numbered 31 to 45) is also shown for each subject. The left side of Figures 4 and 5 (sessions numbered 1 to 15) shows the response rate per minute for each subject across the last 15 sessions of VI 30 sec dark training. The median response rate per minute for the last 10 sessions of VI 30 sec dark training (sessions numbered 6 to 15) is also shown for each subject. The points on the ordinate are logarithmically spaced.

Light trained Bird 2399's response rate in both \( S^D \) and \( S^A \) components shows a rapid initial acceleration that yields rates of behavior moderately greater than those occurring during VI 30 sec training. The response rate in \( S^D \) slowly separates from the rate in \( S^A \), reaching the greatest separation at Session 32. From this point on, the rate in \( S^D \) drops off and somewhat stabilizes. However, the rate in \( S^A \) continues to increase (although erratically), thus reducing the separation from the \( S^D \) rate. Nevertheless, as indicated by the median \( S^D \) and \( S^A \) rates for the last 15 sessions, as well as visual inspection, Bird 2399's keypecking was to a slight degree differentially controlled by the component-correlated auditory stimuli. From the 1st session, light trained Bird 8460's (Figure 5) rate of keypecking in \( S^D \) and \( S^A \) components far surpassed the median response rate for the last 10 sessions of VI 30 sec training. The separation between the response rate in \( S^D \) and the response rate in
$S^\Delta$ was relatively large for the first several sessions, but quickly thereafter, sustained separation of any significance between the rate in the two components was almost completely eliminated. As shown by the median response rate for both across the last 15 sessions of discrimination training (Sessions numbered 36 through 45), the separation was so slight, given the extremely high rate of responding, that differential control of keypecking by the component-correlated auditory stimuli appears negligible.

Dark trained Bird 1634 (Figure 4) developed a response rate in the $S^D$ component which was moderately greater than the median response rate for the last 10 sessions of VI 30 sec training. The response rate in $S^\Delta$ immediately began decreasing, quickly placing it well below the median VI 30 sec training response rate. For the most part, the dramatic separation between the $S^D$ and $S^\Delta$ rates of keypecking was due to relatively large decreases in $S^\Delta$ responding. While keypecking in $S^D$ did undergo some significant rate changes, these changes were less related to the "goodness of discrimination" than were the changes in rate that occurred in $S^\Delta$. The greatest relative separation between $S^D$ responding and $S^\Delta$ responding is observed in Session 35, following which $S$ responses quickly increased and the separation was permanently diminished. Despite this decrement, Bird 1634's behavior seems to be largely controlled by the component-correlated discriminative stimuli. Dark trained Bird 6018 began the first several sessions of discrimination training with both $S^D$ and $S^\Delta$ response rates well below the median VI 30 sec training rate of
Approximately midway through discrimination training, the response rate in $S_D$ underwent an increase that was somewhat sustained for the rest of the experiment and produced a median marginally greater than the median resulting from VI 30 sec training. Although the relative separation between $S_D$ responding and $S_A$ responding was not nearly so pronounced as Bird 1634's, moderate separation was basically maintained across the last 15 sessions (numbered 31 to 45) of discrimination training. Occurring singularly and in combination throughout discrimination training, rate changes in both $S_D$ and $S_A$ components contribute to Bird 6018's "goodness of discrimination." Data indicate that the component-correlated auditory stimuli exerted a moderate degree of control over Bird 6018's keypecking behavior across the last 15 sessions of discrimination training.

Figure 6 shows the obtained reinforcement rate per minute across the last 10 sessions of auditory discrimination training for each subject. For Subject 2399, the obtained reinforcement rate during discrimination training underwent considerable variation across sessions, thus making a comparison with the obtained rate for VI 30 sec training (Figure 2) practically impossible. The highly variable obtained reinforcement rate shown during the last 10 sessions of discrimination training was representative of the obtained rate throughout discrimination training. Despite this variable measure, the obtained reinforcement rate was for the most part slightly less than the reinforcement rate obtained during VI 30 sec dark training. Bird 8460 likewise showed a highly variable obtained reinforcement rate.
Figure 6. Reinforcement deliveries per minute for all subjects across the last 10 sessions of auditory discrimination training.
rate across the last 10 sessions of discrimination training, which renders a comparison to the obtained rate during VI 30 sec training exceedingly difficult. Again, as for Bird 2399, the data for Bird 8460 indicate that the obtained reinforcement rate was less during discrimination training than VI 30 sec training. However, in the case of both light trained subjects, this conclusion is tenuous.

Dark trained Subjects 1634 and 6018 showed results similar to those of the light trained subjects except that across most discrimination training less overall variability was evidenced by dark trained subject 1634. However, both Birds 1634 and 6018 generated data indicating a reduction in the obtained reinforcement rate in going from VI 30 sec training to auditory discrimination training.

Table 1 shows the response rate per minute during $S^D$, $S^A$, and the interstimulus interval ISI) for each subject across the last 5 sessions of auditory discrimination training. The ISI was a 5 sec period used to separate component changes during the nult VI EXT schedule. This table is presented so that the response rate per minute during $S^D$ and $S^A$ component presentations may be compared with the response rate per minute during the ISI. With the exception of Bird 6018, all other subjects generated rates of keypecking during the ISI that were marginally greater than the highest component rate, be it $S^D$ or $S^A$. Dark trained Bird 6018's ISI response rates were always lower than the rate in $S^D$ but higher than the rate in $S^A$. 

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Table 1

Response Rate Per Minute During $S^D$, $S^A$, and ISI for Each Subject Across the Last 5 Sessions of Auditory Discrimination Training

<table>
<thead>
<tr>
<th>Sessions</th>
<th>Subjects</th>
<th>L-2399</th>
<th>L-8460</th>
<th>D-1634</th>
<th>D-6018</th>
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<tr>
<td>1</td>
<td>$S^D$</td>
<td>71.9</td>
<td>131.3</td>
<td>39.9</td>
<td>34.3</td>
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<td></td>
<td>$S^A$</td>
<td>57.4</td>
<td>100.8</td>
<td>12.9</td>
<td>23.6</td>
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<td></td>
<td>ISI</td>
<td>92.7</td>
<td>133.5</td>
<td>24.4</td>
<td>24.4</td>
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<td>2</td>
<td>$S^D$</td>
<td>86.3</td>
<td>140.5</td>
<td>36.3</td>
<td>64</td>
</tr>
<tr>
<td></td>
<td>$S^A$</td>
<td>68.4</td>
<td>93.6</td>
<td>10.2</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>ISI</td>
<td>93.5</td>
<td>146.3</td>
<td>35.6</td>
<td>51</td>
</tr>
<tr>
<td>3</td>
<td>$S^D$</td>
<td>88.7</td>
<td>137.8</td>
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<td>64.7</td>
</tr>
<tr>
<td></td>
<td>$S^A$</td>
<td>68.3</td>
<td>137.9</td>
<td>11.7</td>
<td>33.8</td>
</tr>
<tr>
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<td>ISI</td>
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<td>146.8</td>
<td>27.1</td>
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<td>64.4</td>
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<tr>
<td></td>
<td>$S^A$</td>
<td>60.6</td>
<td>144.6</td>
<td>9.6</td>
<td>22.7</td>
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<td>168.5</td>
<td>44.5</td>
<td>36</td>
</tr>
<tr>
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<td>127.6</td>
<td>13.6</td>
<td>35.4</td>
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<tr>
<td></td>
<td>ISI</td>
<td>107</td>
<td>174.3</td>
<td>46.7</td>
<td>41.8</td>
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CHAPTER IV

DISCUSSION

The results of discrimination training strongly suggest that the auditory stimuli exerted greater differential control over the key-pecking of those subjects behaving in a darkened experimental chamber as opposed to the key-pecking of subjects behaving in a lighted experimental chamber. That the light trained subjects evidenced attenuated auditory stimulus control relative to dark trained subjects appeared unrelated to the preliminary experimental training sessions that occurred prior to discrimination training. The purpose of this experiment was to ascertain if a pigeon's history of reinforcement for visual behavior is sufficient to affect the generation and/or maintenance of auditory stimulus control. All subjects underwent preliminary (pre-discrimination) training in a totally darkened chamber so as to prevent control by visual stimuli from occurring during this phase of the experiment. Until all of the subjects were responding in total darkness, the walls and ceiling of the experimental chamber were covered with nonreflective black cardboard to minimize light that might be reflected from the progressively dimmed green keylight. Furthermore, for the subjects receiving auditory discrimination training in a lighted chamber, the houselight rather than the response key was illuminated so as to further reduce any similarity to the conditions that prevailed.
throughout that portion of preliminary training during which the green keylight was faded. There is an indication that the above precautions were successful in preventing visual stimuli present during preliminary training from later resulting in conditions favoring stimulus generalization for those subjects receiving discrimination training in a lighted experimental chamber. If keypecking controlled by the dimmed green keylight during early preliminary training had generalized to any visually observable features of the lighted chamber during auditory discrimination training, it might be anticipated that the light trained birds would at the onset of the first session of discrimination training soon begin pecking at either the darkened response key or at the illuminated houselight, since these two features of the experimental chamber most resembled the green keylight employed early in preliminary training. This, however, was not the case. At the onset of the first session of auditory discrimination training, light trained subjects did not peck the darkened response key nor did they peck at the houselight. Rather, these subjects wandered about the experimental chamber, pausing occasionally at different locations but not behaving differentially with respect to any particular location. After a few minutes of this behavior, light trained subjects did peck the darkened response key. Apparently, the stimulation produced by pecking the response key generated conditions similar to those under which previous keypecking had occurred since steady state responding began from that point on and continued throughout the experiment. It should be noted here that
because a FR 1 keypeck was required to initiate the introduction of the auditory stimuli at the beginning of each session, these stimuli could not have been responsible for the delay to the first peck. Moreover, the subsequent introduction of these stimuli did not disrupt responding. Finally, as expected, both of the dark trained subjects immediately began keypecking from the onset of the first session of auditory discrimination training.

In the "Results" section, it was noted that the asymptotic levels of auditory stimulus control rather than the acquisition of auditory stimulus control separated the performance of the light trained and the dark trained subjects. Actually, with the exception of dark trained Subject 1634, the obtained asymptotic levels of auditory stimulus control were not as high as might be expected for any of the subjects. And, even with Bird 1634, the discrimination index shows that a score of at least 90% was obtained only once during discrimination training, following which index scores quickly declined and were sustained at more moderate values. It is not clear why the subjects in this study (either light trained or dark trained) failed to come under greater auditory stimulus control. During the last 5 sessions of discrimination training, the subjects were run one at a time to eliminate the possibility that the auditory stimuli occurring in one chamber were being superimposed on the behavior of an organism being concurrently trained in another chamber. This precaution did not appreciably alter the performance of either light or dark trained subjects. One possible explanation for the relatively
low levels of obtained auditory stimulus control concerns the stimulus dimension along which control was to occur. Instead of tonal frequency or tonal intensity, the auditory stimuli in the present experiment were separated along the dimension of a broken tone ($S^D$) and an unbroken tone ($S^A$). Toward the end of this experiment, the experimenter positioned his head inside the experimental chamber and listened to the alternating tones. It was discovered that when the head was quickly moved back and forth toward the response key, the intensity of the unbroken tone ($S^A$) began to fluctuate in accord with the head movements so as to sound somewhat like the $S^D$ (broken tone). This presumed Doppler effect might have impaired the birds' performance in differentially responding to the defining feature that separated $S^D$ from $S^A$.

For the most part, the light trained subjects evidenced a negligible acquisition curve during discrimination training. This "cellar effect," describing the light trained subjects' acquisition of the discrimination, renders a comparison with the dark trained subjects' performance difficult.

If this experiment were replicated using auditory stimuli separated along a more salient dimension, the resulting data might well reflect a greater difference in acquisition rates between light and dark trained subjects relative to the difference in asymptotic levels obtained by the subjects. Moreover, if significant differences were still found in asymptotic levels of stimulus control between light and dark trained subjects, a within subject study could subsequently
be conducted in which birds alternately underwent auditory discrimination training in a lighted and a darkened chamber. This kind of experiment would provide an excellent analogue to Robinson and Shelley's (1974) single organism study involving pigeons and schedule control in a lighted versus a darkened chamber.

The results of the Robinson and Shelley (1974) experiment may have some relevance to the results of the present study even though differences in experimental design preclude a point-for-point comparison. Robinson and Shelley found that pigeons trained on a VI 1 min schedule of reinforcement exhibited reduced response rates per session during dark chamber responding as compared to the rates during light chamber responding although the obtained reinforcement rates remained approximately equal across both experimental conditions. With respect to the present study, the response rates per minute in $S^D$ were lower for the dark trained birds than for the light trained birds. Moreover, all of the subjects can be ranked according to the number of responses emitted during $S^D$, and this ranking will be found to be inversely related to the goodness of discrimination.

Stated differently, the lower the rate of $S^D$ responding, the greater was the differential control exerted by the auditory stimuli during discrimination training. As for the obtained reinforcement rates, both light and dark trained subjects showed decreased rates in going from preliminary VI 30 sec training to auditory discrimination training. Nevertheless, superior schedule control was indicated for the dark trained subjects inasmuch as they showed fairly stable rates of
obtained reinforcement during discrimination training whereas both light trained subjects showed considerable variation in their obtained reinforcement rates across discrimination training.

In looking at the rate of responding during the $S^D$ component of discrimination training for light and dark trained subjects, two subjects (dark trained Bird 1634 and light trained Bird 8460) showed immediately elevated rates of keypecking relative to the rates occurring during preliminary VI 30 sec dark training. Elevated rates of behavior during the $S^D$ component of a multiple schedule relative to baseline responding is known as behavioral contrast (Reynolds, 1961a; Reynolds, 1961b; and Terrace, 1966a). However, the procedure employed in the present experiment differs from traditional procedures in which the response rate in the $S^D$ component of discrimination training is compared to the response rate occurring during the training preceding discrimination training. Typically, the stimulus conditions during prediscrimination training are identical to the stimulus conditions during the $S^D$ component of discrimination training. In the present experiment, the stimulus conditions during VI 30 sec preliminary dark training were not identical to the stimulus conditions occurring during the $S^D$ component of discrimination training. This discrepancy between baseline stimulus conditions and the stimulus conditions present during the $S^D$ component of discrimination training was not as great for dark trained subjects as for light trained subjects. For the dark trained subjects, VI 30 sec preliminary training differed from $S^D$ periods occurring during
discrimination training in that auditory stimuli were not introduced until discrimination training began. For the light trained subjects, not only were the auditory stimuli first introduced at the onset of discrimination training, but for these subjects the chamber was darkened during preliminary VI 30 sec training and then illuminated once discrimination training began. Contrast effects relative to preliminary VI 30 sec training might be expected to occur for both light and dark trained subjects since for both groups there were some similarities between stimulus conditions present during VI 30 sec preliminary training and stimulus conditions present during discrimination training. However, greater initial contrast effects (within the first 3 sessions) between responding occurring during preliminary training and responding occurring during discrimination training might be anticipated for the dark trained subjects since the stimulus conditions present during preliminary training and discrimination training had more properties in common than was the case for light trained subjects. Yet as shown by the data, one dark trained subject (1634) and, to a much greater degree, one light trained subject (8460) evidenced initial contrast effects during the SD component of discrimination training relative to preliminary training. Neither dark trained Subject 6018 nor light trained Subject 2399 showed initial contrast effects in going from preliminary to discrimination training. These results can probably best be explained by returning once again to the study by Robinson and Shelley (1974). As already noted, these experimenters found that pigeons trained on a VI 1 min
schedule of reinforcement generated lower rates of keypecking in a
darkened chamber than in a lighted chamber. In the present experi-
ment, the lesser initial contrast effects anticipated from the light
trained subjects relative to dark trained subjects may have been
counterbalanced by an increase in rate for the former due to the
transition from a darkened chamber to a lighted chamber.

As previously mentioned, in attempting to analyze contrast ef-
fects when going from preliminary training to discrimination training,
a difficulty arises in that stimulus conditions present during pre-
liminary training were not identical to the stimulus conditions
present during the $S^D$ component of discrimination training. Actual-
ly, a discussion of contrast effects relative to this experiment is
possible in which stimulus conditions are identical across the compo-
nents to be compared. For both light and dark trained subjects alike,
sequential behavioral contrast effects should have occurred in the $S^D$
component of discrimination training when that component was preceded
by an $S^A$ component, as compared to an $S^D$ component that was preceded
by another $S^D$ component (Terrace, 1966b). It is indeed unfortunate
that the data collection program employed in this experiment did not
accommodate an analysis of sequential contrast effects.

Looking back at the results of this experiment involving stimu-
lus control in a lighted as opposed to a darkened chamber, a
theoretical analysis seems warranted that suggests some reasons as
to why these results occurred. Why did the dark trained subjects
come under greater control of a nonvisual stimulus than did their
light trained counterparts? In *Science and Human Behavior* (1953, pp. 271-273), Skinner discusses in detail the precurrent behaviors involved in seeing. One such behavior involves looking at the thing seen while the other behavior involves looking for the thing seen. When what an organism sees becomes discriminative for reinforcement, the thing seen acquires conditioned reinforcing properties. Later, under similar stimulus conditions and given the appropriate level of deprivation or aversive stimulation, the probability that the organism will begin looking for the thing seen is increased. Quite early in the history of a visually equipped organism, behavior such as looking or scanning comes quickly under the control of extremely frequent and powerful sources of reinforcement. So powerful are these sources of intermittent reinforcement that, in fact, scanning the environment soon becomes a highly regular and permanent feature of the organism's ongoing repertoire of behavior. Moreover, things seen in the periphery of an organism's visual field are often not seen in their entirety. Under these conditions, stimulus generalization most likely ensures that the organism will look toward or scan the area of stimulus impingement.

The above analysis, coupled with the results of the present experiment, strongly suggests that pigeons employed in studies involving an experimental analysis of behavior come to the experimental chamber equipped with a rich repertoire of scanning behavior that is the product of continually prevailing contingencies of reinforcement. In the Robinson and Shelley study (1974, p. 398), these
experimenters point to "various unspecified concurrent reinforcement contingencies" as attenuating the control exerted by the experimentally programmed schedule of reinforcement in a lighted chamber. It is highly probable that these same sources of concurrent reinforcement were responsible for the inferior auditory stimulus control evidenced by light trained as opposed to dark trained subjects during discrimination training. For the light trained subjects, the illuminated experimental chamber provided stimuli that, given the organisms' histories of reinforcement, naturally controlled frequent scanning behavior. In addition, control by visual stimuli could have been enhanced if upon occasion scanning behavior shared a close temporal proximity to scheduled reinforcement produced by a keypeck. The control exerted by these visual stimuli rendered less effective the control exerted by the auditory stimuli. For those subjects performing in a darkened chamber, the opportunity to scan the experimental chamber was virtually eliminated, and thus generated conditions that favored greater auditory stimulus control.
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