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WITHIN-SESSION ANALYSIS OF VISUAL DISCRIMINATION

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Within-session changes in responding by pigeons during a maintained successive discrimination procedure were examined in four experiments. In the first two experiments, which involved discrimination of visual flicker rate, within-session changes in responding were minimal or absent. A third experiment, which examined discrimination of rectangular forms, demonstrated that the absence of within-session changes in responding was not limited to flicker-rate stimuli. A fourth experiment showed that the absence of within-session changes in responding was not due to high task difficulty in the previous experiments. For the group of subjects in each experiment, within-session changes in responding did not influence discrimination performance. Therefore, measures of overall response rate accurately represented responding both within and across sessions. The occasional appearance of within-session decreases in responding for a few birds may be attributable to satiation.

Key words: visual discrimination, within-session responding, dimensional contrast, flicker rate, rectangular form, key peck, pigeon

A number of recent studies have reported the presence of systematic within-session changes in responding (e.g., McSweeney, Hatfield, & Allen, 1990; McSweeney & Hinson, 1992; McSweeney, Roll, & Cannon, 1994). Instead of remaining constant throughout the session, responding may take one of three consistent forms. Responding sometimes increases monotonically during the session. At other times, responding decreases monotonically during the session. And in some cases, responding shows a bitonic profile, first increasing to a peak, then decreasing during the remainder of the session. These within-session changes in responding may be of general importance for studies of conditioning, in that aggregate measures of behavior, such as total-session averages, may misrepresent performance at any given moment in time (McSweeney & Hinson, 1992).

An immediate concern is whether within-session changes in responding are both sufficiently pervasive and of sufficient magnitude to warrant concern. To begin, it is now clear that systematic changes in responding can occur in a wide variety of settings (e.g., McSweeney & Roll, 1993). Moreover, it is equally clear that within-session changes in responding can be of large magnitude (e.g., McSweeney, 1992). Thus, under many circumstances, within-session changes in responding can have a significant impact on estimates of overall performance.

Nonetheless, within-session changes in responding do not appear in all circumstances. Recent studies have shown that if frequency of reinforcement is low or the magnitude of reinforcers is small, within-session changes in responding are minimal or completely absent (Bizo, Bogdanov, & Killeen, 1998; Palya & Walter, 1997). For example, Palya and Walter showed that when the portion of food reinforcers was reduced to a minimum size, within-session changes in responding were eliminated. Similarly, Bizo et al. demonstrated that magnitude of the within-session decline in responding is directly related to amount of the reinforcer ingested and is inversely related to ingestive capacity of the subject. Bizo et al. also explain why some previous studies, such as those by Roll, McSweeney, Johnson, and Weatherly (1996) and Cannon and McSweeney (1995), may have underreported the impact of satiety variables on the decline in responding often seen late in the session. Taken together, these studies provide strong evidence that when variables that contribute to satiety are controlled, there is no significant decline in responding during the experimental session.

Within-session changes in responding are sometimes absent in discrimination training procedures. For example, Hinson and Ten-

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nison (1998) studied discrimination of visual flicker by pigeons, using either two-key concurrent schedules or a discrete-trial matching procedure. When the procedure allowed a continuous measure of choice, no significant changes in response rate occurred within sessions. Moreover, for both continuous and discrete-trial choice, there was no change in the quality of visual discrimination throughout the session, as given by A′, a nonparametric discriminability index derived from signal-detection theory (e.g., Grier, 1971; Macmillan & Creelman, 1996). These results have points of similarity and difference with another study of within-session changes in visual discrimination (McSweeney, Weatherly, & Swindell, 1996). For example, in a delayed matching procedure, these authors found no change in a general accuracy measure, percentage correct. Yet, they still found declines in overall levels of responding during the session that varied inversely with delay interval.

The present studies are intended to clarify our previous failure to find within-session changes in responding. Because our earlier studies were based on choice procedures, in this paper we examine whether similar results are obtained with single-response, successive discrimination procedures. Our first two experiments employed a maintained generalization procedure with flicker-rate stimuli. This procedure allowed us to examine overall responding and the form of a maintained gradient. Two additional experiments looked for within-session changes during discrimination training with visual forms, a stimulus continuum quite different from flicker rate.

EXPERIMENT 1

METHOD

Subjects

Four homing pigeons with varied training histories served as subjects. These pigeons had no prior experience with visual discrimination procedures. The birds were maintained at 80% of their free-feeding weights and were housed in a local vivarium with a 12:12 hr light/dark cycle.

Apparatus

The experiments were carried out in a Gerbrands operant conditioning chamber with internal dimensions of 30 cm by 30 cm by 32 cm. A Gerbrands translucent pecking key was affixed to the front wall about 27 cm above the floor. A 6-W houselight provided diffuse illumination in the chamber. An aperture (5 cm by 4 cm), 15 cm below the key, provided access to a food magazine. Mixed grain presented for 3 s was used as a reinforcer. The experimental chamber was part of a larger soundproofing box, which contained a fan for ventilation and for masking of extraneous noise. Experimental events and data collection were controlled by a dedicated single-board microcomputer in the same room.

Visual stimuli were produced by a standard light-emitting diode (LED), with a peak emission wavelength of 580 nm. The LED was located about 2 cm behind the pecking key. The luminance of the steady LED was approximately 38 cd/m^2. When producing flicker-rate stimuli during the experiment, the duty cycle of the LED was equal on and off.

Procedure

After one session of autoshaping to initiate responding to the key, training for Experiment 1 began. The pigeons were trained on a successive discrimination procedure. One stimulus, designated S−, was signaled by a flicker rate of 53 Hz. Responses during this stimulus were never reinforced by food (i.e., this stimulus was correlated with extinction). Twelve other stimuli, ranging from 52 to 40 Hz, in steps of 1 Hz, were designated S+. Responses during these stimuli were reinforced by a variable-interval (VI) 60-s schedule using intervals based on the progression suggested by Fleshler and Hoffman (1962).

A daily session consisted of 110 consecutive stimulus presentations, with each presentation 30 s in duration. As a result, total session duration was approximately 58 min, including the time taken by reinforcer delivery. During the session, the selection of each consecutive stimulus was determined by a pseudorandom process, with the provision that the probability of selection of S− or S+ on each occasion was .5. Thus the single S− value appeared on about half of the presentations, and the 12 S+ values appeared equally on the other half of presentations. Training was carried out 7 days per week for a total of 21 sessions. Overall response rates appeared

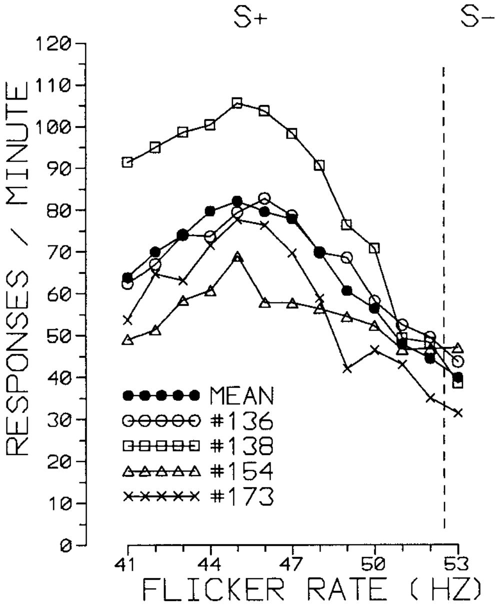

Fig. 1. Mean response rate during each flicker stimulus for the last seven sessions of Experiment 1. Individual functions appear along with the group mean.

to be stable after 14 sessions, as evidenced by small session-by-session changes and no obvious trend across sessions.

RESULTS

Figure 1 provides discrimination gradients for each bird, and the group mean, for the last seven sessions of training. Each curve shows mean response rate during each flicker-rate stimulus. In general terms, the pattern of the gradient is consistent across birds, although there is some variation among birds in absolute rate of responding. Each gradient shows positive dimensional contrast (e.g., Blough, 1975; Hinson & Tennison, 1997). That is, S+ responding was highest during stimuli an intermediate distance from S− along the flicker continuum.

Statistical significance of changes in responding in all of our experiments will be based on Friedman analysis of variance (ANOVA) (see Siegel & Castellan, 1988). This nonparametric ANOVA procedure avoids metric problems that may occur using conventional ANOVA with response rates, and also avoids potential problems that can arise from individual differences in overall rate of responding.

To assess the statistical reliability of response rates in the discrimination gradients of Figure 1, we treat each bird as an independent case, and the bird's response rate during each of the 13 flicker stimuli as a repeated measure. With 4 birds (cases) and 13 stimuli (12 degrees of freedom) in the analysis, the Friedman statistic was $F_r(12, N = 4) = 44.87$, which is significant at $p < .001$. Thus, response rate did change reliably as a function of stimulus.

Figure 2 provides a display of within-session responding. The left panel represents a moving average of responding within the session. During successive 1-min intervals, the mean of responding for the next 5 min was taken until roughly 5 min before the end of the session. This method provides a better indication of momentary variability in responding throughout the session than simply averaging 5-min bins, as is often done (see Hinson & Tennison, 1998; Schaal, 1996). Note that one can still derive 5-min time bins by examining each fifth point along the curve.

In the left panel of Figure 2, S− response rate is plotted along with S+ response rate. For this and later figures, we collapsed responding across all S+ values because we found no important differences in the within-session pattern for different S+ stimuli. The figure includes the group mean response rate and the standard error of the mean (*SEM*) for each point. Inspection reveals a modest trend of increase in response rate during the first few minutes, and a slight trend of decrease later on for both S− and S+ responding. But these mean changes are dwarfed by the group variability across successive minutes. For example, only a few data points in either the S+ function or the S− function differ from one another by as much as 1 *SEM.*

To determine whether any of these changes were significant, we analyzed responding during 11 successive 5-min intervals with a Friedman ANOVA. For S− responding, the obtained value was $F_r(10, N = 4) = 16.05$, $p > .05$, and for S+ responding the value was $F_r(10, N = 4) = 22.91$, $p < .01$. Multiple comparisons for S+ responding by bin showed that responding during the first time bin was reliably lower, $F_r(10, N = 4) = 22.86$, $p < .01$, but that there were no differences among other time bins for S+.

We also carried out multiple comparisons

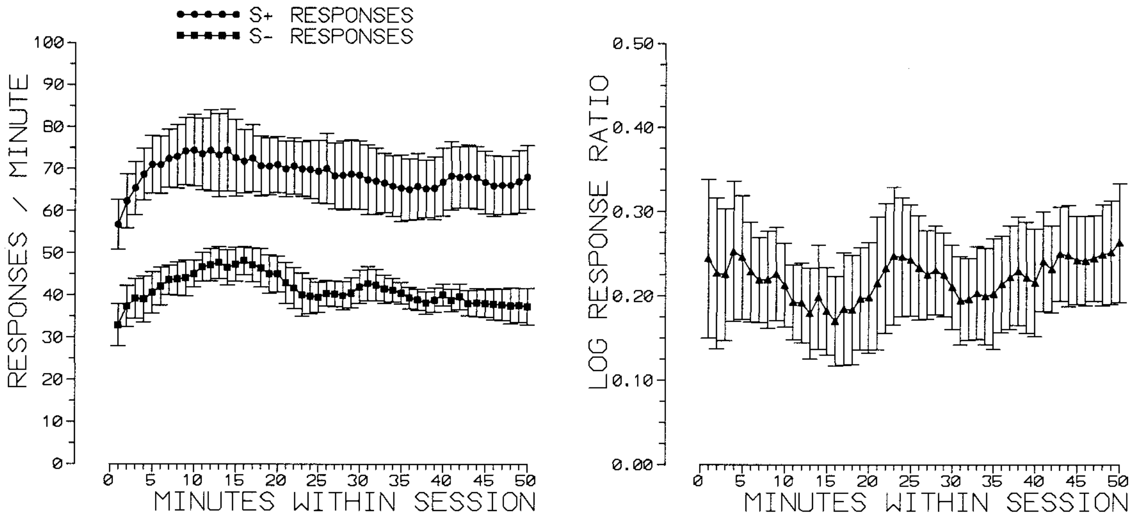

Fig. 2. Moving averages of response rate taken each minute during the first 50 min of the session. Each point is the group mean for 5 consecutive minutes. Error bars are the standard error of the mean. Left panel: response rates for S− (solid squares) and S+ (solid circles). Right panel: logarithm of the ratio of response rate during S+ to response rate during S−.

across the 11 time bins for each of the 13 S+ values to insure that collapsing across the S+ stimuli in our earlier analysis did not hide any significant findings. We found that responding for 52 Hz, the stimulus closest to S−, was significantly lower in the first time bin, $F_r(10, N = 4) = 25.06$, $p < .01$, than in other time bins. There were no other significant differences. Given the large number of comparisons (i.e., 12 stimuli by 11 bins), this result could easily be due to chance variation alone.

The right panel of Figure 2 displays an index of overall discrimination between S+ and S−, namely, the logarithm of the ratio of S+ response rate to S− response rate. Thus, the right panel shows the log ratio of the curves in the left panel, with a mean and *SEM* for each point. There is no obvious systematic change in this measure within the session, a conclusion confirmed by Friedman ANOVA, $F_r(10, N = 4) = 11.13$, $p > .05$.

Figure 3 shows moving averages of response rate during S+ and S− for individual birds. For S+, each bird's curve shows an increase in response rate during the first few minutes of the session and no large change thereafter. Responding during S− was more variable, with 2 birds' curves showing only slight variations in response rate within the session, on the order of about five responses per minute. The remaining 2 birds showed a pattern of responding that was not systematic in any simple way. In summary, the individual results shown in Figure 3 are consistent with the group results shown in Figure 2. There do not appear to be any noteworthy individual differences among birds on this procedure.

Relative response measures sometimes provide results different from absolute measures (see Bizo et al., 1998). To explore this possible difference, we examined responding within sessions using a measure based on the proportion of responding within each session for each bird. For each of the 13 flicker stimuli, we calculated the proportion of total responding that occurred during 11 consecutive 5-min time bins. Thus, for each stimulus, the sum across the 11 time bins would equal 1. This normalization procedure was designed to compensate for the differences in absolute response rate among different flicker stimuli that could conceivably mask within-session changes. After normalizing responding for each stimulus, we computed the mean proportion across all stimuli. The left panel of Figure 4 provides the results from this analysis. Each point is the mean proportion of responding obtained during each of 11 time bins, along with the SEM for the group. Inspection reveals that these normalized response rates show no trend within sessions.

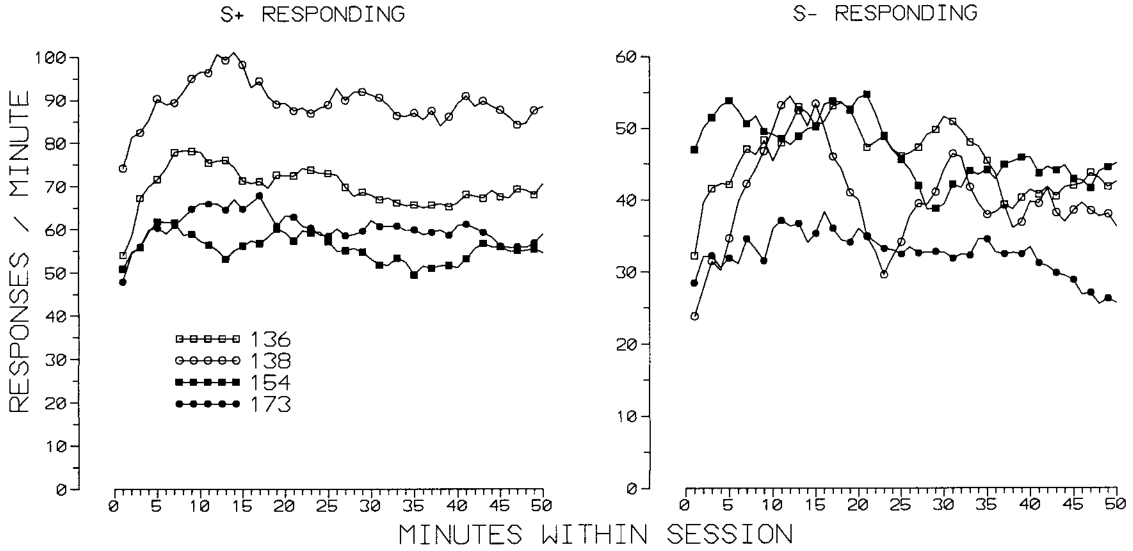

Fig. 3. Moving averages for the individual subjects in Experiment 1. Left panel: response rate during S+. Right panel: response rate during S−.

Thus, the stability of responding within a session is observed with both absolute and relative response measures.

The right panel of Figure 4 examines the amount of variation in the shape of the discrimination gradient attributable to changes in responding within a session. Once again, we used the proportion of total responding

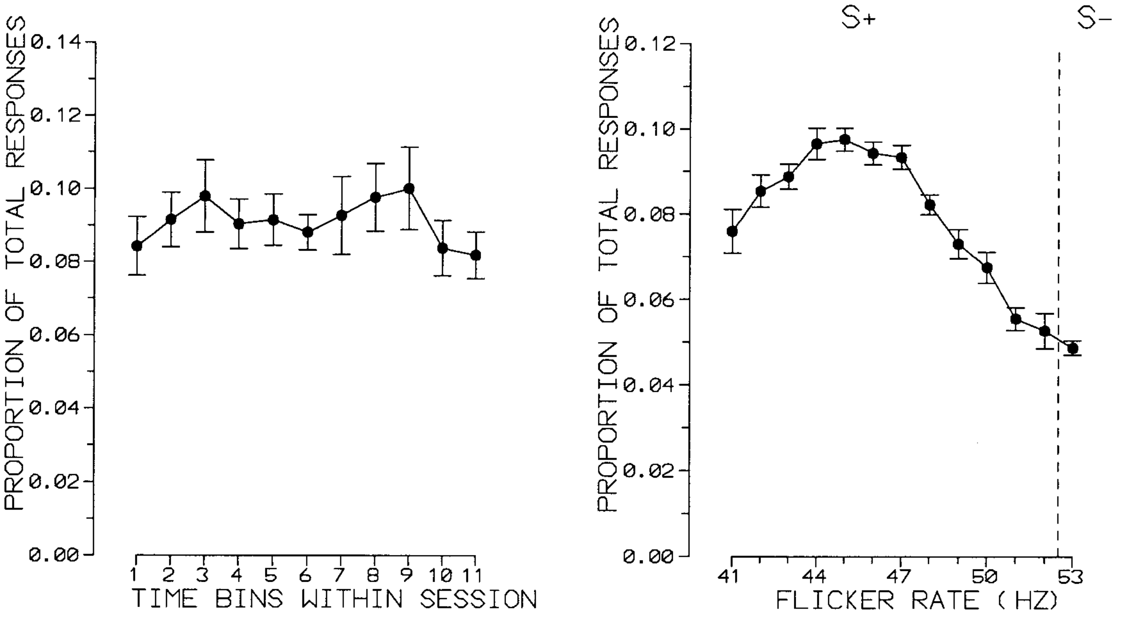

Fig. 4. Left panel: mean normalized response rate during consecutive 5-min time bins within the session. Each point is the mean proportion of responding averaged across all stimuli within the time bin. Error bars are the standard error of the mean. Right panel: relative responding during each stimulus. Each point is the mean proportion of responding to each stimulus averaged across the 5-min time bins within session. Error bars are the standard error of the mean.

during each session for each bird to normalize response rates. We calculated for each of 13 stimuli the proportion of responding within each of 11 consecutive 5-min time bins. The figure shows the mean of these proportions taken across all time bins. However, the focus of the right panel is the error bars showing the *SEM* for the proportion of responding across all time bins. The error bars show the total variability in responding across time bins. Hence, if there was great variability in responding to specific stimuli within the session, these error bars should be large. To the contrary, the right panel shows small error bars for all stimuli. Our conclusion is that the form of the discrimination gradient was consistent throughout the session.

DISCUSSION

The results from Experiment 1 using a successive discrimination procedure are consistent with our earlier findings using choice procedures (Hinson & Tennison, 1998). There was a small increase in responding during the first few minutes of S+ responding, but S− responding did not change significantly within a session. Further, there were no indications of changes in discrimination between S− and S+ during the session, based on either an aggregate measure of S+ responding or a measure of the shape of the discrimination gradient. Thus, there was little impact of time within session on responding in this experiment.

EXPERIMENT 2

For Experiment 2, there were some procedural changes intended to enhance within-session changes in responding. First, we changed from VI to fixed-interval (FI) reinforcement. Previous findings indicate enhanced within-session changes with an FI contingency compared to a VI contingency (e.g., McSweeney, Roll, & Weatherly, 1994). Second, we increased the overall rate of reinforcement, a manipulation known to augment changes in within-session responding (e.g., McSweeney & Hinson, 1992). Third, more birds were included in Experiment 2 in case the small group size in Experiment 1 provided insufficient statistical power and thereby obscured detection of within-session changes.

In addition, Experiment 2 compared an operant contingency, in which responding was required for reinforcement, with a Pavlovian contingency, in which reinforcement was delivered independently of responding. Previous work has reported similar within-session changes in responding for these contingencies (e.g., McSweeney, Swindell, & Weatherly, 1996). We also extended the range of flicker-rate stimuli used for training. Perhaps with a broader range of stimuli, we may be able to detect differences in within-session responding that were not evident with a narrower range of difficult-to-discriminate stimuli.

METHOD

Subjects

Nine homing pigeons served as subjects. Three birds were experimentally naive, 3 birds had limited experience with simple schedules of reinforcement, and the remaining 3 birds had a variety of training experiences. None of the birds had prior experience with visual flicker-rate discrimination tasks. The birds were maintained at 80% of their free-feeding weights and housed in a local vivarium with a 12:12 hr light/dark cycle.

Apparatus

The experiments were carried out in a Campden Instruments three-key operant conditioning chamber. The internal dimensions of the chamber were 35 cm by 35 cm by 33 cm. The center pecking key was 2.72 cm in diameter, and was located 27.5 cm from the floor and about 17 cm from either side. The two side keys, which were not used, were covered with black tape. A 6-W houselight provided diffuse illumination throughout the chamber during experimental sessions. An aperture (5 cm by 6 cm), located in the middle of the front panel 13.5 cm from the floor, provided access to the food magazine. Mixed grain presented for 3 s was used as a reinforcer. The experimental chamber was part of a larger soundproofing box, which contained a fan for ventilation and for masking of extraneous noise. Experimental events and data collection were controlled by a dedicated microcomputer.

Discrimination training was based on visual stimuli that differed in flicker rate. The stimuli were produced by an LED like that used in Experiment 1. The LED was located 2 cm behind the center pecking key. The luminance of the steady LED was approximately 38 cd/m^2. Duty cycle of the flickering LED was equal on and off.

Procedure

The pigeons were trained on a successive discrimination procedure similar to that used in Experiment 1. One stimulus, designated S−, was signaled by a flicker rate of 53 Hz. Twelve other stimuli, designated S+, were signaled by flicker rates ranging from 50 to 17 Hz, in 3-Hz steps.

Three different training conditions were employed. In the operant condition, responses during S− and S+ were reinforced according to a probabilistic FI 20-s schedule. For S+, the first response after 20 s always resulted in 3-s access to grain. For S−, the first response after 20 s produced 3-s access to food on approximately 3% of occasions. On the other 97% of occasions, the first response after 20 s produced a 3-s interval with no food and with the houselight and LED turned off. Note that in this condition, responding was required during all stimuli to end the current presentation and move on to the next stimulus. Because this experiment compared operant and Pavlovian conditions, we wanted the response and temporal contingencies for S− and S+ presentation to be as similar as possible in each condition. Thus, for both S− and S+, stimulus presentations and transitions to the next stimulus were response dependent, rather than S− presentations being response independent.

In the Pavlovian condition, reinforcers were delivered during S− and S+ exactly as in the operant condition, with the exception that no response was required to end the current presentation and proceed to the next. Each stimulus presentation ended after 20 s with food or blackout, as appropriate, and was then followed by the next stimulus presentation, regardless of responding.

In the brief Pavlovian condition, the contingencies were exactly like those in the Pavlovian condition, with the single exception that each stimulus presentation was 5 s in duration rather than 20 s.

The group of 9 birds was subdivided into three equal groups. These three groups received counterbalanced orders of the three training conditions. Each training condition consisted of 14 daily sessions, with 120 20-s (or 5-s) stimulus presentations during each session. Session duration averaged about 44 min for the operant condition, 43 min for the Pavlovian condition, and about 13 min for the brief Pavlovian condition, including time taken by reinforcer delivery. Responding appeared to be stable after seven sessions. As in Experiment 1, the probability of stimulus selection during each session was .5 for either S− or S+.

RESULTS

Figure 5 shows mean discrimination gradients taken over the last seven sessions for operant and Pavlovian conditions. Rather than plotting nine overlapping individual functions in the graph, only a group mean function and *SEM* for each point are presented. Response rates during the brief Pavlovian condition were too low for analysis, so this condition will not be discussed further.

The left panel of Figure 5 shows the familiar positive dimensional contrast profile for the operant condition, and the right panel shows a similar function for the Pavlovian condition. The general form of the gradient is highly similar between the two conditions, with the major differences being higher overall responding for the operant condition and higher variability among subjects in the Pavlovian condition. A Friedman ANOVA for the operant condition, $F_r(12, N = 9) = 65.42$, $p < .001$, and the Pavlovian condition, $F_r(12, N = 9) = 33.16$, $p < .001$, confirms that response rate changed significantly as a function of flicker stimulus.

Figure 6 displays moving averages for the operant condition comparable to those provided in Figure 2. Responding for both S− and S+ did not change systematically within the session for the group of birds. A Friedman ANOVA based on response rate during eight consecutive 5-min time bins revealed no significant differences, in that S− responding yielded $F_r(7, N = 9) = 6.67$, $p > .05$, and S+ responding yielded $F_r(7, N = 9) = 6.41$, $p > .05$. Moreover, there was no significant change in the log response ratio discrimination measure across the time bins, $F_r(7, N = 9) = 7.74$, $p > .05$. Multiple comparisons between all individual stimuli across time bins

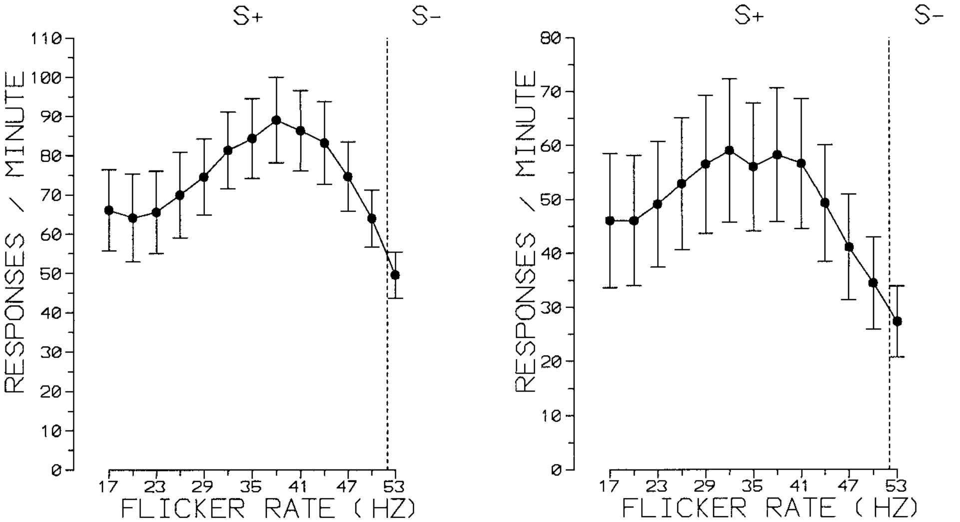

Fig. 5. Mean response rate during each flicker stimulus for the last seven sessions of Experiment 2. Left panel: results for the operant condition. Right panel: results for the Pavlovian condition. Error bars are the standard error of the mean.

revealed no significant differences in responding.

Figure 7 displays moving averages of response rates for individual birds in the operant condition. Curves for the 9 birds are divided into upper and lower panels so the individual functions are easier to distinguish. With the exception of 1 bird whose curve shows a novel cyclic pattern, there were only small changes within sessions for S+ responding. The major difference among birds is in absolute rate of responding rather than within-session pattern. Responding during S− was more variable. Two birds' curves show a consistent increase in responding during S−. The remaining 7 birds' curves show unsystematic variability. As in Experiment 1, the group mean is a good representation for the

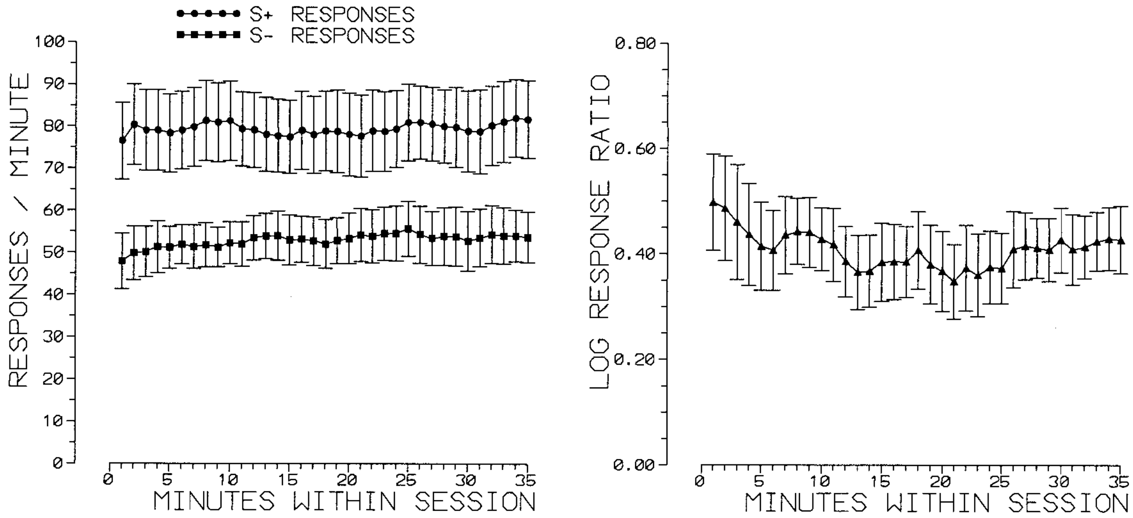

Fig. 6. Moving averages of response rate taken each minute during the first 50 min of the session for the operant condition of Experiment 2. Each point is the group mean for 5 consecutive minutes. Error bars are the standard error of the mean. Left panel: response rates for S− (solid squares) and S+ (solid circles). Right panel: logarithm of the ratio of response rate during S+ to response rate during S−.

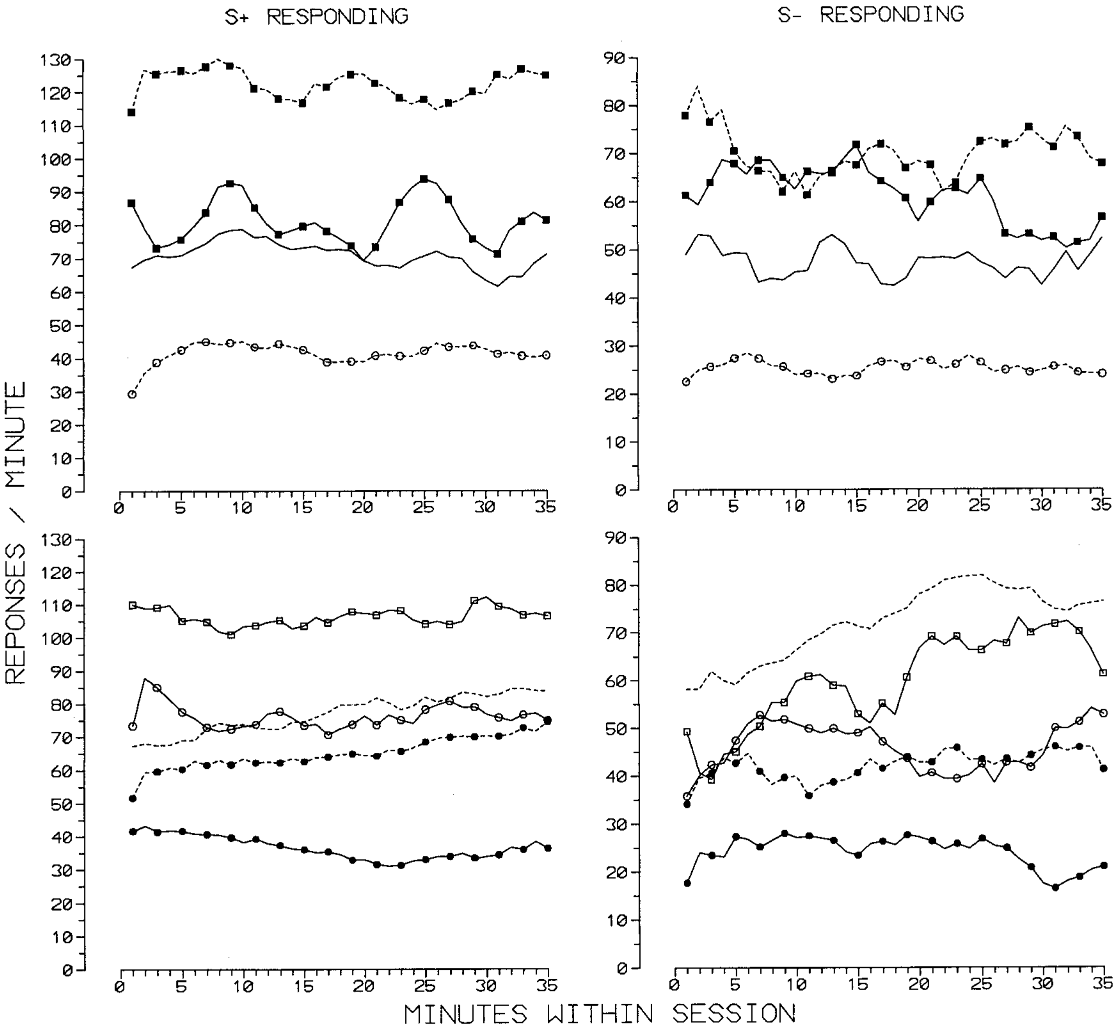

Fig. 7. Moving averages for the individual subjects in the operant condition of Experiment 2. Left panel: response rate during S+. Right panel: response rate during S−.

individuals in the operant condition of Experiment 2.

Figure 8 provides mean moving averages for the Pavlovian condition. There was no obvious group trend for mean S+ or S− response rate within a session, as shown in the left panel, although *SEM*s are greater in the Pavlovian condition. The right panel shows lower overall discrimination and greater variability in the Pavlovian condition compared with the operant condition. A Friedman ANOVA based on responding during eight consecutive 5-min time bins indicates no significant differences for either S− response rate, $F_r(7, N = 9) = 5.29$, $p > .05$, or S+ response rate, $F_r(7, N = 9) = 4.70$, $p > .05$. Also, the log discrimination ratio did not change significantly across time bins, $F_r(7, N = 9) = 6.23$, $p > .05$. As in the operant condition, multiple comparisons between all individual stimuli across time bins revealed no significant differences in responding.

Figure 9 provides moving averages of response rates for individual subjects in the Pavlovian condition. For 3 birds, S+ response rate increased during the first few minutes of the session, whereas for 1 bird response rate increased during the last few minutes. Otherwise, S+ response rate was quite stable throughout the session. And as in the operant

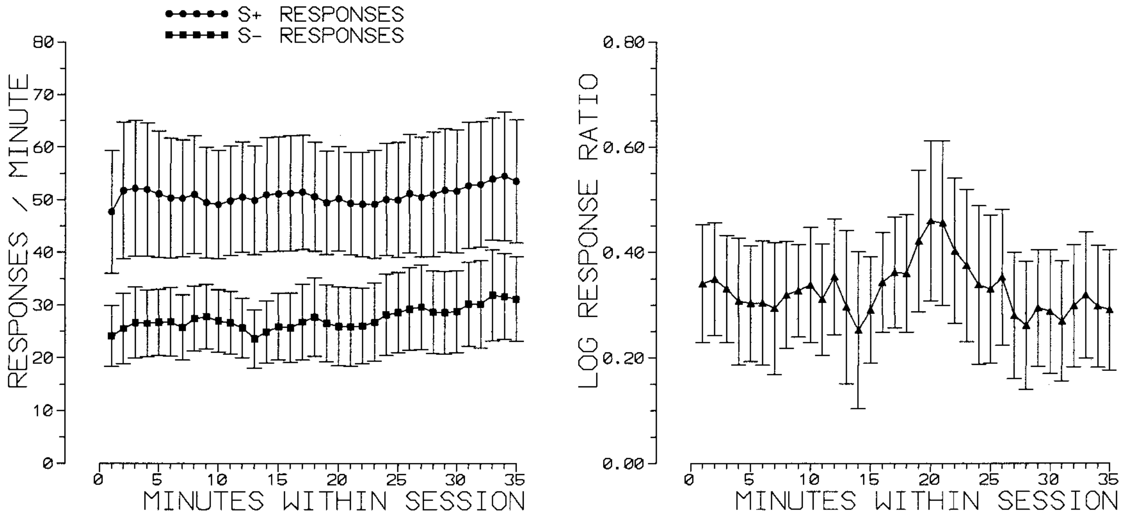

Fig. 8. Moving averages of response rate taken each minute during the first 50 min of the session for the Pavlovian condition of Experiment 2. Each point is the group mean for 5 consecutive minutes. Error bars are the standard error of the mean. Left panel: response rates for S− (solid squares) and S+ (solid circles). Right panel: logarithm of the ratio of response rate during S+ to response rate during S−.

condition, responding among individuals was much more variable during S−. In two cases S− rate increased during the session, whereas in three other cases rate fluctuated in cycles of increase and decrease. Examining the functions for S+ and S− for each bird, there was no consistent change in responding over time. Sometimes S− response rate increased as S+ decreased, and sometimes S+ response rate increased as S− decreased. In summary, there were individual differences among birds, but these differences do not allow us to put the birds into distinct groups. Therefore, the mean function is a reasonable description of the whole set of performances.

Figure 10 displays results for relative response rates, comparable to those in Figure 4, for the operant condition of Experiment 2. The left panel shows that relative responding was steady across time bins. The right panel shows that the maintained discrimination gradient was consistent across time bins.

Figure 11 provides results for relative response rates for the Pavlovian condition of Experiment 2. As shown in the left panel, relative responding was consistent across time bins, although it was slightly lower in the first 5-min bin. As shown in the right panel, responding to each stimulus was fairly consistent regardless of time within session. Overall variability was lowest for the S+ and the S− that were most similar to one another. In general terms, measures of relative responding within a session were similar for operant and Pavlovian contingencies.

DISCUSSION

Experiment 2 confirms that responding does not change significantly within a session for either a response-dependent or response-independent training procedure. The only noteworthy differences appear to be the higher overall response rate in the operant condition, in which responding was required, and greater variability in responding among subjects in the Pavlovian condition, in which responding was not required. Increasing the rate of reinforcement, and changing the reinforcement contingency from VI to FI did not enhance within-session changes in responding, in terms of either absolute or relative response rates. Although differences in responding among subjects did appear, these differences were not large enough or clear enough to allow us to identify subgroups of birds controlled by separate variables. The group mean function appeared to be an adequate summary for each bird.

Thus far, our failures to find within-session changes in responding during discrimination training have been confined to a stimulus continuum based on flicker rate. It is con-

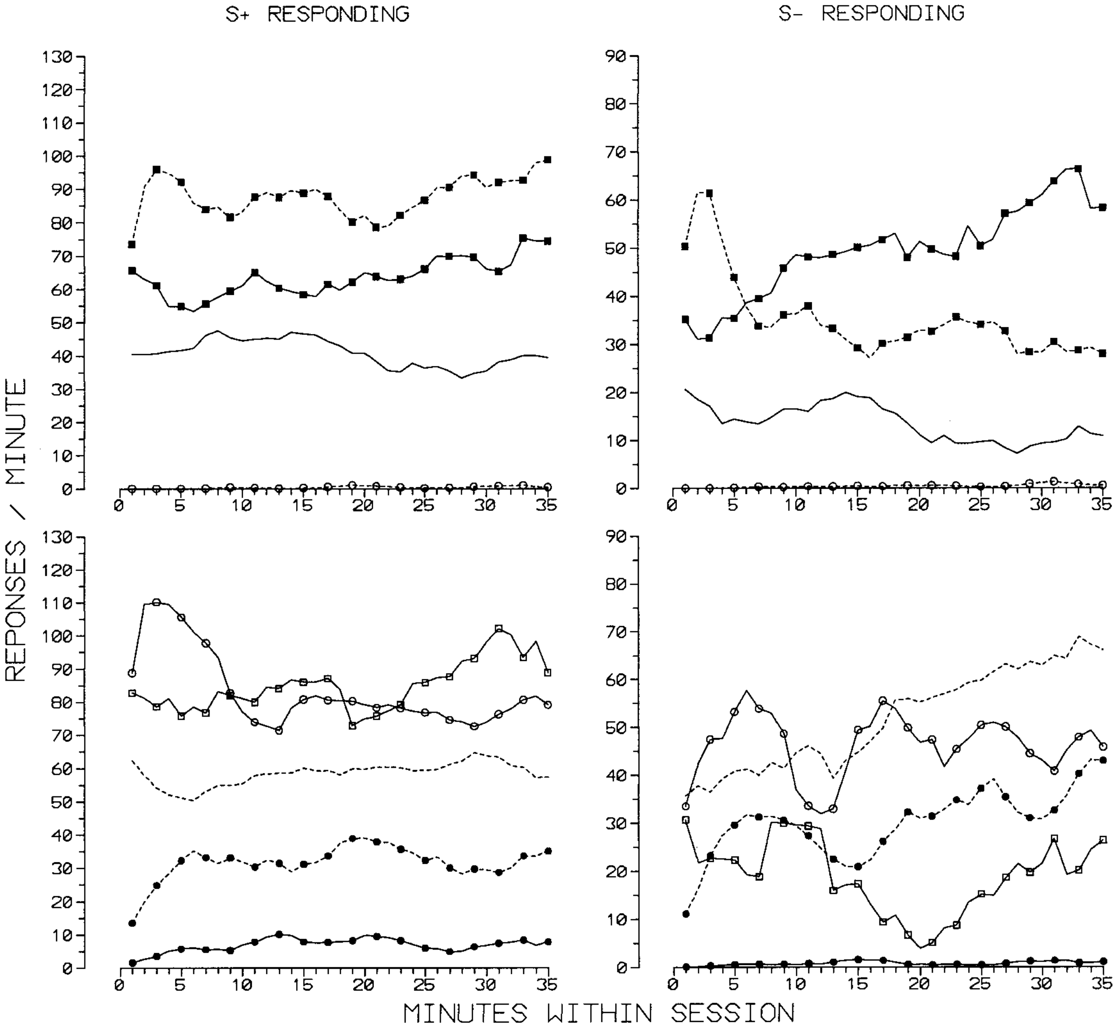

Fig. 9. Moving averages for the individual subjects in the Pavlovian condition of Experiment 2. Left panel: response rate during S+. Right panel: response rate during S−.

ceivable that some unknown property of flicker stimuli prevents the occurrence of systematic within-session changes in responding. Experiment 3 explored this possibility by examining discrimination training based on a visual form continuum (see Hinson, Cannon, & Tennison, 1999).

EXPERIMENT 3

METHOD

Subjects

Four homing pigeons with varied training histories served as subjects. None of these served in Experiments 1 and 2, and none had previous experience with visual form discrimination. The birds were maintained at 80% of their free-feeding weights, and were housed in a local vivarium with a 12:12 hr light/dark cycle.

Apparatus

The experiments were carried out in a Campden Instruments three-key operant conditioning chamber with internal dimensions and properties identical to the apparatus used in Experiment 2 except for the center key. In the present experiment, the center key was made of clear Plexiglas and provided

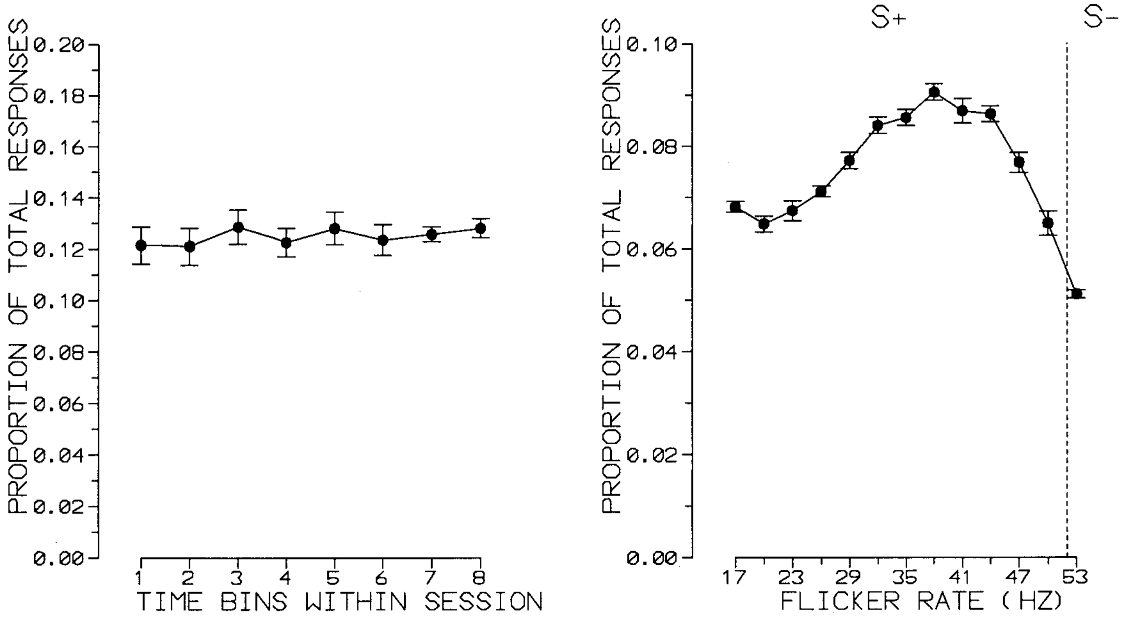

Fig. 10. Left panel: mean normalized response rate during consecutive 5-min time bins within the session. Each point is the mean proportion of responding averaged across all stimuli within the time bin. Error bars are the standard error of the mean. Right panel: relative responding during each stimulus across 5-min time bins within the session. Each point is the mean proportion of responding to each stimulus averaged across 5-min time bins within the session. Error bars are the standard error of the mean.

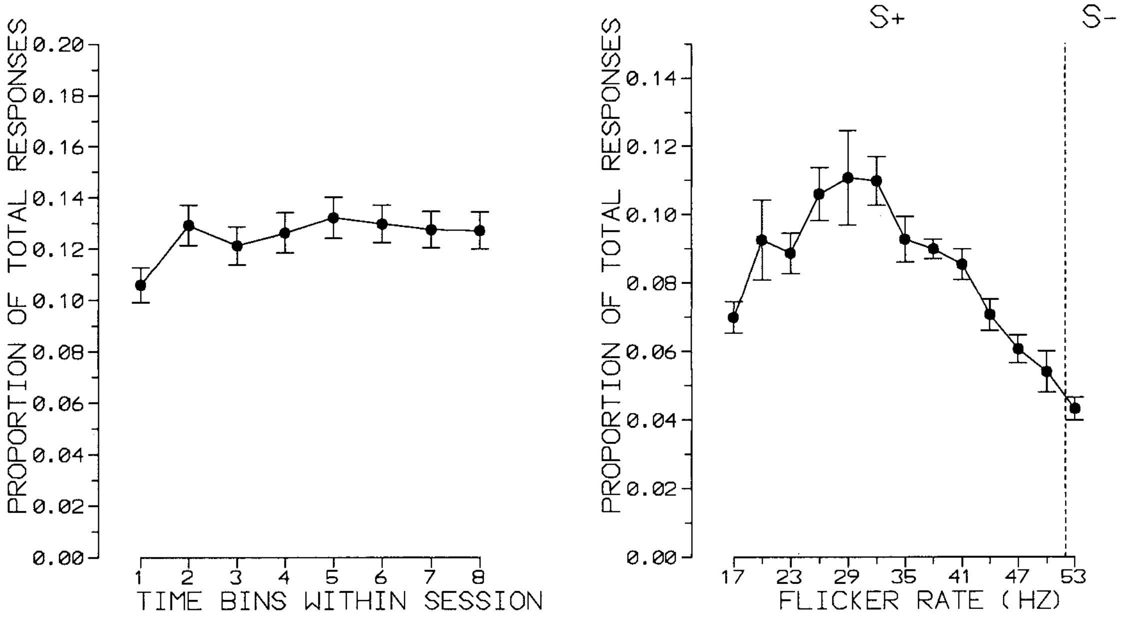

Fig. 11. Left panel: mean normalized response rate during consecutive 5-min time bins within the session. Each point is the mean proportion of responding averaged across all stimuli within the time bin. Error bars are the standard error of the mean. Right panel: relative responding during each stimulus. Each point is the mean proportion of responding to each stimulus averaged across the 5-min time bins within the session. Error bars are the standard error of the mean.

a circular viewing region with a diameter of approximately 4 cm. Mixed grain presented for 3 s was used as a reinforcer.

An IBM XT-type computer controlled real-time contingencies during the experiment and collected all data. Stimuli were displayed on an attached monochrome monitor. The 14-in. monitor had a dot pitch of 0.39 mm with a resolution of 640 × 480 pixels at a 60-Hz refresh rate. All stimuli were drawn from lines 1 pixel wide and appeared in a yellow phosphor. A double lens assembly projected the screen image to the response key. Inspection of the stimuli by the experimenters indicated that the projected form appeared in a totally black background. To the human eye the form looked to be slightly behind the response key, although there were no other strong indications of depth. Movement of viewing position several inches vertically and horizontally had no obvious impact on the quality of the stimulus as it appeared on the key. Size measurements of the stimuli were made on the front of the key.

Procedure

After a single session of autoshaping in the chamber to initiate responding to the key, training began. The birds were trained to discriminate stimuli based on width of a rectangular form. One stimulus was designated S−, and six other stimuli were designated S+. S− was signaled by a rectangular form 8 mm high and 10 mm wide. The six S+ values were rectangles (8 mm high) that were 14, 18, 22, 26, 30, and 34 mm wide.

Responses during S− and S+ were reinforced according to a probabilistic FI 20-s schedule, identical to that used in the operant condition of Experiment 2. For S+, the first response occurring at least 20 s after the onset of the visual stimulus always resulted in 3-s access to mixed grain. For S−, the first response occurring at least 20 s after the onset of the visual stimulus produced food reinforcement on 3% of the presentations. On the other 97% of presentations of S−, a 3-s interval with the houselight off was provided instead of 3-s access to food. Note, once again, that the FI contingency employed in this task required responding to end each stimulus presentation and allow the next to commence.

There were 120 20-s stimulus presentations during each session. Session duration averaged about 44 min, including time taken by reinforcer delivery. The sequence of stimuli was determined by a pseudorandom process, with a .5 probability of selecting either S− or S+. Each bird received 14 sessions conducted once per day, 6 or 7 days per week. Responding appeared to be stable after seven sessions.

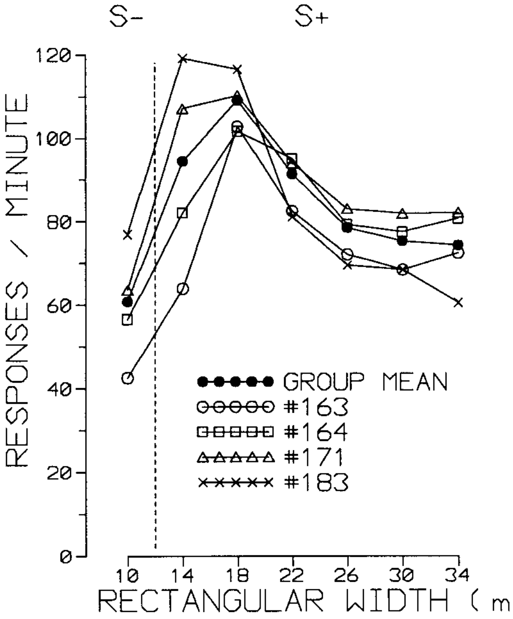

Fig. 12. Mean response rate during each rectangular form stimulus for the last seven sessions of Experiment 3. Individual functions appear along with the group mean.

RESULTS

Figure 12 provides discrimination gradients for each subject and the group mean, averaged over the last seven sessions of training. Each gradient shows the familiar positive dimensional contrast effect. The main difference among birds is the level of discrimination between S− and the S+ that was most similar to the S− in width. Changes in response rate across stimuli were significant by Friedman ANOVA, $F_r(6, N = 4) = 14.51$, $p < .05$.

The left panel of Figure 13 displays moving averages for S− and S+ response rates. Although there is an indication of an increase in response rate during the first few minutes, this increase was well within the range of variability throughout the session. A Friedman ANOVA for responding during eight consec-

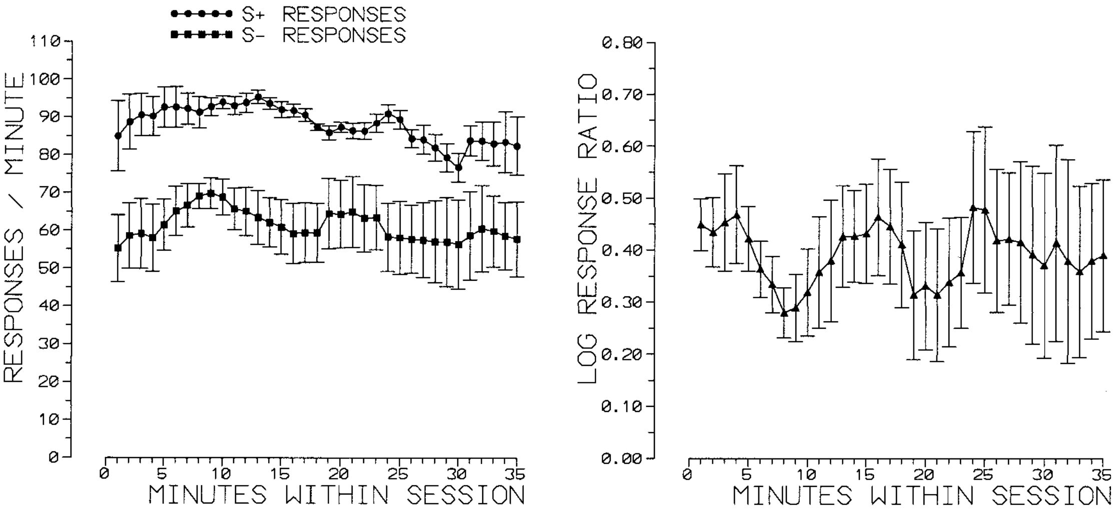

Fig. 13. Moving averages of response rate taken each minute during the first 50 min of the session for Experiment 3. Each point is the group mean for 5 consecutive minutes. Error bars are the standard error of the mean. Left panel: response rates for S− (solid squares) and S+ (solid circles). Right panel: logarithm of the ratio of response rate during S+ to response rate during S−.

utive 5-min intervals revealed no significant changes within the session for either S−, $F_r(7, N = 4) = 7.67$, $p > .05$, or S+, $F_r(7, N = 4) = 11.58$, $p > .05$. The right panel provides the moving average of the log response ratio between S+ and S−. Although there was considerable variability across time, there was no systematic or reliable change within the session, $F_r(7, N = 4) = 6.0$, $p > .05$.

Figure 14 provides moving averages of response rate within the session for the individual birds. For S+ responding, the greatest variability among subjects was in the first and last few minutes of the session. As in the earlier experiments, there was greater variability in S− responding. Among the group, the clearest pattern is for 1 bird (163) with a consistent decrease in responding within the ses-

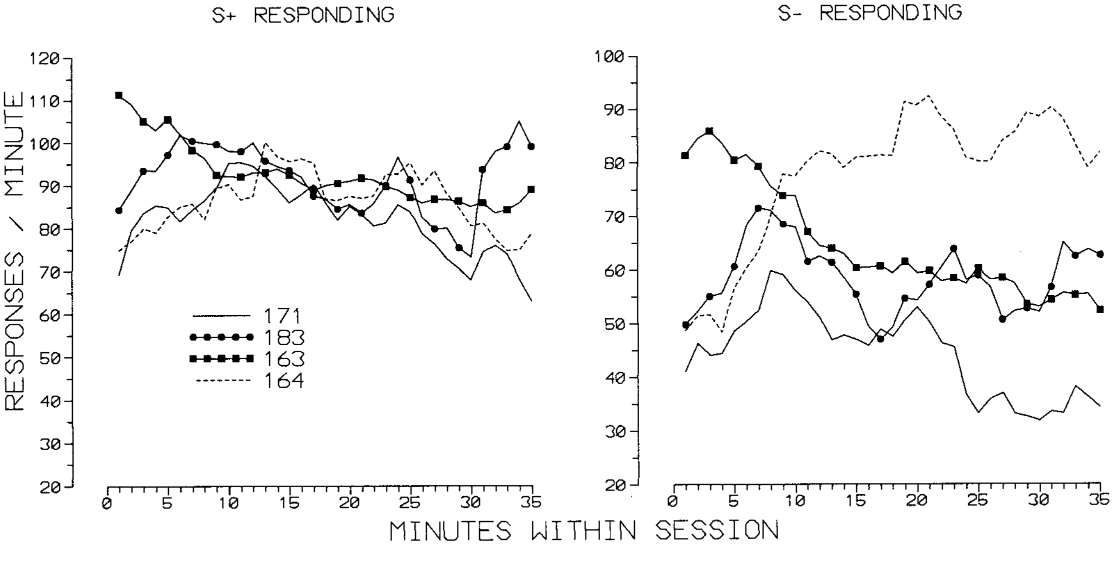

Fig. 14. Moving averages for individual subjects in Experiment 3. Left panel: response rate during S+. Right panel: response rate during S−.

sion during both S− and S+. For this bird, response rate for both S+ and S− declined by over 20 responses per minute from the beginning to the end of the session. Later on we will discuss a possible explanation of the pattern for this bird. In summary, despite some differences among individuals in responding within a session, overall discrimination performance, shown in Figure 12, was fairly similar for all birds.

The left panel of Figure 15 gives the mean of the normalized response rates across time bins within the session. The profile reveals that there was no systematic increase or decrease in responding. The right panel shows the variability in gradient form across time bins within the session. Once again, gradient form was highly consistent throughout the session.

DISCUSSION

Changing training stimuli from flicker rates to rectangular forms did not have a measurable impact on within-session responding. The pattern of results in Experiment 3 was similar to results obtained in Experiments 1 and 2, in that responding did not change significantly within the session. For the group of birds in Experiment 3, there was no reliable systematic change in absolute rate, relative rate, or change in the form of the discrimination gradient. Thus, the absence of within-session changes in Experiments 1 and 2 cannot be attributed to properties of the flicker-rate continuum.

Given that the stimulus continuum is not crucial, it is possible that the overall difficulty of the discrimination has an impact on within-session changes in responding. For instance, all three of the experiments discussed thus far involved stimuli that are difficult to discriminate. Perhaps if an easier discrimination were used, like that used by McSweeney, Swindell, and Weatherly (1996), within-session changes in responding might appear. Experiment 4 provides a direct comparison of a fairly difficult discrimination, like those in Experiments 1, 2, and 3, and a fairly easy discrimination.

EXPERIMENT 4

METHOD

Subjects and Apparatus

Eight homing pigeons with varied training histories served as subjects. Two of the birds had been subjects in Experiment 2. None of these birds had previous experience with visual form discrimination tasks. The birds were maintained at 80% of their free-feeding weights, and were housed in a local vivarium with a 12:12 hr light/dark cycle.

The experiments were carried out in the apparatus used in Experiment 3.

Procedure

After preliminary autoshaping in the chamber to initiate responding to the key, training began. The 8 birds were divided into two equal groups. One group, designated *10 stimulus,* received training with five S− values and five S+ values distributed along the continuum of rectangular width. For the 10-stimulus group, all stimuli were 8 mm high. The five S− values were 10, 13, 16, 19, and 22 mm wide. The five S+ values were 25, 28, 31, 34, and 37 mm wide. The other group, designated *two stimulus,* received training with one S− and one S+ along the width continuum. Both stimuli were 8 mm high. The S− was 10 mm wide, and the S+ was 37 mm wide. Thus, the two-stimulus condition provided training with the extremes of the width continuum used in the 10-stimulus condition.

Responses during S+ were reinforced according to an FI 20-s schedule, and S− responses appeared in extinction. There were 120 stimulus presentations, each 20 s in duration, for each session. For both groups, the sequence of stimuli was randomly determined, with a .5 probability of selecting either S− or S+ on a given presentation. Session duration averaged about 43 min, including time taken by reinforcer delivery. The birds in each group received 14 daily sessions. Responding appeared to be stable after seven sessions.

RESULTS AND DISCUSSION

Figure 16 shows mean response rate during each stimulus for each bird and the group mean. Taking into account some individual differences in overall response rate, the resulting discrimination functions are consistent among birds in each group. The discrimination gradient for the 10-stimulus group was monotonic, and therefore does not show the enhancements characteristic of dimensional contrast (see Blough, 1975). The extreme stimuli along the width continuum ap-

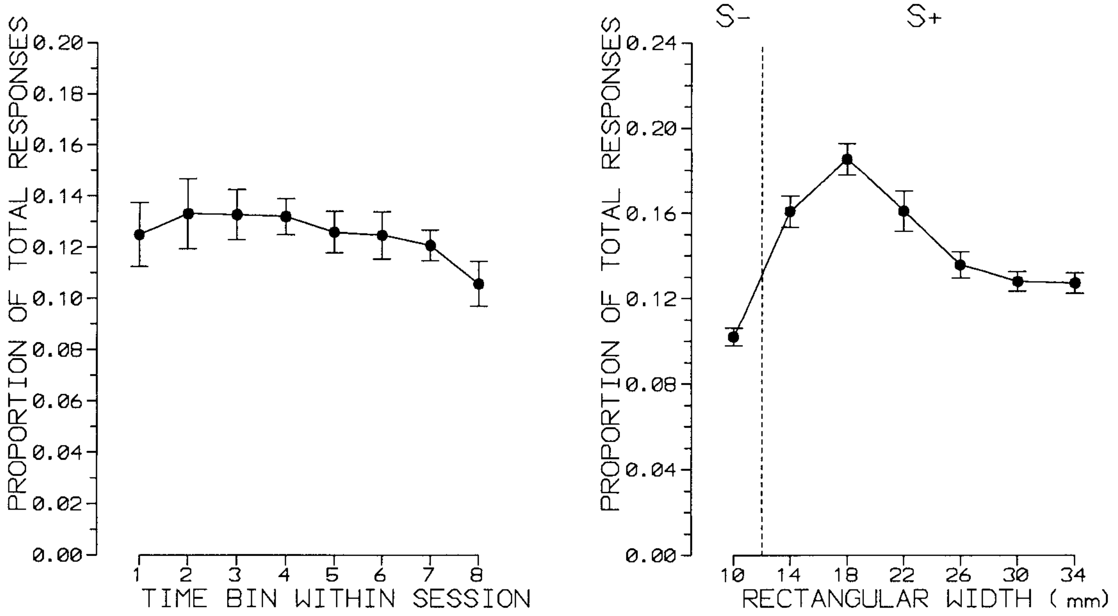

Fig. 15. Left panel: mean normalized response rate during consecutive 5-min time bins within the session during Experiment 3. Each point is the mean proportion of responding averaged across all stimuli within the time bin. Error bars are the standard error of the mean. Right panel: relative responding during each stimulus. Each point is the mean proportion of responding to each stimulus averaged across the 5-min time bins within the session. Error bars are the standard error of the mean.

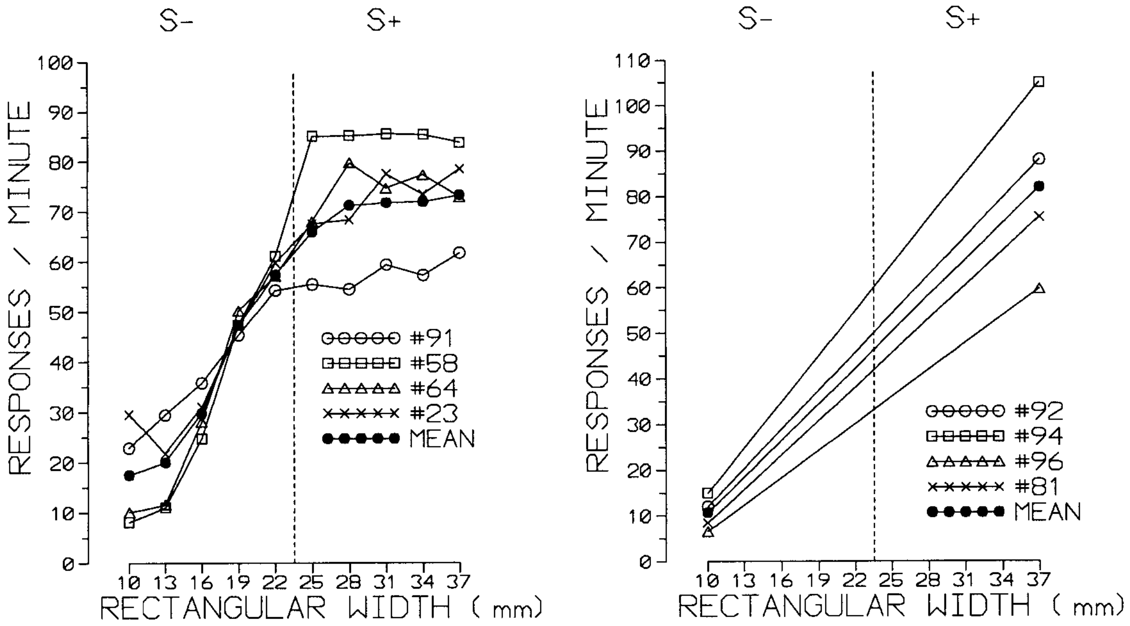

Fig. 16. Mean response rate during each rectangular form stimulus for the last seven sessions of Experiment 4. Left panel: results for the 10-stimulus group. Right panel: results for the two-stimulus group. Each panel contains individual and mean functions.

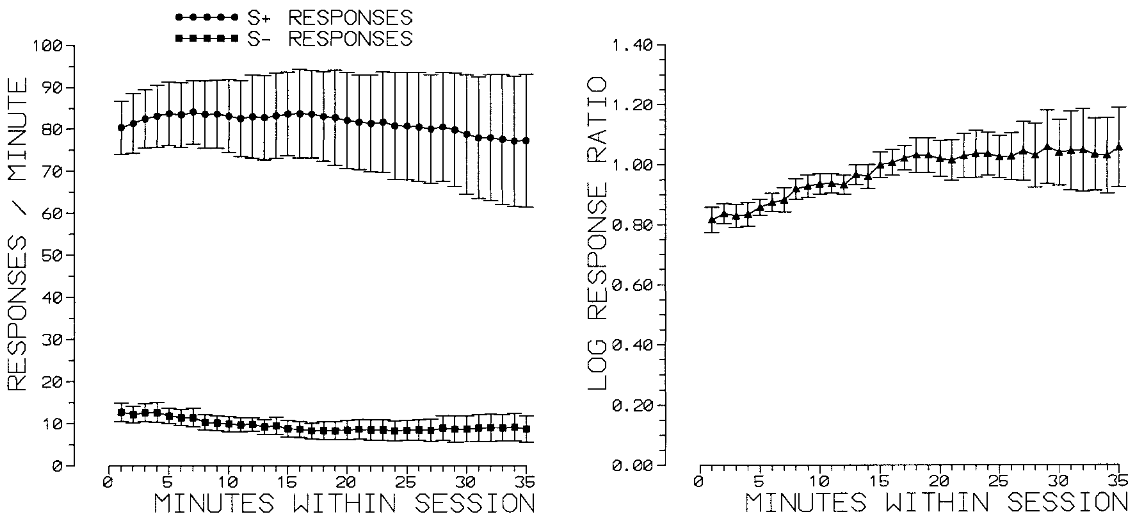

Fig. 17. Moving averages of response rate taken each minute during the first 50 min of the session for the two-stimulus group in Experiment 4. Each point is the group mean for 5 consecutive minutes. Error bars are the standard error of the mean. Left panel: response rates for S− (solid squares) and S+ (solid circles). Right panel: logarithm of the ratio of response rate during S+ to response rate during S−.

pear to have been somewhat better discriminated by the two-stimulus group. Responding changed significantly as a function of stimulus for both the 10-stimulus group, $F_r(9, N = 4) = 33.38$, $p < .001$, and the two-stimulus group, $F_r(2, N = 4) = 4.0$, $p < .05$.

The left panel of Figure 17 provides moving averages of response rate for S+ and S− for the two-stimulus group. Response rates for S+ and S− were stable with no obvious change within the session. A Friedman ANOVA, based on responding during eight consecutive 5-min time bins, revealed no significant change for either S− responding, $F_r(7, N = 4) = 11.67$, $p > .05$, or S+ responding $F_r(7, N = 4) = 2.33$, $p > .05$. The right panel shows that the group mean discrimination ratio tended to increase. Nevertheless, this trend was not statistically reliable, $F_r(7, N = 4) = 11.58$, $p > .05$.

Figure 18 provides moving averages of responding within the session for the 10-stimulus group. To make the comparison with the two-stimulus group more direct, this figure shows responding only during the two extreme values of S− and S+. Compared with Figure 17, the left panel of Figure 18 shows a modest decline in mean response rate for S+ during the session. But a Friedman ANOVA indicated no statistically significant change in responding during the session for either S−, $F_r(7, N = 4) = 12.27$, $p > .05$, or S+, $F_r(7, N = 4) = 7.58$, $p > .05$. The moving average for the discrimination ratio, in the right panel of Figure 18, is slightly lower than for the two-stimulus group. But there was no reliable change in the ratio across time within the session, $F_r(7, N = 4) = 13.25$, $p > .05$. Comparing Figures 17 and 18, there was no apparent influence of task discrimination difficulty on within-session changes.

Figure 19 provides individual moving averages for the two-stimulus group. For 3 birds, S+ responding was quite steady throughout the session. However, for 1 bird (96) there was a large and consistent decline in S+ response rate across the session. Moreover, response rate during S− also declined steadily for this bird. Figure 20 shows individual moving averages for the 10-stimulus group. In this case, the curves for 2 of the birds show consistent declines in S+ responding during the session, although S− responding declined consistently for only 1 of the 2 birds.

For the 13 birds in the first two experiments, there were hardly any noteworthy changes in responding within the session. But in Experiment 3, the response rate of 1 of the 4 birds clearly declined during the session, and in Experiment 4, the response rates of 3 of the 8 birds declined. If a discrimination

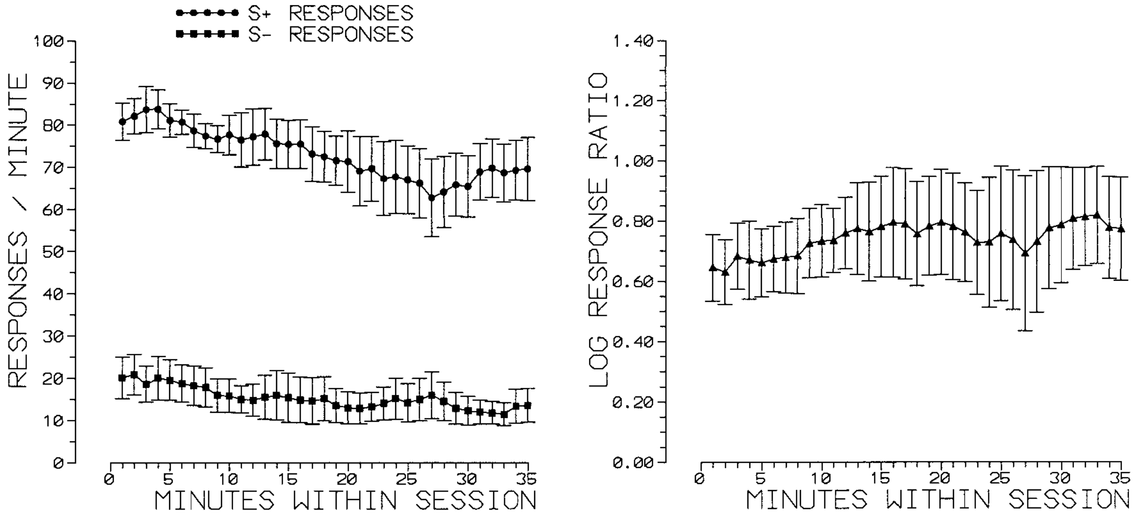

Fig. 18. Moving averages of response rate taken each minute during the first 50 min of the session for the 10-stimulus group of Experiment 4. Each point is the group mean for 5 consecutive minutes. Error bars are the standard error of the mean. Left panel: response rates for S− (solid squares) and S+ (solid circles). Right panel: logarithm of the ratio of response rate during S+ to response rate during S−.

procedure does not consistently produce a change in responding in all subjects, it is reasonable to ask what it is about particular birds that contributes to a decline in responding. Several previous investigators have suggested that within-session declines in responding are produced by satiation (e.g., Bizo et al., 1998; Palya & Walter, 1997). If this explanation is correct, birds with the lowest feeding capacity should be most likely to show the effect of satiation.

To test this explanation, the feeding capacity of the 12 birds in Experiments 3 and 4 was measured.[1] Each bird was placed in the experimental chamber and was given 1 hr of

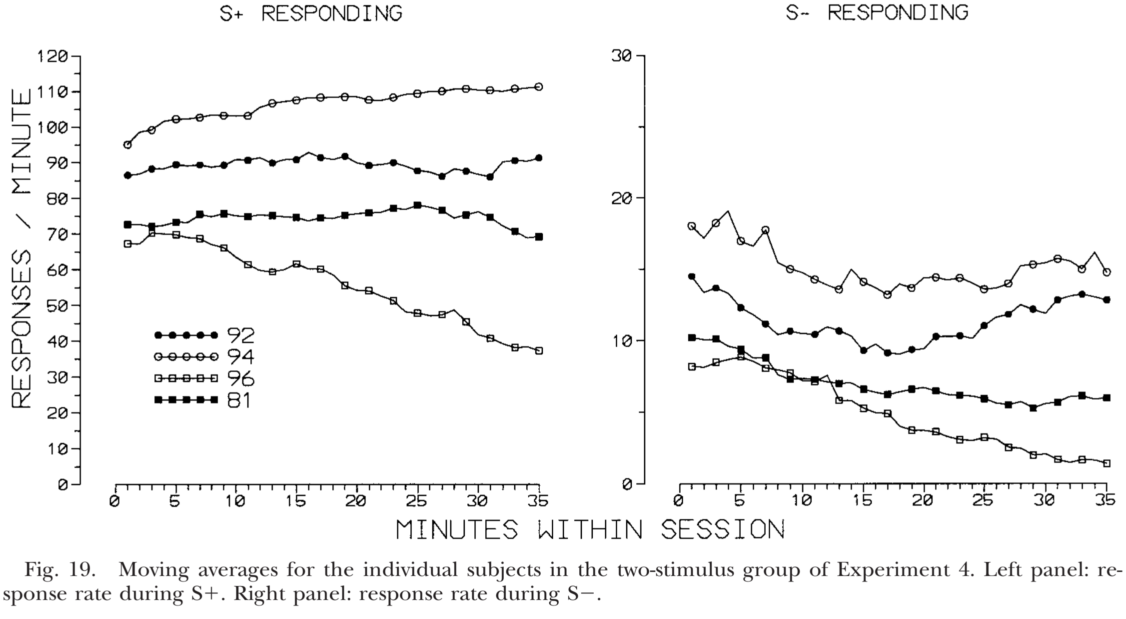

Fig. 19. Moving averages for the individual subjects in the two-stimulus group of Experiment 4. Left panel: response rate during S+. Right panel: response rate during S−.

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[1] We thank Thomas DeMarse for suggesting this measure.

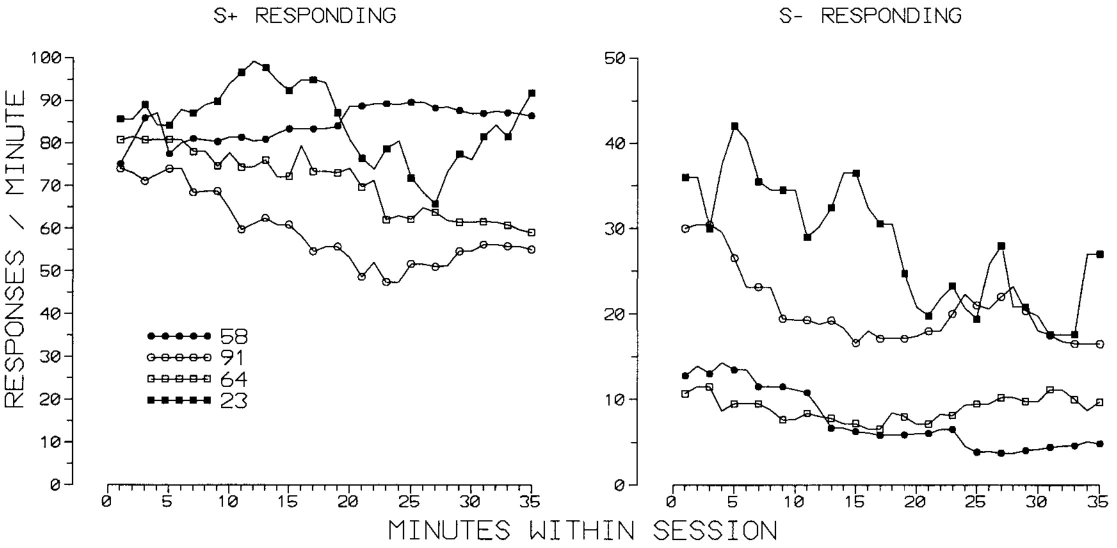

Fig. 20. Moving averages for the individual subjects in the 10-stimulus group of Experiment 4. Left panel: response rate during S+. Right panel: response rate during S−.

fixed-ratio (FR) 1 with 3 s of mixed grain as the reinforcer. The bird was weighed before and after the session, as was the grain in the magazine. Results of this capacity test are given in Table 1. As can be seen by visual inspection, 4 of the 12 birds produced a consistent decline in responding within the session. By consistent decline, we mean both that response rate was lower during the last 5-min time bin than during the first time bin, and that response rate decreased across successive 5-min time bins on at least two thirds of the occasions. The 4 birds with the lowest food capacities were those whose response rates most consistently declined within the session. Thus, satiation is likely to have been the controlling variable for the within-session decline for birds in Experiments 3 and 4.

Table 1

Food capacity, in grams of mixed grain consumed in 1 hr, for individual subjects in Experiments 3 and 4. The presence or absence of a within-session decline in responding is indicated.

Experiment	Bird	Capacity (g)	Within-session decline
3	163	23	Yes
	164	38	No
	171	44	No
	183	41	No
4	91	25	Yes
	58	36	No
	64	22	Yes
	23	42	No
	92	35	No
	94	41	No
	96	27	Yes
	81	44	No

GENERAL DISCUSSION

We reported earlier the absence of within-session changes in responding during discrimination training with flicker stimuli using two types of choice procedures (Hinson & Tennison, 1998). Our current results confirm and extend those findings. We found no large or statistically reliable within-session changes in responding for groups of birds trained on a successive discrimination procedure. This result was obtained with both operant and Pavlovian training contingencies. Further, the same results were obtained with discrimination training involving visual forms. Within-session changes in responding also failed to appear in both relatively easy and relatively difficult discrimination tasks.

A positive conclusion of these studies is that one need not be overly concerned about the impact of within-session changes in responding during discrimination training procedures. In all the cases reported here, high absolute rates of responding were obtained, and consistent maintained discrimination gradients were obtained, without a serious impact of within-session changes in responding. Therefore, in the present studies, response measures averaged over and across sessions accurately represented responding at any time during the session.

Given that within-session changes in responding do occur in many settings (McSweeney & Hinson, 1992; McSweeney & Roll, 1993), it is curious that such changes failed to occur here. The parameters chosen for training in all of the present experiments are consistent with parameters that have been reported to produce significant within-session changes in responding. Based on prior reports, large within-session changes in responding should appear within approximately the first 15 to 25 min of the session (e.g., McSweeney, Roll, & Cannon, 1994). Our session duration varied from roughly 45 to 60 min across the four experiments, well beyond those previously established limits. In addition, earlier work indicates that high rates of reinforcement (e.g., McSweeney & Hinson, 1992; Weatherly, McSweeney, & Swindell, 1995) and the use of multiple rather than simple schedules (e.g., McSweeney, 1992) should enhance within-session changes in responding. Yet, we found no evidence of systematic changes within a session across our experiments, even though our procedures provided high rates of reinforcement delivered on multiple schedules.

When we examined the performance of individual subjects, we did find a minority in the last two experiments that exhibited a consistent decline in responding during the session. Because of the limited number of these subjects, there was no statistically significant impact on the group as a whole. It should also be noted that the overall maintained generalization gradients for animals that showed a within-session decline in responding did not differ appreciably from other subjects. Thus, individual differences in responding that appeared locally in time did not seem to be reflected in differences in global discrimination performance.

Previous investigators, such as Palya and Walter (1997) and Bizo et al. (1998), have noted important differences in the degree to which the response rates of individual animals decline during the session. These authors have argued that animals become satiated to different degrees based on their body mass and ingestive capacity. From this perspective, one could argue that within-session changes in responding were largely absent in the present studies because satiation for most animals was minimal. There is evidence for this account. For example, in the present studies, the reinforcer in all cases was 3-s access to food. All of our animals required consistent postsession feedings to maintain their 80% weights. Further, in most other experiments with pigeons examining within-session effects (see McSweeney, Hinson, & Cannon, 1996), and in the visual discrimination study with pigeons cited earlier (McSweeney, Weatherly, & Swindell, 1996), reinforcer duration was 5 s. Given the demonstrated importance of reinforcer amount when weight and actual ingestion have been measured (e.g., Bizo et al., 1998; Palya & Walter, 1997) and in other cases in which overall rates of reinforcement are high (e.g., Cannon & McSweeney, 1995), it is plausible that reinforcer duration may be the critical variable. Finally, the finding in the present studies that birds with the smallest food capacities were the ones whose response rates declined during the session is consistent with a satiation explanation.

An alternative interpretation is given by McSweeney, Hinson, and Cannon (1996), who argued that within-session changes in responding reflect the joint action of sensitization and habituation to the reinforcer. According to this account, a bitonic within-session pattern of responding reflects the prevalence of sensitization early in the session, followed by the dominance of habituation later in the session. Depending on the parameters of the experiment, one may observe the dominance of sensitization or habituation, leading to monotonic increases or decreases in responding.

Adopting this view, one could argue that the discrimination procedures employed here effectively eliminated habituation. Perhaps with multiple, rapidly changing stimuli, attention was maintained at a high level throughout the session. Indeed, we have argued that attentional processes are necessary to explain dimensional contrast and other dimensional discrimination phenomena (see Hinson et al., 1999; Hinson & Tennison, 1997). However, this account would not explain the absence of an early-session increase in responding in the present studies. Nor would it explain why, in other studies (e.g., McSweeney, 1992), more rapid stimulus change enhanced within-session changes in responding. Finally, one would need to demonstrate that ingestive capacity reflects habituation rather than satiation.

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