THE UNIVERSITY OF MANITOBA

TOPOGRAPHICAL VARIATIONS IN RESPONDING DURING AUTOSHAPING AND OMISSION TRAINING IN PIGEONS

by

Gloria D. Evans

A Thesis

Submitted to the Faculty of Graduate Studies

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of Master of Arts

Department of Psychology

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Abstract

This study examined response topography in two pigeons under fixed-trial autoshaping and fixed-trial omission training. A specially constructed apparatus continuously recorded the spatial coordinates of an hypothetical point on the bird's head as it moved freely in the chamber, key-pecking and engaging in all other activities.

Both birds key-pecked within the first session of autoshaping, and developed stable patterns of withdrawal from the ITI stimulus and approach and key-pecking to the CS, with some abortive pecking directed at the CS. During omission, ITI patterns were disrupted and both subjects initially increased the frequency of abortive pecking. In later sessions, the original (or similar) ITI pattern returned, abortive pecking disappeared, and pecks were redirected from the key to areas near the key during the CS. Approach to the CS and pecking in its vicinity were maintained despite the omission contingency. Following the removal of the omission contingency, key-pecking increased for both birds; for one bird, however, it remained at a low level and the response topography developed in the presence of the CS during omission persisted. For the other bird, all pecks were redirected back to the key during the CS. A third pigeon consistently approached the CS but failed to key-peck during autoshaping and was not exposed to the omission contingency.

These data demonstrate the strong control the CS exerts over approach and pecking behavior, despite the acquisition of efficient omission performance. This suggests the importance of both stimulus-reinforcer and response-reinforce relationships in the control of autoshaped key-pecking. Behavior during the ITI suggests the joint operation of inhibitory control by the ITI stimulus, and adventitious reinforcement of superstitious behaviors by onset of the CS.

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INTRODUCTION

In 1968 Brown and Jenkins reported a study in which magazine-trained, but experimentally naive, food-deprived pigeons were conditioned to peck a lighted response key through response-independent pairings of keylight illumination and feeder operations. In their procedure, a keylight was illuminated for 8 sec, and at its offset, the food magazine was operated for 4 sec. All pigeons in their study commenced pecking at the lighted key within six to 119 pairings of the keylight and the feeder. Brown and Jenkins labelled this phenomenon "autoshaping", as the pigeons appeared to "shape" themselves to keypeck.

Since then, the response-independent acquisition of key-pecking directed toward a stimulus signalling food reinforcement has been replicated many times with pigeons, and has been extended to include other species (e.g., rats, chicks, quail, squirrel monkeys, fish, dogs, and children), other responses (e.g., lever pressing, key pressing, courting or aggressive displays directed toward the stimulus), and other reinforcers (e.g., water, heat, electrical brain stimulation, access to a sexual partner, termination of shock, and access to a social space). (See Peele and Ferster, 1982; reviews by Hearst and Jenkins, 1974; and Schwartz and Gamzu, 1977).

Brown and Jenkins' demonstration was of interest as a rapid, automated, and consistent procedure for establishing key-pecking in naive pigeons. However, their results were of even greater interest for their theoretical implications. Key-pecking had long been considered the "prototypic" operant response, and was (similar to other directed skeletal responses) widely assumed to be under the control of response-reinforcer contingencies. However, in the Brown and Jenkins study, key-pecking appeared to be under the control of forward pairings of a stimulus (key-

light illumination) and a reinforcer (food). This represented an example of a directed skeletal response under the apparent control of a Pavlovian conditioning procedure (Davey, Oakley, and Cleland, 1981).

In this paradigm, the food in the hopper is the unconditioned stimulus (US). Through repeated pairings, the keylight which immediately precedes food becomes the conditioned stimulus (CS), and a conditioned pecking response (CR) emerges and is directed - not at the food magazine - but rather at the CS, the keylight. However, the mere presence of a Pavlovian stimulus-reinforcer pairing does not ensure that the behavior in question is controlled, completely or in part, by that particular relationship. Brown and Jenkins (1968) and Herrnstein (see Terrace, in Locurto, Terrace, and Gibbon, 1981), among others, have argued that key-pecking in the autoshaping situation is gradually shaped through adventitious reinforcement of orientation and approach behaviors. Davol, Steinhauer, and Lee (1977) and Sperling, Perkins, and Duncan (1977) suggest that pecking at the illuminated feeder generalizes to pecking at the illuminated key, which is then adventitiously reinforced by feeder operations. However, Williams and Williams (1969) argue that the reliability of the phenomenon suggests a more deterministic mechanism than response shaping by adventitious reinforcement, which, as Jenkins (1977) points out, presumably would not almost invariably culminate in the rapid acquisition of key-pecking during the CS as opposed to other possible responses.

. In fact, the majority of the literature suggests that key-pecking in the autoshaping situation is primarily controlled by the programmed stimulus-reinforcer relationship. In addition to the procedural identity of autoshaping with Pavlovian conditioning, studies examining serial, trace, and delay paradigms in autoshaping (e.g., Lucas, Deich, and Wasserman,

1981; Newlin and LoLordo, 1976) have uncovered functional relationships similar to those in classical conditioning paradigms. A forward stimulus-reinforcer pairing appears to be a necessary condition for the acquisition of key-pecking in an autoshaping situation. However, it is not necessary that a feeder operation follow each CS presentation; key-pecking will emerge and be maintained provided there is a differential positive association of keylight and food, i.e., key illumination is positively associated with an increase in the average frequency of reinforcement (Gamzu and Schwartz, 1973; Gamzu and Williams, 1973).

Key-pecking does not develop reliably following: (1) backward pairings of food and keylight; (2) CS- or US-alone trials; (3) intermittent feeder presentations with continuous keylight illumination; or (4) random or explicitly unpaired presentations of the keylight and the feeder (Bilbrey and Winokur, 1973; Brown and Jenkins, 1968; Hearst and Jenkins, 1974; Schwartz and Gamzu, 1977; Wasserman, Hunter, Gutowski, and Bader, 1975). Presumably, key-pecking would develop at least occasionally in these situations if adventitious reinforcement were the primary mechanism controlling the behavior. During autoshaping, the first key-peck reliably occurs during the CS, and key-pecking remains confined to those intervals, rarely occurring during the inter-trial interval (ITI), when the keylight stimulus signals a period of non-reinforcement (Brown and Jenkins, 1968; Jenkins and Moore, 1973). This suggests that the keylight is important in controlling responding. In addition, with some exceptions (e.g., Gamzu and Schwam, 1974; Woodruff and Williams, 1976), the topography of the CR is closely related to the topography of the consummatory behavior directed at the US. For example, Jenkins and Moore (1973) found that pigeons contacted the key with grain-pecking movements when the US was grain, and drinking-like movements when the US was water.

Gamzu and Schwartz (1973) and Gamzu and Williams (1973) argue that the keylight-food association necessary for the acquisition of key-pecking is also required for maintenance of the response. Removing the association between the keylight and food by presenting unsignalled food during the ITI virtually eliminates autoshaped key-pecking.

A differential positive association between the keylight and food appears to be necessary for the acquisition and maintenance of key-pecking during autoshaping; however, this does not imply that adventitious reinforcement does not also contribute to the emergence and persistence of key-pecking. Indeed, many studies point to the interaction of stimulus-reinforcer and response-reinforcer relations in the control of autoshaped key-pecking. For example, Woodruff, Connor, Gamzu, and Williams (1977) independently manipulated the stimulus-reinforcer and the response-reinforcer relationships jointly controlling key-pecking in a situation similar to autoshaping, and found that the stimulus-reinforcer relationships exerted greater control when the response-reinforcer relationships were weak, and the response-reinforcer relationships exerted greater control when the stimulus-reinforcer relationships were weak.

In many autoshaping procedures, a peck to the key during the CS is immediately followed by darkening of the key and presentation of the reinforcer. Consequently, a response-reinforcer relationship is explicitly programmed following acquisition of the first key-peck (Brown and Jenkins, 1968). A fixed trial procedure, in which pecks during the CS have no scheduled consequences, is often used to eliminate this programmed response-reinforcer contingency; however, adventitious reinforcement of key-pecking may still occur, due to the close temporal contiguity of key-pecks during the CS, and food presentation at CS-offset (Atnip, 1977). The difficulty in separating the effects of stimulus-reinforcer and response-

reinforcer relationships in these two instances is that both the programmed stimulus-reinforcer pairing and the programmed or adventitious response-reinforcer contingency are positive, and therefore both tend to support key-pecking.

Williams and Williams (1969) introduced a negative, rather than a positive, response-reinforcer dependency into an autoshaping situation in an attempt to separate the relative controlling effects of these two relationships. In their omission training paradigm, keylight-food pairings were presented as in the typical autoshaping situation; however, a key-peck during the CS caused the keylight to be darkened, and prevented delivery of the scheduled reinforcer. This also reduced the absolute number of stimulus-reinforcer pairings, as CS's in which a key-peck occurred were not followed by reinforcement. However, the differential positive association of keylight and food necessary to maintain responding in an autoshaping situation was preserved (Gamzu and Schwartz, 1973; Gamzu and Williams, 1973). In contrast to the standard operant omission paradigm where intermittent keylight-food pairings are not programmed, and where responding is rapidly eliminated by the negative response-reinforcer contingency (Uhl, 1973), key-pecking was maintained at substantial levels, as measured by the cumulative number of responses during omission training. Williams and Williams (1969) concluded that the persistence of responding despite response-dependent nonreinforcement indicated that key-pecking was primarily controlled by the stimulus-reinforcer relationship, and was relatively insensitive to, and unmodifiable by, its consequences.

This persistence of responding under omission conditions has been demonstrated repeatedly in pigeons (e.g., Jenkins, 1982; Schwartz and Williams, 1972; Woodard, Ballinger, and Bitterman, 1974), in rats (e.g., Atnip, 1977; O'Connell, 1979; Stiers and Silberberg, 1974), and in chicks

(e.g., Wasserman, Hunter, Gutowski, and Bader, 1975; Woodruff and Starr, 1978). However, the literature does not support the conclusion that autoshaped key-pecks are relatively insensitive to their consequences, or that persistent responding during omission is sufficiently reliable to be used as a criterion test for control by stimulus-reinforcer relationships, as suggested by Gamzu and Schwam (1974).

In the omission procedure used by Williams and Williams (1969), the first key-peck during the CS terminated the trial. Therefore, responses were limited to one per trial, and only two dependent measures were possible: (1) the cumulative number of responses during omission trials; and (2) the latency to the first key-peck. The cumulative number of responses diminished slightly from the response-independent autoshaping situation, but remained higher than would be found in a standard operant omission training paradigm. In addition, response latency increased during omission training compared to autoshaping. The negative response-reinforcer contingency was effective in eliminating key-pecking only when a second key was introduced into the chamber. This key was illuminated simultaneously with the negative key, but responses to this second key had no scheduled consequences. Birds redirected pecking from the negative key to this irrelevant key and successfully averted the omission contingency. This suggests that although responding is maintained during omission training, autoshaped key-pecks are not insensitive to their consequences.

Few studies since Williams and Williams (1969) have reported the cumulative number of responses during omission training as a dependent measure. The most commonly-used measure is the number of CS-intervals with a response. Most studies employing that measure have reported sustained responding during omission training, although at reduced levels when compared to standard autoshaping. A smaller number of studies (e.g., Barrera,

1974, and Woodruff and Williams, 1976, with pigeons; Gamzu and Schwam, 1974, with squirrel monkeys; Davey, Oakley, and Cleland, 1981, Locurto, Terrace, and Gibbon, 1976, and Stiers and Silberberg, 1974, with rats) have reported substantial decreases in the number of CS-intervals with a response during omission training. However, it is difficult to compare results across studies because of: (1) procedural differences (e.g., Barrera, 1974, programmed sequential signals prior to food delivery and ran an extended number of omission trials; Stiers and Silberberg, 1974, used a concurrent two-lever procedure with one lever an omission lever, and the second associated with a random control condition or autoshaping; Woodruff and Williams, 1976, presented water reinforcers via surgically implanted cannulae in the pigeons' beaks); and (2) species differences (e.g., in both squirrel monkeys and rats, in contrast to pigeons, the topography of the consummatory response to the US is unlike the topography of responding to the CS during autoshaping).

Response latency has rarely been used as a dependent measure; however, all studies which report response latency also report that it increases during omission training (Barrera, 1974; Locurto, Terrace, and Gibbon, 1976; Williams and Williams, 1969). Barrera (1974) suggested that the increase in response latency was related to changes in response topography during omission training.

A fixed-trial omission procedure (pecks during the CS prevent reinforcer delivery at CS-offset, but do not immediately terminate the trial) allows the inclusion of a third dependent measure - rate of key-pecking or bar-pressing during the CS. Both rates decrease dramatically (often to extinction or random control levels) during omission training (Atnip, 1977; Davey, Oakley, and Cleland, 1981; Deich and Wasserman, 1977; Locurto, Terrace, and Gibbon, 1976; Lucas, 1975; Schwartz and Williams, 1972;

Woodard, Ballinger, and Bitterman, 1974). Concurrent with this decrease in the rate of responses which result in the omission of reinforcers is an increase in the rate of responses which do not result in omission. For example, Atnip (1977) reported that the rate of bar-presses in rats decreased, but that the rate of bar-contacts actually increased. Similarly, although the rate of key-pecking in pigeons decreases, pecking directed around the area of the key (Barrera, 1974; Woodruff and Williams, 1976), directed toward other areas of the chamber (Barrera, 1974), or terminating in front of the key (Lucas, 1975) increases.

These and similar observations are usually interpreted to mean that contact with the CS is maintained despite the omission contingency. However, it is unclear whether this is due to the signalling value of the keylight, adventitious reinforcement of contact behaviors, or both. In addition, the change to response topographies which avert the omission contingency is taken as evidence that at least some components of the CR are sensitive to the negative response-reinforcer dependency. Equally possible, however, is a loss of response strength due to the introduction of partial reinforcement caused by sustained omission responding.

This introduces a major problem with the omission paradigm as a procedure to separate the effects of stimulus-reinforcer and response-reinforcer relationships in autoshaping. As discussed earlier, in the standard autoshaping procedure both the stimulus-reinforcer and response-reinforcer relationships are positive and tend to support key-pecking or bar-pressing. Williams and Williams (1969) adapted the omission procedure in order to change the direction of one of these relationships (the response-reinforcer relationship) while holding the other (the stimulus-reinforcer relationship) constant. Unfortunately, this is not the case. Sustained responding during omission training means that at least some CS-presentations

are not followed by reinforcers. The schedule of stimulus-reinforcer pairings changes from 100% reinforcement during autoshaping to partial reinforcement or even extinction during omission training.

The classical conditioning literature suggests that CS's (e.g., eye blinks, nictitating membrane responses) are dynamic and change in frequency and, more importantly, in topography with repeated pairings, and with changes in US intensity, in interstimulus interval duration (Coleman and Gormezano, 1977; Smith, 1968; Smith, Coleman, and Gormezano, 1969), and in reinforcement schedule (Levey and Martin, 1968). For example, on unreinforced trials during partial reinforcement, a blended CR/UCR occurs which differs in topography from responses on reinforced trials. As response strength weakens with repeated extinction trials, the amplitude of this response decreases and its placement in time shifts from trial to trial (Levey and Martin, 1968).

There has been little examination of the topography of autoshaped responses during partial reinforcement or extinction. However, Gibbon, Farrell, Locurto, Duncan, and Terrace (1980) suggest that the shift from long to short duration key-pecks during extinction after autoshaping may represent a loss of response strength. This change in response topography may be analogous to the change in topography during extinction described by Levey and Martin (1968). This means that without controls for shifts in reinforcement frequency, changes in response topography during omission training cannot be clearly attributed to either sensitivity to the negative response-reinforcer contingency or to a shift to partial reinforcement.

Davey, Oakley, and Cleland (1981) reported one of the few studies to use yoked subjects to control for changes in reinforcement frequency during omission training. Response topographies of their omission subjects

changed so that CS-contact was maintained but the omission contingency was averted, while topographies of yoked subjects did not change despite the reduction in reinforcement frequency. Since the negative response-reinforcer dependency was the only difference between the two groups, Davey, Oakley, and Cleland attributed the change in topography to the effect of the omission contingency.

Although they attributed the change in topography in their study to the negative response-reinforcer contingency, they suggested that omission training could alter response topography in three ways. First, response topographies which result in the omission of reinforcers might be selectively eliminated. This might suggest that these components are sensitive to the negative response-reinforcer dependency. Alternatively, this might represent a decrease in the magnitude of the CR produced by partial reinforcement. Second, new response topographies which do not result in omission of reinforcers might develop. These new topographies might represent early components of a response sequence which become more apparent with the loss of later components, or a different food-related response which was disinhibited when a competing response was suppressed by the omission contingency. Third, existing topographies might be redirected to other areas of the chamber, possibly as other stimuli become better predictors of reinforcement than the keylight.

In the standard autoshaping situation, rats press the lever by pawing. However, they also make contacts by touching, nosing, biting, or licking the lever. Under omission training, lever-presses, pawing, and manual touching are eliminated, and replaced by an increase in the frequency of orienting, sniffing and nosing on or around the lever (Davey, Oakley, and Cleland, 1981; Locurto, Terrace, and Gibbon, 1976; Stiers and Silberberg, 1974).

Lucas (1975) reported that pigeons ceased to key-peck when key-pecking was placed under an omission contingency. However, prekeypecks (pecking movements directed at the key which do not culminate in key-contacts) increased in frequency and occurred at a high rate. Only the actual key-contact was omitted. Similarly, approaches to the key were eliminated when approach was placed under an omission contingency, while orienting toward the key was preserved (Lucas, 1975; Wessells, 1974). Barrera (1974), Williams and Williams (1969), and Woodruff and Williams (1976) reported that pecking was maintained during omission training, but that pecks were redirected from the key to other areas of the chamber (particularly close to the key). In addition, a number of Barrera's subjects developed novel topographies such as neck-arching, bowing and pacing, which were not observed during autoshaping.

The literature suggests that rats avoid an omission contingency by selectively eliminating particular response topographies and increasing the frequency of other topographies already present in their repertoires. However, the results with pigeons are not as clear: pigeons have been reported to selectively eliminate particular terminal response components, redirect existing topographies, or develop novel response forms under omission training. Consequently, further investigation of changes in response topography under autoshaping and omission training in pigeons is required. Since it is difficult to predict the conditions under which these different alterations in topography might occur, or how they might develop, it is necessary to observe and record in sequence all of the movements of the pigeons in the experimental chamber. This study employed a specially constructed apparatus which recorded the precise spatial coordinates of an hypothetical point on the subject's head, as the pigeon moved freely in the experimental chamber, key-pecking and engaging in

other activities. These spatial coordinates were sampled 30 times per second, providing a nearly continuous permanent record of head movements and changes in position in the chamber throughout the entire session.

An A-B-C-B within-subject design was used to record and compare response topographies in pigeons exposed to: (A) continuous illumination of the ITI stimulus (white keylight) without feeder presentations; (B) fixed-trial autoshaping; and (C) fixed-trial omission training. A control condition such as random presentations of keylight and feeder was not included, as the conditioning parameters used in this study were standard in the literature and had been demonstrated to be reliable in producing autoshaped key-pecking (Perkins, Beavers, Hancock, Hemmendinger, Hemmendinger, and Ricci, 1975; Terrace, Gibbon, Farrell, and Baldock, 1975).

The primary aim of this study was to provide a thorough description of response topography in pigeons during autoshaping and omission training. Although this study focused on topographical changes occurring following the addition of a negative response-reinforcer dependency to the standard autoshaping paradigm, controls (such as yoked subjects) for reinforcement frequency were not included. Therefore, changes in topography during omission could not be clearly attributed to either the negative response-reinforcer dependency, or to changes in the stimulus-reinforcer relationship due to partial reinforcement.

Of particular interest was the precise sequence of orienting and approach behaviors culminating in the first key-peck during autoshaping. Previously, only anecdotal accounts of the sequence of behaviors leading to the first key-peck had been reported, and this sequence is of interest in light of the controversy described above concerning the acquisition of the first key-peck.

Across acquisition trials in classical conditioning, CR-onset latency

decreases (Smith, Coleman, and Gormezano, 1969). If autoshaping is a Pavlovian phenomenon, then latency to the first key-peck following CS-onset should decrease over trials as well. This study examined mean latency to the first key-peck across autoshaping sessions to assess whether a reliable decrease in latency occurred, and to relate that to changes in response topography across acquisition.

Schwartz and Williams (1972) and Williams and Williams (1969) suggested that latency to the first key-peck following CS-onset increases during omission training, compared to autoshaping. This study attempted to replicate that shift, and to relate it to changes in topography during omission.

Key-pecking does not occur reliably during the ITI (Brown and Jenkins, 1968; Jenkins and Moore, 1973). Newlin and LoLordo (1976) reported the occurrence of a minimal amount of key-pecking during early ITI's; however, there has been virtually no description in the literature of other behaviors which occur during the ITI. There is some evidence that organisms tend to withdraw from an inhibitory stimulus (e.g., Hearst and Jenkins, 1974; Wasserman, Franklin, and Hearst, 1974). The keylight correlated with the ITI in the present study satisfied the requirements for the development of a conditioned inhibitory stimulus (Hearst, 1972). Therefore, it was of interest to observe whether or not subjects withdrew from the area of the key during the ITI, and what other behaviors occurred.

In summary, there were a number of different issues which were addressed in this study:

1) What topographical changes occur during omission training following autoshaping in pigeons?

2) What is the sequence of behaviors which culminates in the first key-peck during autoshaping?

3) Does mean latency to the first key-peck after CS-onset decrease

during autoshaping, and how does this relate to changes in response topography?

4) Does mean latency to the first key-peck after CS-onset increase during omission training, and how does this relate to changes in topography?

5) What behaviors occur during the ITI?

METHOD

Subjects

Subjects were three experimentally naive male White Carneaux pigeons. They were maintained at approximately 80% of their free-feeding weights throughout the study; however, water was available at all times in their home cages. They were housed in individual cages in a colony room containing other experimental pigeons. Prior to each sesssion, the birds' heads were coloured black (excluding the beak) with black paste shoe polish applied with a cotton-tipped applicator.

Apparatus

A specially constructed operant chamber for pigeons was used. The chamber measured 58 cm square and 39 cm high. Two perpendicularly oriented video cameras were directed through the two clear glass front walls of the chamber; the two rear walls were constructed of white opaque Plexiglas, and the lid was clear Plexiglas. The entire experimental room, which measured 3.1 m square, was painted flat white, and was brightly lit by four banks of fluorescent ceiling lights. This ensured that the chamber was evenly illuminated, and that shadows and other dark areas were minimized. A white noise generator and speaker provided a masking stimulus in the room.

An aluminum panel, painted white, containing a response key and a food-hopper aperture was mounted on one of the opaque rear walls of the chamber. The response key was 2.8 cm in diameter, and was located with its center 19.8 cm from the floor, and 27.5 cm from the front glass wall of the chamber; the food aperture was located at the centre of the aluminum wall, 10.5 cm above the floor. The response key was transilluminated by a red light during CS intervals, and by a white light during the ITI. The food hopper was continuously illuminated by a dim white light

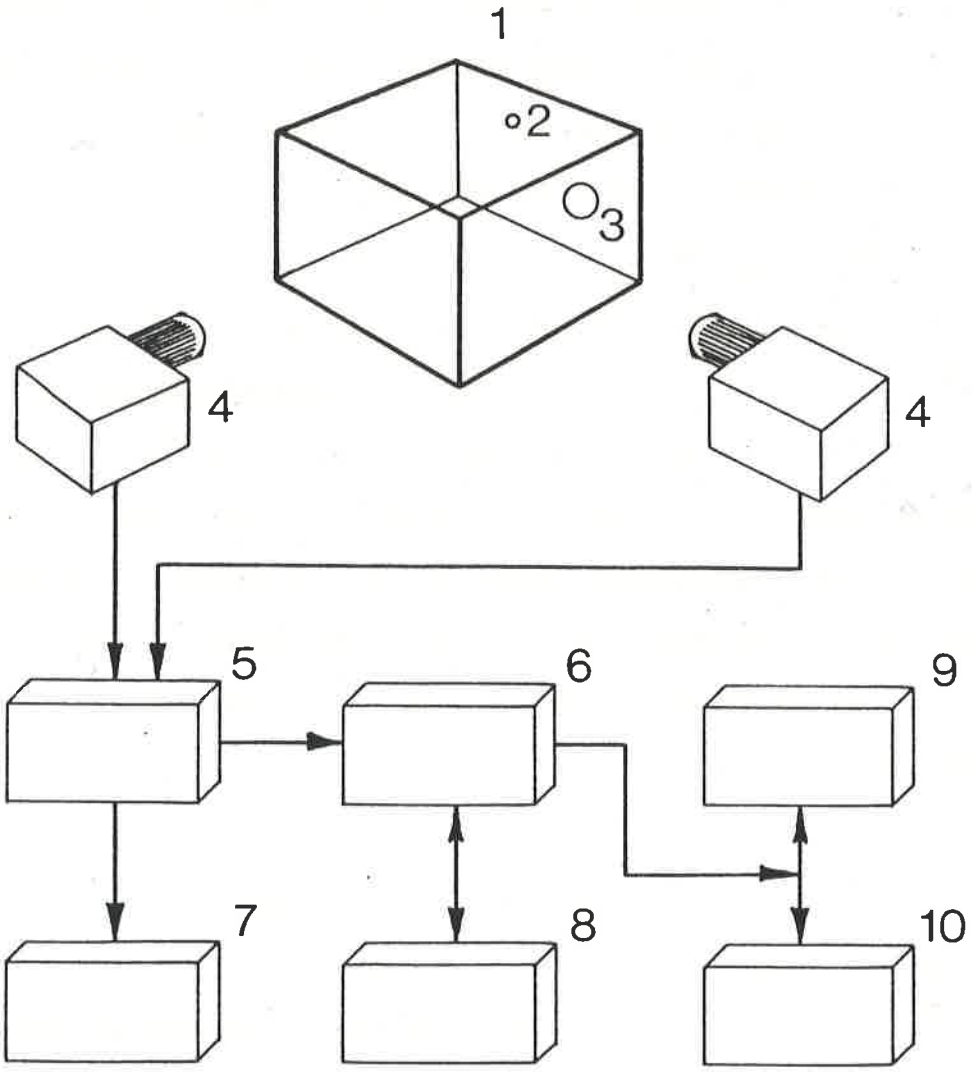
to prevent shadows, and was brightly illuminated during feeder presentations. A force of approximately 0.11 N on the response key closed a switch for electronically detecting key pecks. A feedback relay provided a brief click following each effective key-peck. Reinforcement consisted of 3-sec access to the food hopper, which contained Purina Racing Pigeon Checkers. During the 3-sec reinforcer interval, the keylight was off and the feedback relay did not operate.

The two video cameras were connected to an electronic logic system programmed to compute, at 1/30-sec intervals, the spatial (X, Y, and Z) coordinates of the center of the highest dark area scanned by the cameras. Each bird's head was painted black, as mentioned above, so that the head was the only dark area in an otherwise white chamber. Thus, the logic system computed changes in the position of an hypothetical point on the pigeon's head in three-dimensional space as the bird engaged in key-pecking and other activities in the chamber. Changes in position occurring during food presentations were not recorded, since the bird's head was usually in the hopper aperture during food presentations, and therefore was not visible to the video cameras. From these data, the logic system computed the absolute distance of the head from the key at 1/30-sec intervals. Subsequently, these values were averaged in a ratio of three segments to one, yielding 10 samples of data per sec. The logic system was connected to a Cromemco Z-2D microcomputer programmed to control experimental sessions, and collect and analyze the incoming data, which were stored on flexible mini-discs. Graphed data were displayed on the output of either a Hazeltine CRT screen or an Epson dot matrix printer. Figure 1 shows a schematic representation of the entire system.

Procedure

General experimental procedures. Sessions were conducted at approx-

Figure 1. A schematic representation of the apparatus.



1. Chamber
2. Response Key
3. Food Aperture
4. TV Cameras
5. Logic System
6. Microcomputer
7. TV Monitor
8. Disc Storage
9. CRT
10. Printer

imately the same time each morning until day 24 when running time was shifted 3 hours later in the day where it remained for the rest of the study. Each autoshaping or omission session was terminated after 60 trials. Baseline sessions (Phase A) were terminated after one hour. Prior to each session, subjects were weighed and their heads coloured black. Subjects were fed as required in their home cages following the sessions, in order to maintain their weights at approximately 80% of ad lib weights.

Experimental design. The design was an A-B-C-B design. Phase A consisted of baseline exposure to the white keylight (ITI stimulus) alone. Phase B corresponded to a fixed-trial response-independent autoshaping procedure, and Phase C to a fixed-trial response-dependent omission training procedure. Subject #5052 received two baseline sessions, nine sessions of autoshaping, twelve sessions of omission training, and a final eighteen sessions of autoshaping. Subject #1134 received two baseline sessions, seven sessions of autoshaping, thirty sessions of omission training, and a final five sessions of autoshaping. Subject #6859 received two baseline sessions, but failed to key-peck after eighteen sessions of autoshaping. Consequently, he was not exposed to the omission procedure. On day 3 of autoshaping, reinforcer duration was increased from 3 to 4 sec for that subject alone, and remained at that value for all subsequent sessions.

Preliminary training. Prior to the baseline sessions, the birds were magazine-trained. They were placed in the chamber with the food hopper raised and the feeder aperture brightly illuminated. Once the subject had approached the raised hopper and consumed grain for approximately 20 sec, the hopper was repeatedly lowered and raised at random intervals independently of the bird's behavior. This continued until the bird approached and consumed food within 3 sec for 10 consecutive trials. The feeder

light was bright only when the hopper was raised. The keylight was never illuminated during magazine training.

Baseline. Baseline sessions lasted one hour. The white keylight was continuously illuminated; there were no feeder presentations, and the feeder light was dim.

Fixed-trial autoshaping. During autoshaping, the keylight was illuminated by a red light for a fixed period of 8 sec. At the end of the 8 sec, the keylight was darkened, and reinforcement was presented for 3 sec. This pairing of keylight and feeder operation constituted a trial. Trials were separated by a variable inter-trial interval with a mean of 60 sec, and a range from 30 to 90 sec. During the ITI, the keylight was illuminated by a white light. Pecks to the key during the red keylight, the ITI, and feeder operations were recorded, but had no scheduled consequences.

Fixed-trial omission training. Keylight presentations and ITI's in omission training were identical to those during autoshaping, but pecks to the key during the CS resulted in omission of the scheduled reinforcer at the end of the 8 sec CS-interval. The keylight changed from red to white at the onset of the ITI; however, the reinforcer was not presented. Neither onset of the next trial, nor duration of the programmed ITI was affected by food omission. All key-pecks during the CS, the ITI, and feeder presentations were recorded, although key-pecks during the ITI and feeder operations had no scheduled consequences.

Dependent measures and data analysis. Dependent measures included: (1) number of trials with a key-peck; (2) mean rate of key-pecking during the CS; (3) mean rate of key-pecking during the ITI; (4) cumulative recordings of CS and US presentations and key-pecks; (5) mean latency to the first key-peck following CS-onset; (6) wave patterns describing the absolute distance of the bird's head from the response key; and (7) Y vs. X,

and Z vs. X plots of the path of the bird's head as it moved around the experimental chamber. Measures 1, 2, and 4 above are those commonly used in studies of autoshaping and omission training and were included to ensure that the phenomenon had been replicated according to standard measures. Measure 5 was included to provide a quantitative record of a phenomenon which has been only rarely reported. Measures 6 and 7 provided detailed, nearly continuous records of the precise sequence of behaviors occurring during each session, and were used, in tandem with visual observations made during each session, to assess changes in response topography.

Numerical measures (1,2,3, and 5 above) were graphed across trials and analyzed by visual inspection. Wave patterns and movement plots (6 and 7 above) were computer-graphed trial by trial from stored data and were sorted visually into informative and representative groups of patterns both within and across sessions. Both wave patterns and movement plots were expanded as required to enlarge detail. This technique had been used previously in our laboratory to examine response topography associated with fixed interval, variable interval, differential reinforcement of low rate, differential reinforcement of high rate, and extinction schedules of reinforcement.

RESULTS

Figures 2 and 3 show two dependent measures used frequently in studies of autoshaping and omission training (i.e., trials with a key-peck, and response rate during the CS) and two dependent measures reported infrequently (i.e., response rate during the ITI and mean latency to the first key-peck during the CS). Figure 2 shows data from Bird #5052, and Figure 3 from Bird #1134.

Panel A in Figure 2 shows the number of CS-presentations with at least one key-peck across all sessions. For Bird #5052, the first key-peck occurred during the CS-interval in trial #20 of the first session of autoshaping; key-pecks occurred in 37 of the remaining 40 trials on that day. The number of CS-presentations with a key-peck increased rapidly and stabilized at approximately 58 per session for the final seven days of autoshaping. Following the introduction of the omission contingency, the number of trials with a key-peck decreased steadily to less than six per day for the final five days of omission training. For four of these five days, no more than one key-peck occurred during any CS-interval. After the omission contingency was removed, the number of trials with a key-peck increased rapidly and varied around 50 trials per day for nine sessions before decreasing to 12 trials per session by the final day of autoshaping, which was lower than during Phase 1 of autoshaping, but higher than during the final sessions of omission training.

Panel B in Figure 2 shows the mean rate in responses per min of key-pecking during CS-intervals in all phases. During Phase 1 of autoshaping, response rate rose rapidly to about 52 responses per min and varied between 44 and 52 for the final six sessions. Response rate dropped following the introduction of omission training and stabilized at almost zero for the final five sessions. Key-pecks occurred during no more than six

intervals on any of those days. With the removal of the negative contingency, rate climbed steadily to about 17 responses per min and then declined slowly to less than two responses per min by the final session, corresponding to a decrease in the number of trials with a key-peck. This rate was only slightly higher than the terminal rate in the previous omission phase.

Panel C in Figure 2 shows mean rate in responses per min during the ITI. Key-pecking during the ITI occurred only during day 1 of autoshaping, at a rate of about two responses per min.

Panel D in Figure 2 shows the mean latency to the first key-peck following CS-onset. Trials without a key-peck were excluded from the computations. Latencies were not graphed for the final five sessions of omission training and the first session of autoshaping in Phase 2, as key-pecks occurred during 10% or less of the trials in each of these sessions. During the first phase of autoshaping, mean latency to the first key-peck rose to a high of 3.6 sec on day 2, and then declined and stabilized at about 2.5 sec for the last six sessions. During the first seven days of omission training, mean latency rose to about 5 sec. This occurred simultaneously with a decrease in both response rate during the CS and the number of trials with a key-peck, indicating that during omission training, key-pecks occurred less frequently and also later in the CS-interval, on the average.

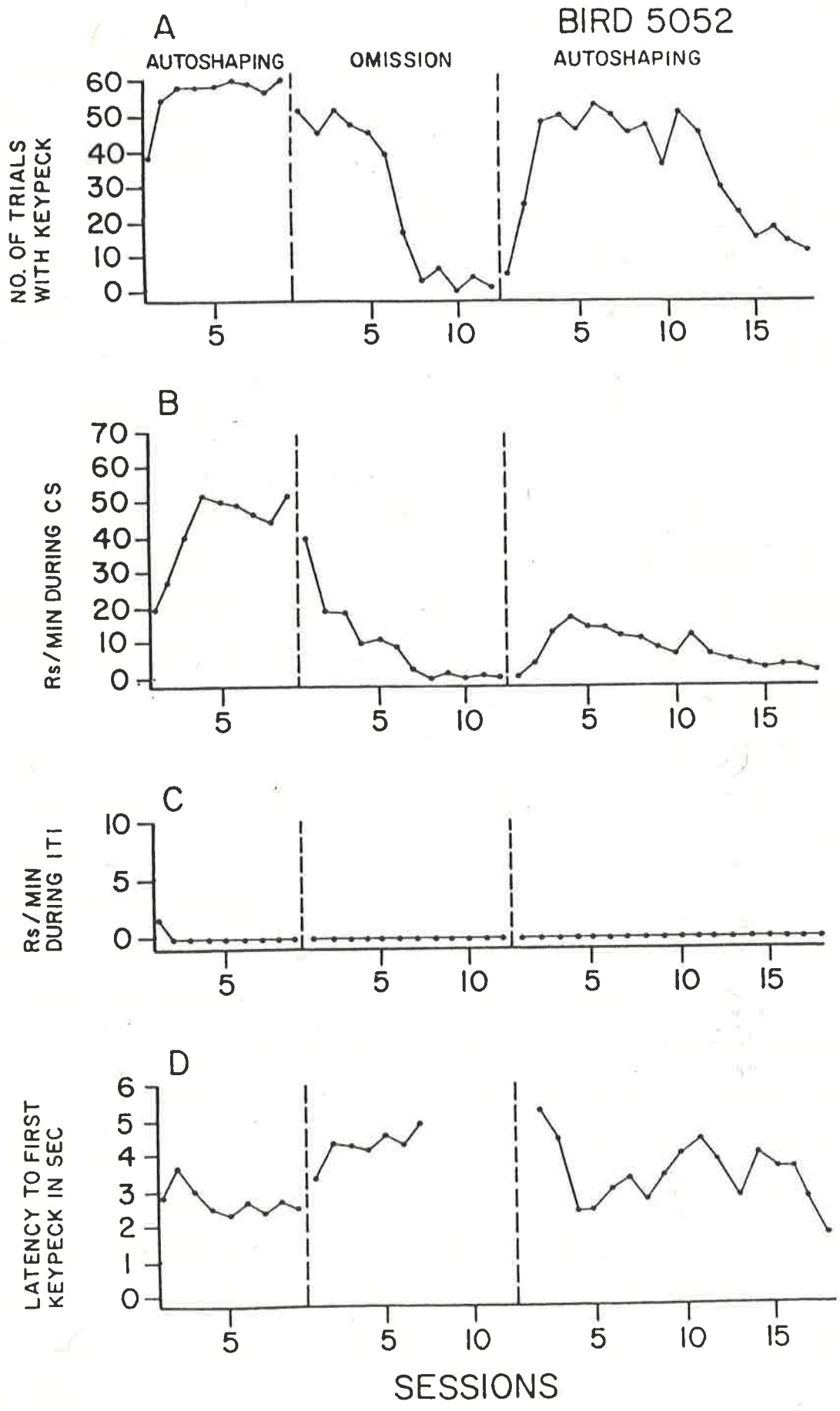
Mean latency during the second phase of autoshaping decreased from 5.2 sec on day 2 to 2.3 sec on day 4, and then varied between 2.3 and 4.3 sec for the next ten sessions. This variability coincided with a fairly steady downward trend in rate during the CS, but with considerable variability in the number of trials with a key-peck (from 23 to 52). The steady decrease in mean latency during the last four sessions of autoshaping, to

a level below that seen during the first phase of autoshaping, coincided with a low and stable response rate during the CS (around 2 responses per min) and few trials with a key-peck (approximately 15 per session). This indicates that by the end of the phase, key-pecks occurred during few trials, typically occurred only once during any one trial, and occurred progressively earlier following CS-onset.

These data suggest that for Bird #5052, an early effect of omission training was an increase in latency to the first key-peck during the CS (if a key-peck occurred). With extended training, both the number of CS-intervals with a key-peck and the rate during those intervals declined to almost zero, suggesting that the negative contingency was effective in suppressing key-pecking. Some recovery of key-pecking occurred when the negative contingency was removed, but by the end of the second phase of autoshaping, the number of trials with a key-peck and the rate during the CS had declined almost to omission training levels. Interestingly, during omission training, both response rate and the number of trials with a key-peck declined while response latency increased; however, during autoshaping in Phase 2, decreases in rate and the number of trials with a key-peck were accompanied by a sharp decrease in mean response latency. During omission, those key-pecks which did occur occurred late in the CS-interval, on the average, while during the second phase of autoshaping, they occurred early in the CS-interval.

Figure 3 shows the same response measures for Bird #1134. Panel A in Figure 3 shows the number of CS-presentations with at least one key-peck. The first key-peck for this subject occurred to the ITI stimulus on trial #1 of day 1 of autoshaping. The second key-peck occurred to the red keylight on trial #1. Key-pecks occurred on 58 of 60 trials on day 1 of autoshaping, and on every trial for the remaining six sessions of

Figure 2. Number of CS-presentations with a key-peck, response rate in key-pecks per min during CS-intervals, response rate in key-pecks per min during ITI's, and mean latency to the first key-peck following CS-onset for Bird #5052 across all phases. Panel A shows the number of CS-presentations with a key-peck; Panel B shows mean response rate during the CS; Panel C shows mean response rate during the ITI; and Panel D shows mean latency to the first key-peck following CS-onset.


A
BIRD 5052
AUTOSHAPING
OMISSION
AUTOSHAPING
NO. OF TRIALS WITH KEYPECK
60
50
40
30
20
10
0
5
5
10
5
10
15
B
Rs/MIN DURING CS
70
60
50
40
30
20
10
0
5
5
10
5
10
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C
Rs/MIN DURING ITI
10
5
0
5
5
10
5
10
15
D
LATENCY TO FIRST KEYPECK IN SEC
6
5
4
3
2
1
0
5
5
10
5
10
15
SESSIONS

autoshaping. The effect of omission training was to reduce the number of trials with a key-peck and to introduce considerable variability. Trials with a key-peck ranged from 44 to 60 during the first 22 sessions of omission, and then decreased further and ranged between 27 and 42 for the final eight sessions, stabilizing around 35 trials per session. This is considerably higher than the terminal number of trials with a key-peck for Bird #5052, and many more sessions (30 vs. 12) were required to achieve even that reduction in the number of trials. Following removal of the omission contingency, the number of trials with a key-peck increased rapidly to the level seen during the first phase of autoshaping.

Panel B in Figure 3 shows the rate of key-pecking in responses per min during the CS-interval over all sessions. Rate was high (93 responses per min) on the first day of autoshaping and rose irregularly to about 125 responses per min by the final day of autoshaping. Rate declined rapidly and steadily to about 32 responses per min by the fourth day of omission training, but became extremely variable from day 5 to day 16, ranging from 12 to 40 key-pecks per min. The downward trend in rate from day 16 to day 23 corresponds to a similar steady downward trend in the number of trials with a key-peck. Both measures increased slightly and then stabilized over the final seven sessions of omission.

Panel C in Figure 3 shows key-peck rate in responses per min during the ITI for all phases. An appreciable amount of key-pecking during the ITI occurred during the first three sessions of autoshaping in Phase 1. The rate of key-pecking during those three days declined steadily from 10.6 to 2.4 responses per min. Fewer than .5 responses per min occurred on days 4 and 5 of autoshaping. Some key-pecking during the ITI occurred on days 18 to 21 of omission training; however, the maximum rate was .22 responses per min.

Panel D in Figure 3 shows the mean latency to the first key-peck during CS-intervals across all sessions. Again, trials without a key-peck were excluded. Mean latency during autoshaping in Phase 1 was extremely stable at about 1.9 sec for all sessions. Mean latency increased and became variable during omission sessions. Mean latency increased steadily to 4.8 sec during the first seven days of omission, concurrent with a reduction in rate during the CS from 119 to 19 key-pecks per min. Despite this increase in mean latency and the large decrease in rate, the number of trials with a key-peck decreased only slightly (from 60 to about 50). This indicates that early in omission, key-pecks continued to occur during most CS-presentations; however, few key-pecks occurred during any one interval, and the first key-peck occurred late in the interval on the average.

Mean latency varied around 3.5 sec for the next nine sessions, but did not appear to relate systematically to changes in either response rate during the CS or the number of trials with a key-peck. The downward trend in both rate and number of trials with a key-peck between sessions 16 and 23 corresponded to a steady increase in latency from 2.6 to 3.7 sec. During the final seven sessions, when both response rate and the number of trials with a key-peck were relatively low and stable, latency decreased and varied around 2.7 sec. Mean latency declined steadily from 3.3 to 2.4 sec during Phase 2 of autoshaping, coinciding with an increase in both response rate during the CS and the number of trials with a key-peck.

These figures suggest that for Bird #1134, the omission contingency produced an immediate decrease in the rate of key-pecking during the CS and an increase in the mean latency to the first key-peck following CS-onset. This is similar to Bird #5052; however, in contrast to #5052, #1134 did not show a large reduction in the number of CS-presentations

with a key-peck, even after extended exposure to the omission contingency. These data suggest that for #1134, key-pecking was maintained during omission, albeit at a lower rate than during autoshaping.

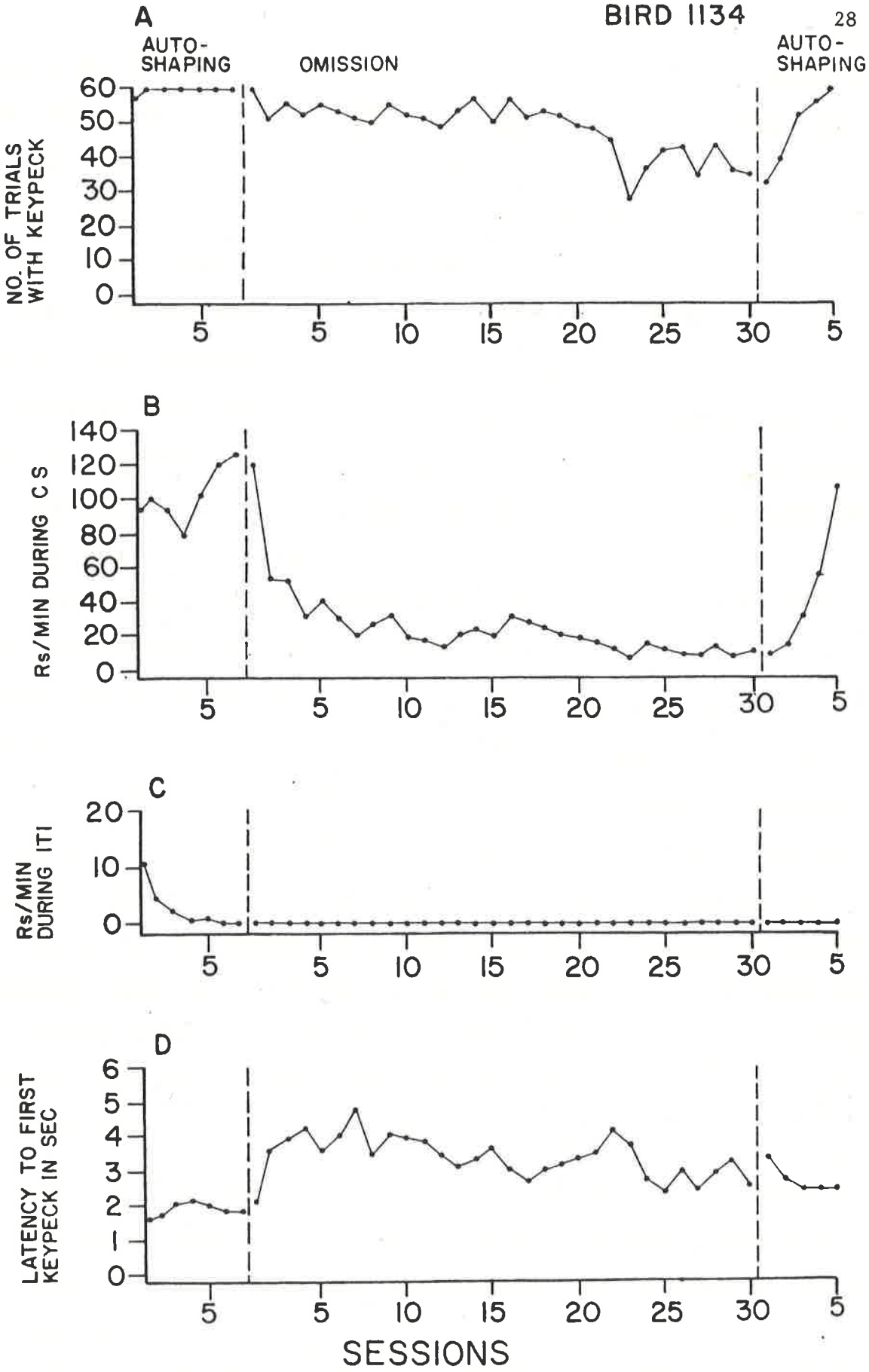
Similar figures are not shown for Bird #6859. This subject failed to key-peck after 18 days or 1080 trials of autoshaping. On days 1 and 2 of autoshaping, Bird #6859 failed to consume any reinforcers, in part due to slow approaches to the feeder. Consequently, on day 3, the feeder duration was increased from 3 to 4 sec and the subject was able to consume at least some food on 58 out of 60 feeder presentations. The 4-sec feeder duration remained in effect for the remaining 15 sessions of autoshaping for this subject.

The above response measures suggest that autoshaped key-pecks were sensitive to the omission contingency in both subjects that were autoshaped to key-peck. In each case, mean response latency increased and the response rate during the CS and the number of trials with a key-peck decreased compared to autoshaping. However, for subject #1134, neither response rate nor the number of trials with a key-peck declined to the levels of subject #5052, despite extended training; in other words, key-pecking was more effectively suppressed in Bird #5052 than in Bird #1134.

A detailed examination of measures of response topography suggests two findings which are not apparent from the data described above: (1) the great similarity in the patterns of responding between #5052 and #1134, despite the apparent disparity in CS-rate and number of trials with a key-peck; and (2) the persistence of high-rate pecking during the CS despite the omission contingency for both subjects. Figures 4 to 9 for Bird #5052, 10 to 14 for Bird #1134, and 15 for Bird #6859 provide detailed illustrations of response topography across all phases.

Figure 4 shows response topography for Bird #5052 during baseline

Figure 3. Number of CS-presentations with a key-peck, response rate in key-pecks per min during CS-intervals, response rate in key-pecks per min during ITI's, and mean latency to the first key-peck following CS-onset for Bird #1134 across all phases. Panel A shows the number of CS-presentations with a key-peck; Panel B shows mean response rate during the CS; Panel C shows mean response rate during the ITI; and Panel D shows mean latency to the first key-peck following CS-onset.


A
BIRD 1134
AUTO-SHAPING
OMISSION
AUTO-SHAPING
NO. OF TRIALS WITH KEYPECK
60
50
40
30
20
10
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5
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10
15
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25
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5
B
Rs/MIN DURING C S
140
120
100
80
60
40
20
0
5
5
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20
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C
Rs/MIN DURING ITI
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15
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25
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5
D
LATENCY TO FIRST KEYPECK IN SEC
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5
4
3
2
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0
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25
30
5
SESSIONS

days 1 and 2, and the first day of autoshaping in Phase 1. The graphs in the left column of the figure show the distance of the bird's head from the key over time. For these and all subsequent distance graphs, the absolute distance from the key, which is a composite of distances on the X, Y, and Z axes, is indicated in cm on the vertical axis, and session time in sec on the horizontal axis. Time during reinforcer presentations is not graphed. Pecks are indicated by vertical marks between the upper pair of horizontal lines beneath each graph, and CS-presentations by long vertical marks between the lower pair of horizontal lines. Errors in tracking the movement of the subject are indicated by short marks between this lower pair of horizontal lines.

The graphs in the right column of the figure show X vs. Y or overhead plots of the path of the bird's head as the bird moves about the chamber during the session. These and all subsequent overhead plots are located to the right of distance graphs showing the same segment of session time. The position of the key is indicated by the small dark square at the top of each graph; the feeder is not shown, but is located to the immediate right of the key. The extent of the chamber is indicated by the cursors on the vertical and horizontal axes. For all overhead and all distance graphs, scales are identical to the scales of adjacent graphs unless otherwise indicated. For the overhead plots, 10 data points are averaged for each point plotted unless otherwise indicated. This yields one discrete point per sec of session time. It should be noted that the actual outline of the chamber in the overhead views is not perpendicular to the horizontal and vertical axes, but is actually rotated 15 degrees to the right, to bring a larger area of the chamber into the angle of view of the cameras.

As can be seen from the top row of graphs, which shows the entire

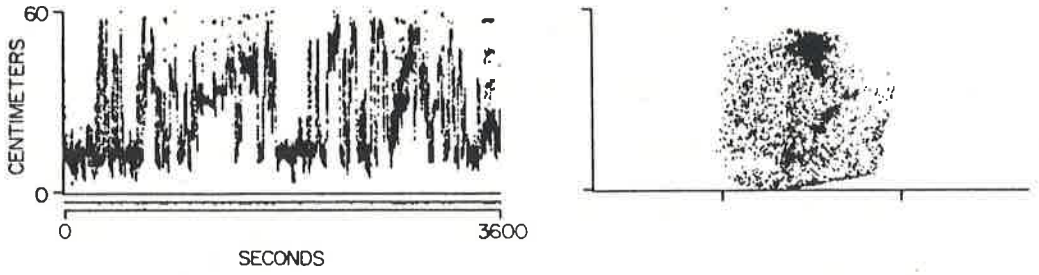
session for baseline day 1, Bird #5052 made numerous close approaches to the feeder and to the white key. When not approaching the feeder and key area, the subject moved randomly around the chamber, or preened at the center or the rear of the chamber. The numerous tracking errors occurred while the subject was preening and his head was momentarily obscured. By day 2 of baseline (see the second row of graphs), the subject made few approaches to the key or to the feeder, but spent most of the session sitting in the center or at the rear of the chamber, often preening.

The lower four rows of the figure show the development of and increase in key-pecking to both the red and white key-lights during the first day of autoshaping, and the subsequent reduction in pecking to the white key by the end of the session. The third row shows distance from the key and the overhead plot from the entire session, and the lower three rows show successive thirds of the session. (Details of the development of the first key-peck are shown in Figure 5). At the beginning of the session, the subject approached the key and the feeder, but missed the first four reinforcer presentations. After consuming the fifth reinforcer, the subject sat or stood in front of the feeder and made increasingly close head movements toward both the red and the white keylights. Some movement away from the key toward the rear of the chamber occurred during the ITI's. The first key-peck occurred to the red key on trial #20. Key-pecks occurred in virtually all subsequent CS-intervals in this session. Pecks to the white keylight first occurred on trial #22, and increased in frequency until about the forty-second trial (see bottom row of the figure). At this time, pecks to the white keylight decreased and circling away from the key to the rear of the chamber increased during the ITI. By the end of session 1 of autoshaping, key-pecks occurred only during the CS-interval. No further key-pecks to the white stimulus occurred on any subse-

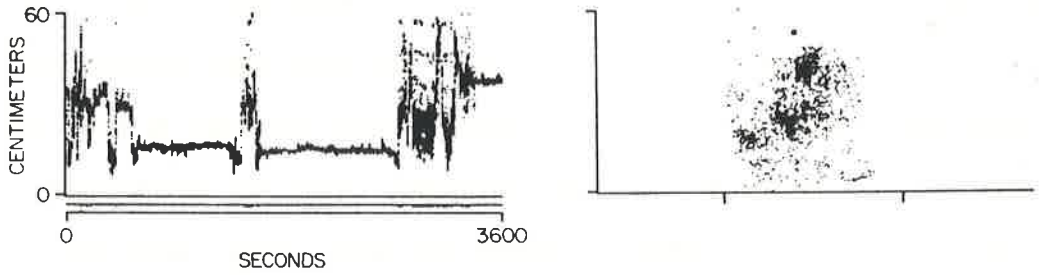
Figure 4. Response topography for Bird #5052 for baseline days 1 and 2, and the first session of autoshaping. The graphs in the left column show absolute distance of the bird's head from the key. Absolute distance in cm is indicated on the vertical axis, and session time in sec on the horizontal axis. Time during reinforcer presentations is not graphed. Pecks are indicated by the vertical marks between the upper pair of horizontal lines beneath each graph, and CS-presentations by the long vertical marks between the lower pair of horizontal lines. Errors in tracking the movement of the subject are indicated by short marks between this lower pair of horizontal lines. The graphs in the right column show X vs. Y or overhead plots of the path of the bird's head as the bird moves around the chamber during the session. These plots are located to the right of distance graphs showing the same segment of session time. The position of the key is indicated by the small dark square at the top of each graph; the feeder is not shown but is located to the immediate right of the key. The extent of the chamber is indicated by the cursors on the vertical and horizontal axes. The outline of the chamber is rotated 15 degrees to the right of perpendicular. One discrete point is plotted per sec of session time.

BIRD 5052

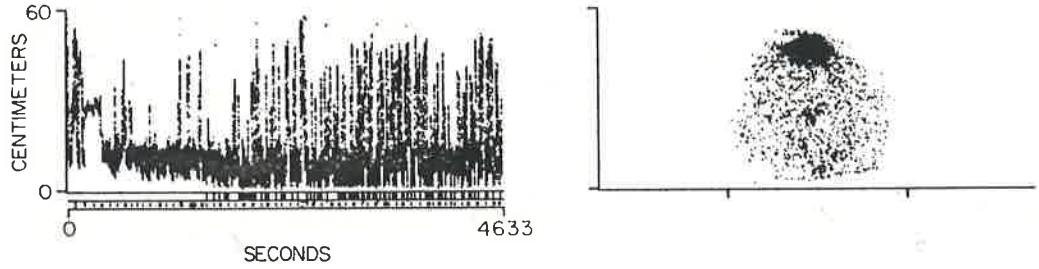
BASELINE DAY 1

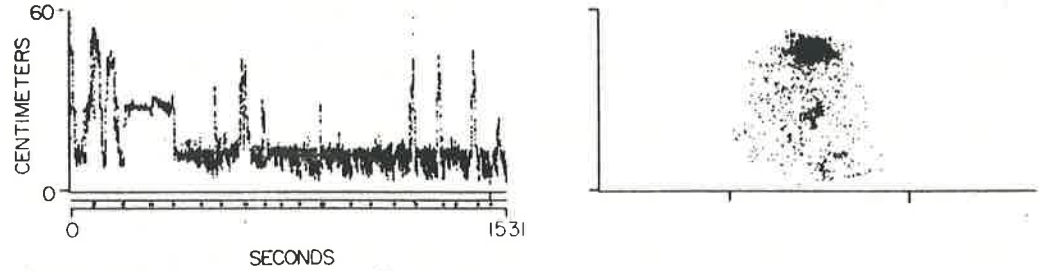


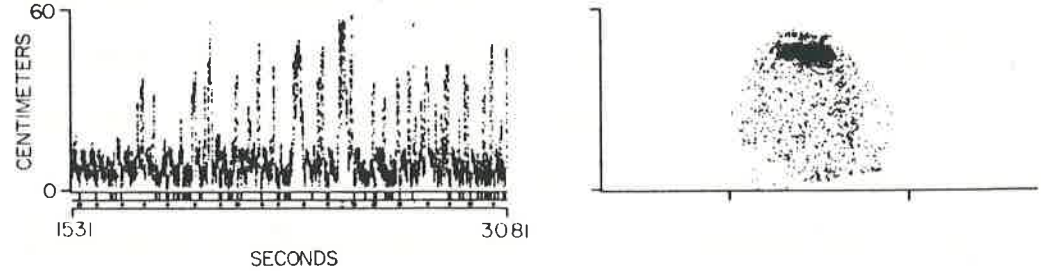
BASELINE DAY 2

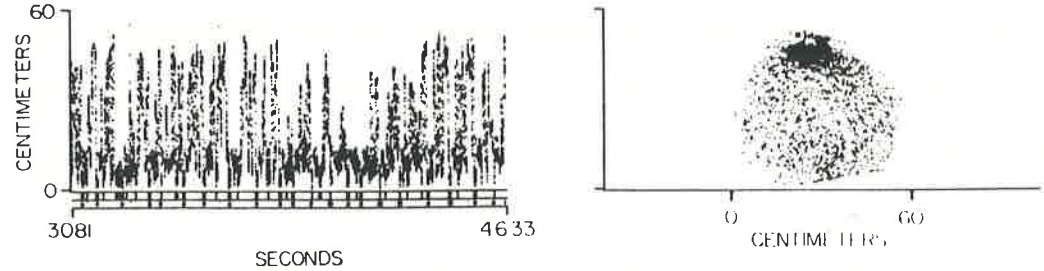


AUTOSHAPING DAY 1









quent sessions.

Figure 5 shows an expanded view of the gradual development to the first key-peck in trial #20, as described above, and a cumulative recording of the entire session as shown in the top row of Figure 5. The graphs in the left column of the figure show distance from the key, and in the right column, corresponding overhead plots of movements around the chamber. The cursor below the bottom horizontal line of the top graph in the left column indicates the segment of the session which is shown in expanded form in the four graphs below. On the cumulative recording, upward deflections of the lower event pen indicate CS-presentations, and downward deflections of the upper pen indicate reinforcer presentations.

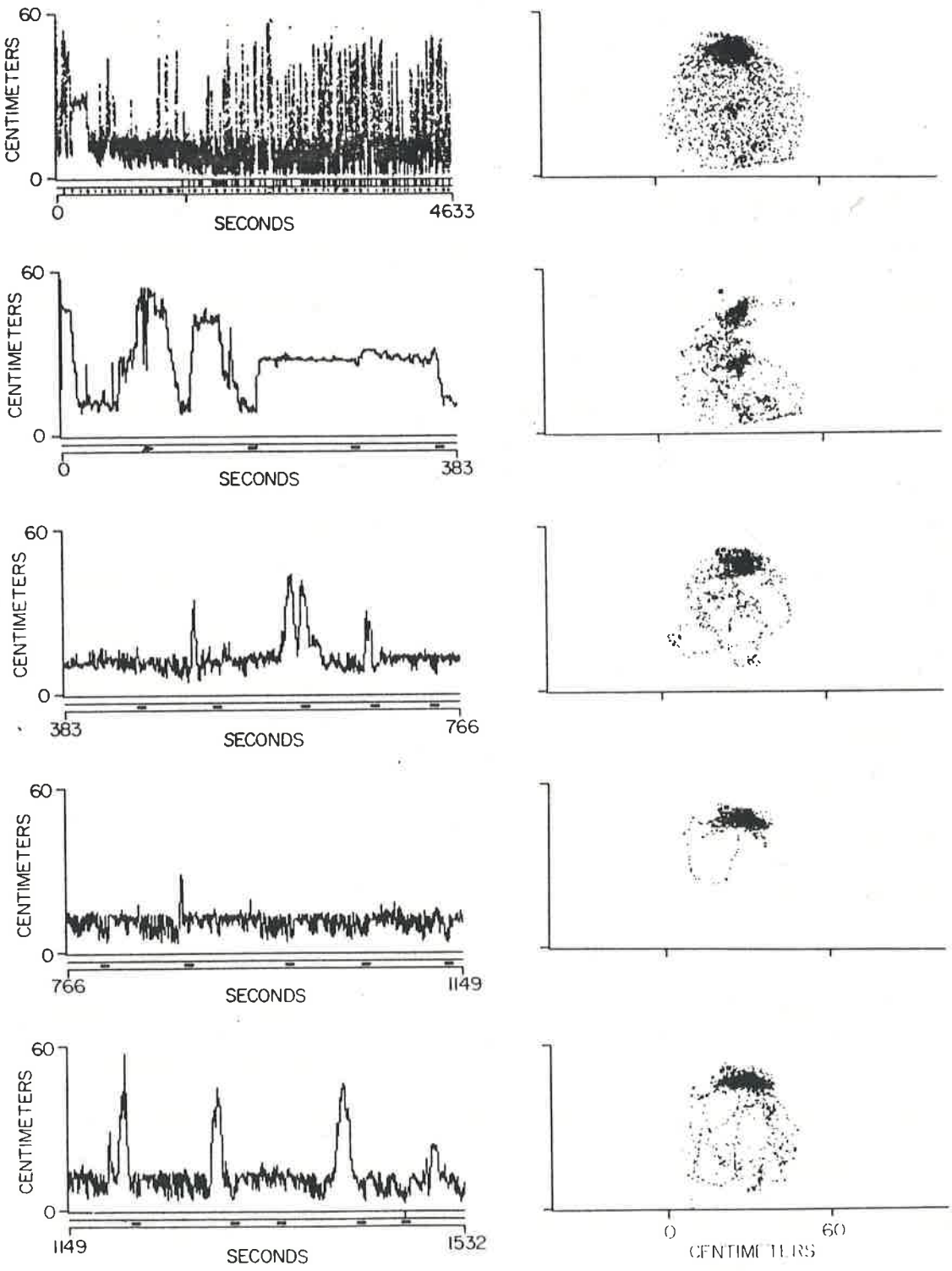
By the end of session 1, the subject reliably withdrew from the area of the key and the feeder at the end of a feeder presentation, and usually sat at the rear of the chamber, oriented out and to the rear, until the next CS. At CS-onset, he rapidly approached and pecked at (abortive key-pecks) and then on the red key throughout the CS-interval. This CS pattern persisted throughout all remaining autoshaping sessions in Phase 1; however, the ITI pattern shifted by day 3. The bird continued to circle to the rear of the chamber following feeder presentations; however, rather than remaining at the rear throughout the ITI, he developed a pattern which included circling of the chamber with repeated approaches to the white key. This new pattern stabilized and persisted for the remaining sessions of autoshaping in Phase 1.

Figure 6 illustrates these stable CS and ITI patterns during the final session of autoshaping in Phase 1. The graphs in the left column and the bottom graph in the right column show distance from the key. In these and all subsequent distance graphs, the cursors beneath the bottom horizontal line of each graph indicate areas which are expanded to show detail

Figure 5. Details of response topography for Bird #5052 for day 1 of autoshaping in Phase 1. The graphs in the left column show absolute distance of the bird's head from the key. Absolute distance in cm is indicated on the vertical axis, and session time in sec on the horizontal axis. Time during reinforcer presentations is not graphed. Pecks are indicated by the vertical marks between the upper pair of horizontal lines beneath each graph, and CS-presentations by the long vertical marks between the lower pair of horizontal lines. Errors in tracking the movement of the subject are indicated by the short marks between this lower pair of horizontal lines. The graphs in the right column show X vs. Y or overhead plots of the path of the bird's head as it moved around the chamber. These plots are located to the right of distance graphs showing the same segment of session time. The position of the key is indicated by the small dark square; the feeder is not shown but is located to the immediate right of the key. The extent of the chamber is indicated by the cursors on the vertical and horizontal axes. The outline of the chamber is rotated 15 degrees to the right of perpendicular. One discrete point is plotted per sec of session time. On the cumulative recording at the bottom of the figure, CS-presentations are indicated by upward deflections of the lower pen, and US-presentations by downward deflections of the upper pen.

BIRD 5052

AUTOSHAPING DAY 1



in lower graphs. The three upper graphs in the right column show overhead views of the session segments in the left column.

Rows 1 to 3 of this figure illustrate clearly: (1) withdrawal from the key and feeder following feeder presentations; (2) circling of the chamber and repeated approaches to the white key during the ITI; and (3) rapid approach to the red key at CS-onset. Row 4 shows the abortive pecks which typically preceded pecks to the key during the CS. The cumulative recording shows the regular pattern of steady key-pecks during the CS and no pecks during the ITI. The area shown in expanded form in rows 2 to 4 above is indicated on the cumulative recording.

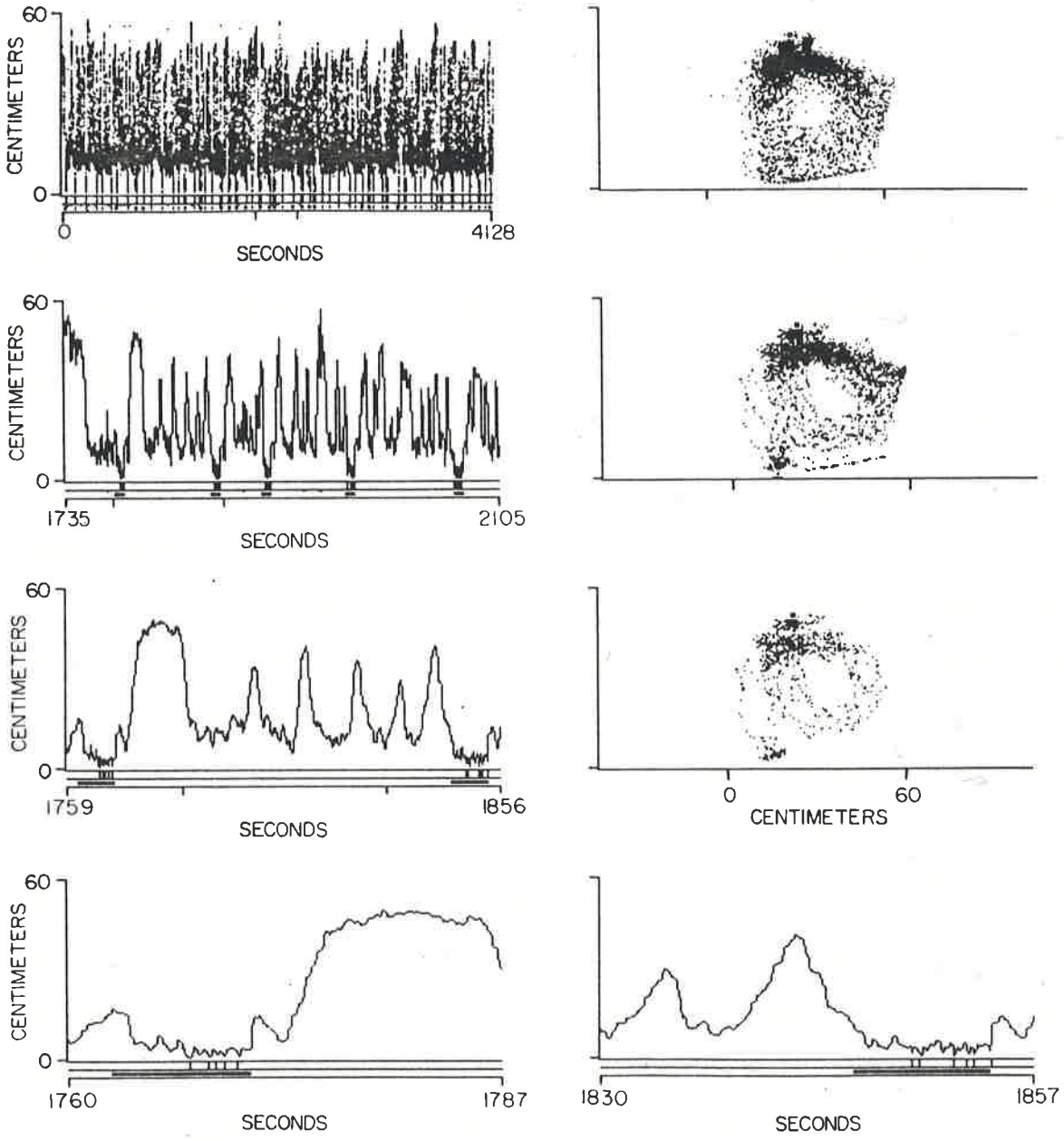
The introduction of the omission contingency for Bird #5052 produced a steady decrease in the number of trials with a key-peck, a decrease in response rate during the CS, and an initial increase in latency to the first key-peck during the CS (see Figure 2). In addition, response topography during both the ITI and the CS was altered by the omission contingency. The first change which occurred during day 1 of omission was an increase in the amount of time spent at the rear of the chamber during the ITI, similar to the ITI pattern during early sessions of autoshaping (see Figures 3 and 4). This was followed by an increase in the number of abortive pecks directed at the key during the CS, and a slight decrease in the number of actual key-contacts during the CS.

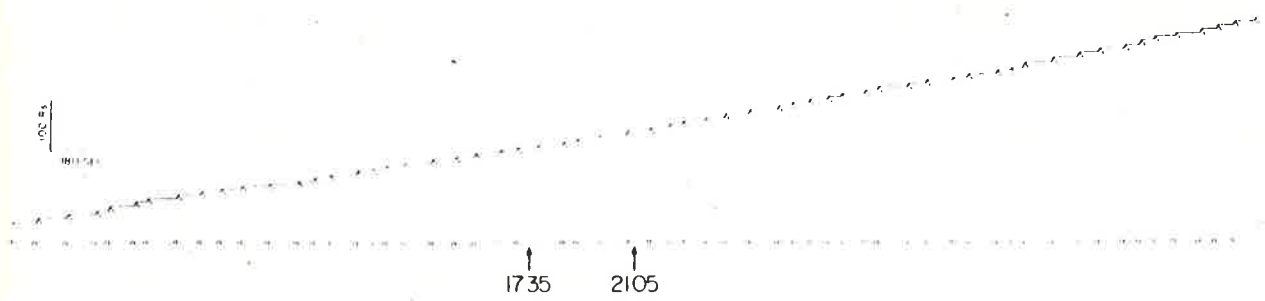
By day 3 of omission training, the subject had resumed frequent approaches to the white key during the ITI, however the random circling seen during the ITI in autoshaping was replaced by circling to the left of the key, particularly after reinforcement, and repetitive pacing from the right rear corner of the chamber to the key and back again throughout the ITI. The subject oriented toward the white key while pacing along the feeder wall. During day 3 as well, pecks on the chamber wall immediately

Figure 6. Stable CS and ITI response patterns during the final session of autoshaping in Phase 1 for Bird #5052. The graphs in the left column and the lower graph in the right column show absolute distance of the bird's head from the key. Absolute distance in cm is indicated on the vertical axis, and session time in sec on the horizontal axis. Time during reinforcer presentations is not graphed. Pecks are indicated by the vertical marks between the upper pair of horizontal lines beneath each graph, and CS-presentations by the long vertical marks between the lower pair of horizontal lines. Errors in tracking the movement of the bird are indicated by the short marks between this lower pair of horizontal lines. The cursors below the bottom horizontal line on each graph indicate areas which are expanded in lower graphs. The graphs in the upper right column show X vs. Y or overhead plots of the path of the bird's head as it moves around the chamber. These plots are located to the right of distance graphs showing the same segment of session time. The key is indicated by the small dark square; the feeder is not indicated but is located to the immediate right of the key. The extent of the chamber is indicated by the cursors on the vertical and horizontal axes. The outline of the chamber is rotated 15 degrees to the right of perpendicular. One discrete point is plotted per sec of session time. On the cumulative recording at the bottom of the figure, CS-presentations are indicated by upward deflections of the lower pen, and US-presentations by downward deflections of the upper pen.

BIRD 5052

AUTOSHAPING DAY 9





to the left of the key first appeared. Over subsequent sessions, the number of abortive pecks directed at the red key decreased and the number of pecks contacting the wall to the left of the key increased. This shift was correlated with an increase in the efficiency of omission responding as measured by a decrease in the number of trials with a key-peck, and an increase in the number of reinforcers per session.

Figure 7 shows the development of this omission pattern of pecking the feeder wall to the left of the key during the CS, and compares this pattern to CS-patterns during Phases 1 and 2 of autoshaping. The graphs on this figure show a Z vs. X view or front elevation of the key and feeder wall. These graphs represent schematically the rear view of the pigeon's head moving against the wall around the key during CS-presentations only. Four CS-presentations selected from the center (trials 28 to 32) of one session are shown in each graph. The left column shows sessions from Phase 1 of autoshaping, the center column from omission training, and the right column from Phase 2 of autoshaping. The height of the chamber in cm is shown on the vertical axis, and a segment (30 cm) of the wall around the key is shown on the horizontal axis for each successive CS-presentation. The solid dark lines between the lower pair of horizontal lines beneath each graph indicate the time-course of each successive CS-interval. Key-pecks during each interval are indicated by the vertical lines above the CS indicators and between the upper pair of horizontal lines. The key position is indicated for each CS-presentation by the small dark square in the body of the graph. One data point is plotted for each 1/10 sec during each CS-interval.

As can be seen in Figure 7, during the first phase of autoshaping and the early sessions of omission training, key-pecks and pecking movements (which cannot be distinguished in this view) were centered on the key

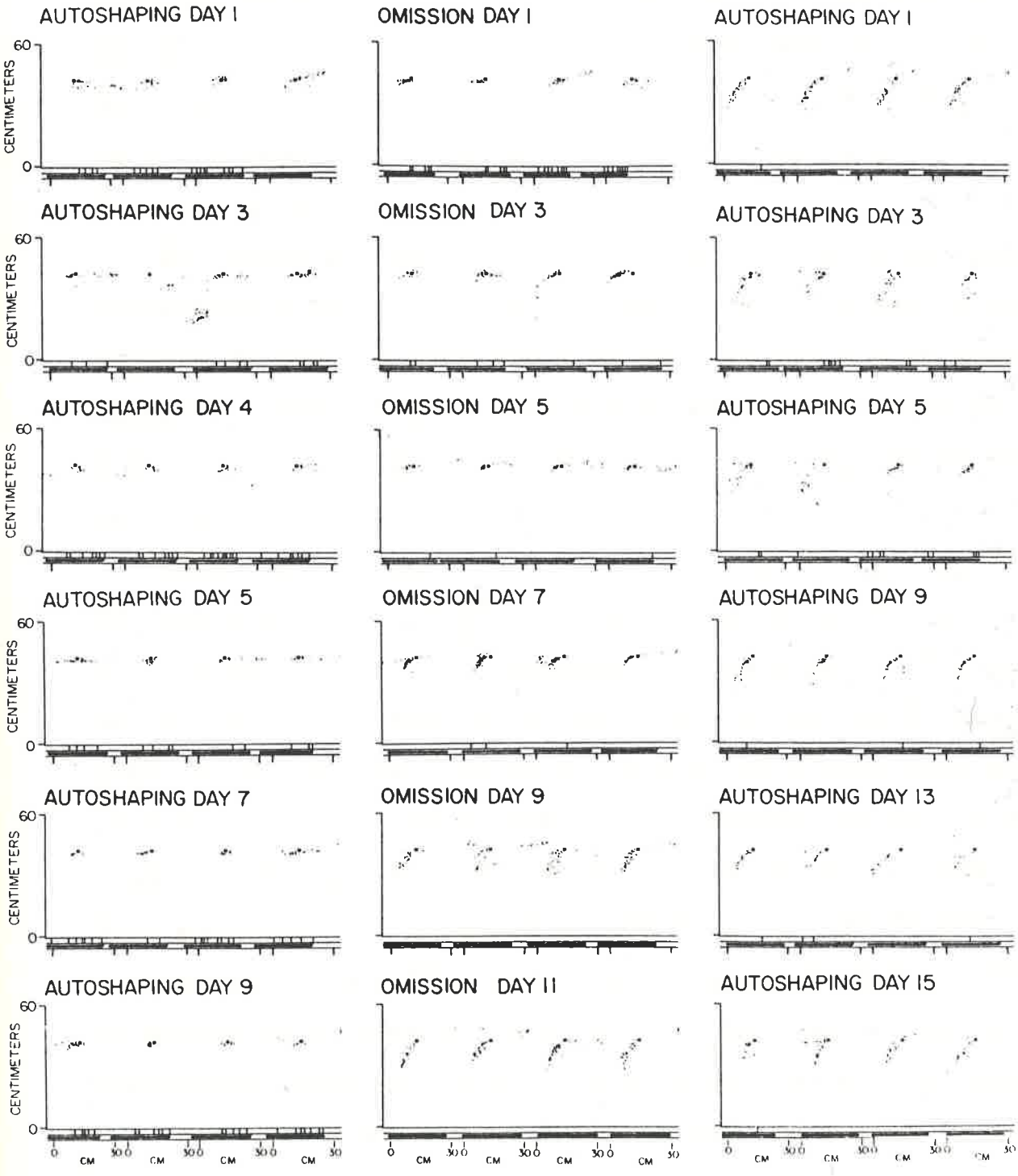
during CS-presentations. However, on day 3 of omission training, pecks began to be redirected from the key to the feeder wall immediately to the left of the key. Beginning in session 7, and persisting throughout all subsequent omission sessions, pecks to the immediate left of the key occurred early in each CS, followed by pecks down the wall to the left of the key and to the floor of the chamber. With this change in topography, very few key-pecks occurred, as can be seen in the graphs for omission days 9 and 11 in Figure 7, and in Figure 2. This shift in topography did not appear to represent a shift to goal-tracking (responding toward the feeder) rather than sign-tracking (responding toward the key) during omission, as all pecks to the wall occurred to the left of the key away from the feeder.

Figure 8 shows in detail stable CS and ITI patterns during day 11 of omission training for Bird #5052. Graphs in the left column show distance from the key. The upper three graphs in the right column show overhead plots corresponding to the distance graphs at the left. The bottom graph in the right column shows pecks to the wall as described in Figure 7 above. The four CS-presentations shown in Figure 8 are those indicated by the cursors in the second graph in the left column.

The graphs in the first three rows of this figure illustrate: (1) the stable ITI pattern which included circling away from the key and the feeder after feeder presentations, followed by repetitive pacing of the right chamber wall and the feeder wall, with frequent approaches to the white key; (2) rapid approaches to the key area at CS-onset; and (3) pecks directed to the left of the key during the CS. This movement to the left of the key is particularly evident in the overhead plots, as well as the graph of head movements in the lower right column. The enlarged view of distance from the key in the bottom graph in the left column indicates

Figure 7. Z vs. X or front elevations showing responding during CS-intervals during sessions from autoshaping, Phase 1, omission training, and autoshaping, Phase 2, for Bird #5052. The graphs on this figure show Z vs. X views or front elevations of the key and feeder, representing schematically the rear view of the pigeon's head moving against the wall during CS-presentations only. CS-presentations from trials 28 to 32 are shown for each session. The left column shows sessions from autoshaping, Phase 1, the center column from omission training, and the right column from Phase 2 of autoshaping. The height of the chamber in cm is shown on the vertical axis, and a 30 cm segment of the wall around the key is shown on the horizontal axis for each successive CS-presentation. The solid dark lines between the lower pair of horizontal lines beneath each graph indicate the time-course of each successive CS-interval. Key-pecks are indicated by the vertical lines above the CS-indicators. Key position is indicated by the small dark square in the body of the graph. One point is plotted for each 1/10 sec during each CS-interval.

BIRD 5052


AUTOSHAPING DAY 1
OMISSION DAY 1
AUTOSHAPING DAY 1
AUTOSHAPING DAY 3
OMISSION DAY 3
AUTOSHAPING DAY 3
AUTOSHAPING DAY 4
OMISSION DAY 5
AUTOSHAPING DAY 5
AUTOSHAPING DAY 5
OMISSION DAY 7
AUTOSHAPING DAY 9
AUTOSHAPING DAY 7
OMISSION DAY 9
AUTOSHAPING DAY 13
AUTOSHAPING DAY 9
OMISSION DAY 11
AUTOSHAPING DAY 15
CENTIMETERS
60
0
0
CM
50
CM
50
CM
50
CM
50

that about six pecks to the wall occurred during each CS-interval. This means that pecks to the wall during the CS occurred at an average rate of about 45 pecks per min during the entire session. This is only slightly lower than the mean rate of key-pecking during Phase 1 of autoshaping, suggesting that the omission contingency did not suppress pecking, but simply redirected it to another area near the key. The cumulative recording of this session shows that only four key-pecks occurred and four reinforcers were omitted.

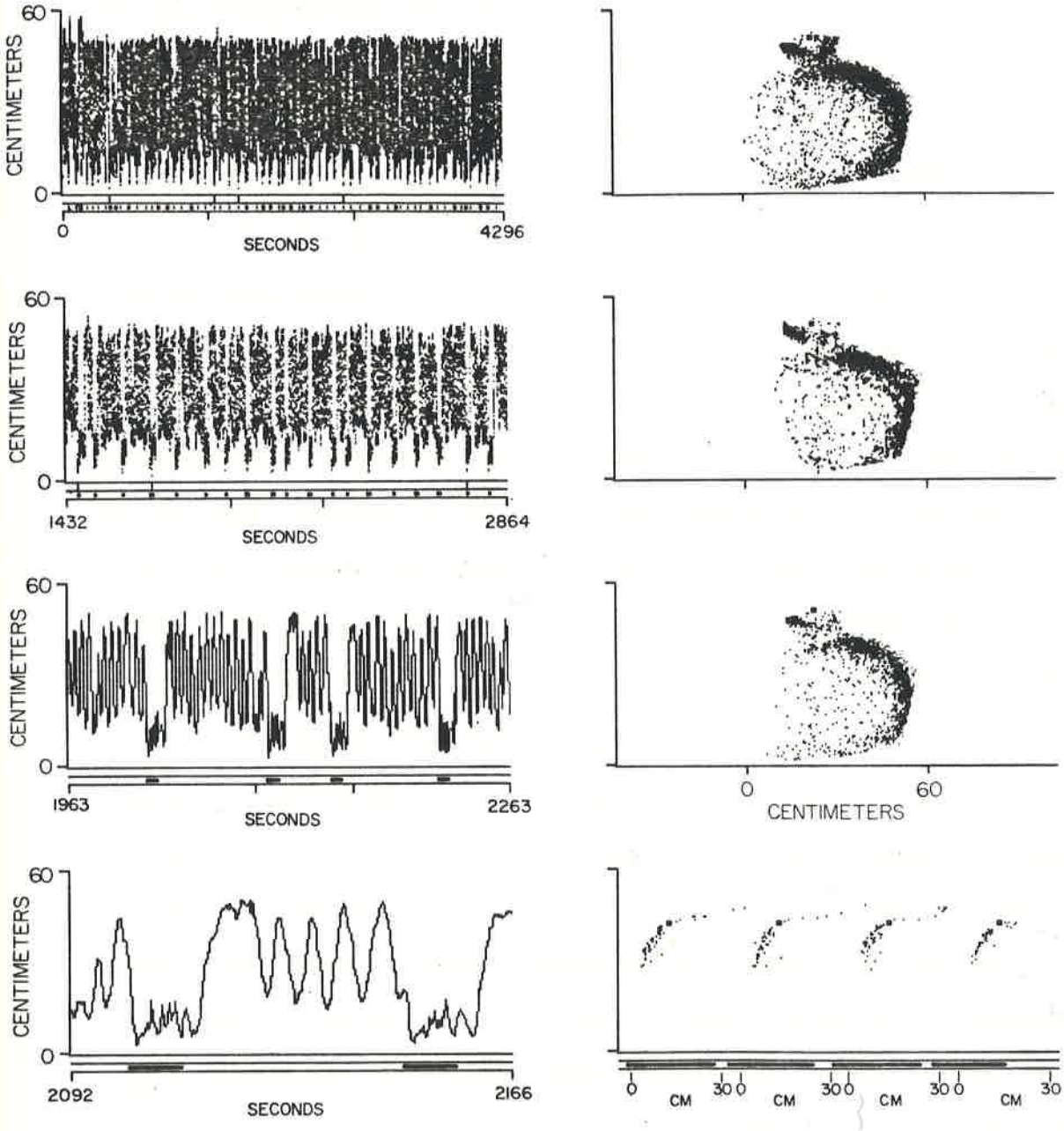
This pattern of pecking the wall during the CS did not change appreciably following the removal of the omission contingency, despite an increase in the number of trials with a key-peck. The number of key-pecks increased in comparison to the final sessions of omission training, but pecks to the wall throughout the final phase of autoshaping remained far more frequent than pecks to the key.

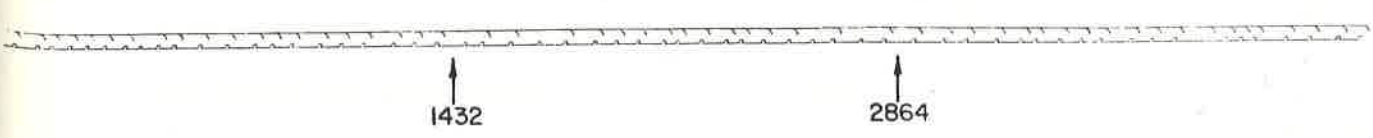
Figure 9 shows CS and ITI patterns following the removal of the omission contingency for Bird #5052. The upper graphs (day 4) are from a session early in Phase 2, when key-pecking was increasing; the lower graphs (day 17) are from a session late in Phase 2, when key-pecking had declined almost to omission levels. For day 4, the upper row of graphs shows distance from the key, and the overhead plot for the entire session. The lower row shows expanded portions of the distance graph from the upper row. These graphs illustrate changes in both the CS-intervals and the ITI's when compared to stable behavior in omission training from Figure 8 above. As indicated by the upper left graph showing distance from the key, and the cumulative recording, key-pecks, including multiple key-pecks, occurred during 50 of 60 trials on day 4, in contrast to one key-peck in each of four trials on day 11 of omission. However, pecking down the wall to the left of the key during the CS was maintained during day 4, and remained

Figure 8. Stable CS and ITI response patterns during the eleventh session of omission training for Bird #5052. The graphs in the left column show absolute distance of the bird's head from the key. Absolute distance in cm is indicated on the vertical axis, and session time in sec on the horizontal axis. Time during reinforcer presentations is not graphed. Pecks are indicated by the vertical marks between the upper pair of horizontal lines beneath each graph, and CS-presentations by the long vertical marks between the lower pair of horizontal lines. Errors in tracking are indicated by the short marks between these lower horizontal lines. Cursors below the bottom line on each graph indicate areas which are expanded in lower graphs. The three graphs in the upper right column show X vs. Y or overhead plots of the path of the bird's head as it moves around the chamber. These plots are located to the right of distance plots showing the same segment of session time. The key is indicated by the small dark square; the feeder is not shown but is located to the immediate right of the key. The extent of the chamber is indicated by the cursors on the vertical and horizontal axes. The outline of the chamber is rotated 15 degrees to the right of perpendicular. One discrete point is plotted per sec of session time. The lower graph in the right column shows a Z vs. X or front elevation showing responding during four successive CS-presentations shown in the distance graph to the left. The height of the chamber is shown in cm on the vertical axis, and a 30 cm area around the key is shown on the horizontal axis. Solid dark lines between the lower pair of horizontal lines indicate the time-course of each CS-interval. Key-pecks are indicated by vertical marks above these lines. One point is plotted for each 1/10 sec. CS-presentations are indicated by upward deflections of the lower pen, and US-presentations by downward deflections of the upper pen on the cumulative recording.

BIRD 5052

OMISSION DAY 11





more frequent than key-pecking. The ITI pattern shown in the upper right graph is more similar to the ITI pattern in Phase 1 of autoshaping than to the final pattern during omission training. Early in autoshaping in Phase 2, the bird made random circling movements of the chamber throughout each ITI, with repeated approaches to the white key, in contrast to the repetitive pacing pattern shown in Figure 8 for omission training.

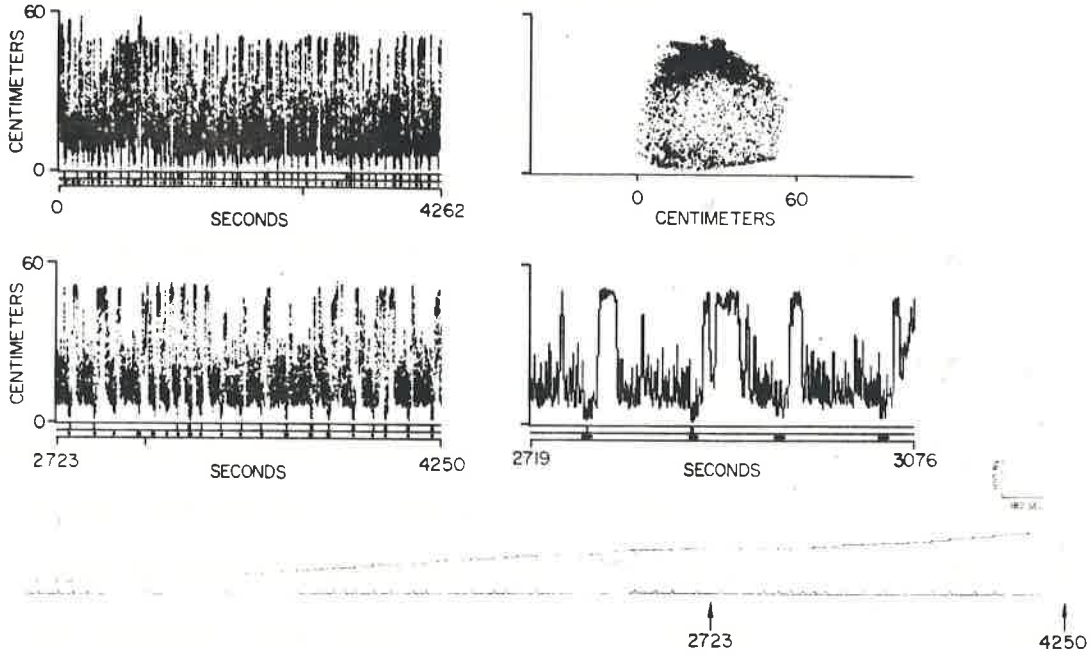
For day 17, graphs in the left column show distance from the key, and the two upper graphs in the right column show corresponding overhead plots. The lower graph in the right column shows a Z vs. X view of pecking down the wall during CS-presentations, as described in Figure 7. The four CS-presentations illustrated are indicated on the distance graph immediately to the left. The stable CS and ITI patterns shown here for day 17 are virtually identical to stable patterns during the previous phase of omission training (see Figure 8). On day 17 of autoshaping in Phase 2, key-pecks occurred during 15 of 60 trials; however, no more than one key-peck occurred during any one trial. This is higher than the level of key-pecking at the end of omission training, but considerably less than the number of key-pecks in Phase 1, or early in Phase 2 of autoshaping. The graphs in the lower row show that pecking to the left of the key and down the wall to the floor continued throughout CS-intervals and was more frequent than pecks to the key. The ITI pattern late in Phase 2 of autoshaping was highly similar to that during omission training. Early in each ITI, the bird paced along the feeder wall oriented toward the white key. As the ITI progressed, the bird paced farther away from the key along the right wall of the chamber before returning to the area of the key. This progressive increase in distance from the key during pacing is evident in the two lower distance graphs in the left column.

In summary, Bird #5052 developed stable patterns of both CS and ITI

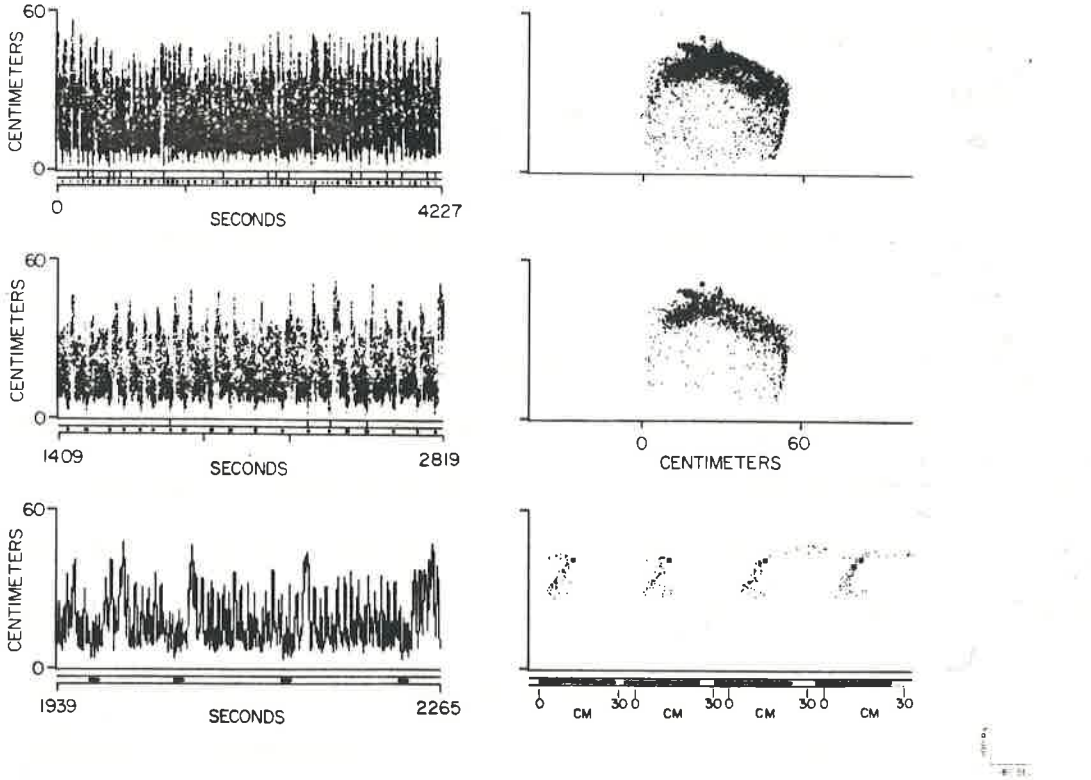
Figure 9. Stable CS and ITI response patterns during autoshaping, Phase 2, for Bird #5052. This figure shows graphs from day 4 (early in autoshaping) and day 17 (late in autoshaping). Graphs in the left column and in the second row of the right column show absolute distance of the bird's head from the key. Absolute distance in cm is shown on the vertical axis, and session time in sec on the lower axis. Time during reinforcer presentations is not graphed. Pecks are indicated by vertical marks between the upper pair of horizontal lines beneath each graphs, and CS-presentations by long marks between the lower pair of horizontal lines. Tracking errors are shown by short marks between this lower pair of lines. Cursors below the bottom line indicate areas expanded in lower graphs. The graph in the fifth row of the right column shows a Z vs. X or front elevation of head movements during successive CS-intervals shown in the distance graph to the left. Height of the chamber in cm is shown on the vertical axis, and a 30 cm segment around the key is shown on the horizontal axis. Solid dark lines between the lower pair of horizontal lines indicate the time-course of each CS-interval. Key-pecks are indicated by vertical marks above these lines. One point is plotted for each 1/10 sec. The remaining graphs in the right column show X vs. Y or overhead plots of the bird's movements. These plots are located to the right of distance graphs showing the same segment of session time. The key is indicated by the small dark square; the feeder is not shown but is located to the immediate right of the key. The extent of the chamber is indicated by the cursors on the horizontal and vertical axes, but is rotated 15 degrees to the right of perpendicular. One discrete point is plotted per sec of session time. CS-presentations are indicated by upward deflections of the lower pen, and US-presentations by downward deflections of the upper pen on the cumulative recordings.

BIRD 5052

AUTOSHAPING DAY 4



AUTOSHAPING DAY 17



behavior in each phase. During Phase 1 of autoshaping, the bird withdrew from the area of the key and made random circling movements of the chamber, with repeated approaches to the white key during the ITI. Key-pecks did not occur to the white key after the first session of autoshaping. At CS-onset, the bird moved rapidly to the key, and first directed abortive pecks at the key, followed by pecks to the key throughout the rest of the CS-interval.

The first change during omission training was an increase in the amount of time spent away from the area of the key during the ITI, similar to that seen early in Phase 1 of autoshaping. This was followed by an increase in abortive pecks directed at the key, and a decrease in actual key-contacts. The omission contingency did not affect approaches to the CS, as the bird continued to approach the red key immediately at CS-onset. By day 5 of omission training, abortive pecks disappeared and most pecks were displaced from the key to the wall immediately to the left of the key. This persisted throughout omission training. Stable omission patterns included rapid approach to the key at CS-onset, and pecks to the left of the key and down the wall to the floor. During the ITI, the subject withdrew from the area of the key, and then paced the right wall of the chamber and the feeder wall, with frequent approaches to the white key.

Following removal of the omission contingency, key-pecking increased for four days, and then declined and stabilized at levels slightly above those at the end of omission training. Mean latency to the first key-peck in the CS-interval decreased below that seen during Phase 1 of autoshaping. This suggests that few key-pecks occurred, but those that did occurred early in the CS-interval, on the average. The omission pattern of approaching the key at CS-onset and pecking down the wall to the left of the key persisted during Phase 2 of autoshaping. With the initial

increase in key-pecking, the ITI pattern shifted to random circling of the chamber and repeated approaches to the white key, similar to that during Phase 1 of autoshaping. However, as key-pecking decreased, the ITI pattern reverted to a pacing pattern similar to that seen during omission training.

ITI patterns across all phases were similar in that the subject withdrew from the area of the key and the feeder following feeder presentations, and made repeated approaches to the white key during the ITI, without key-pecking. Early in both Phase 1 of autoshaping and omission training, the bird spent relatively more time at the rear of the chamber during the ITI. During the remainder of Phase 1, and early in Phase 2 of autoshaping, the subject made random circles of the chamber between approaches to the white key. During stable omission training and late in Phase 2 of autoshaping, the subject repetitively paced the right wall of the chamber and the feeder wall between approaches to the white key.

Despite the apparent differences in omission performance between Bird #5052 and Bird #1134 suggested by Figures 2 and 3, a comparison of response topographies between the two birds shows great consistency. Figures 10 to 14 illustrate response topography during autoshaping and omission for Bird #1134.

Figure 10 shows response topography for Bird #1134 during baseline days 1 and 2, and the first day of autoshaping in Phase 1. The top two rows of graphs show distance from the key and overhead plots of the entire session for baseline days 1 and 2. At the beginning of the first baseline session, Bird #1134 made numerous agitated approaches to the feeder, with only occasional head movements toward the white key before withdrawing to the rear of the chamber. For the remainder of the session, the subject paced the rear wall of the chamber, circled and approached the

feeder, or preened at the rear of the chamber. During day 2 of baseline, the subject initially approached the feeder and then withdrew to the center and rear of the chamber with only occasional approaches to the feeder for the remainder of the session. Compared to Bird #5052, Bird #1134 made few approaches to the white key during baseline.

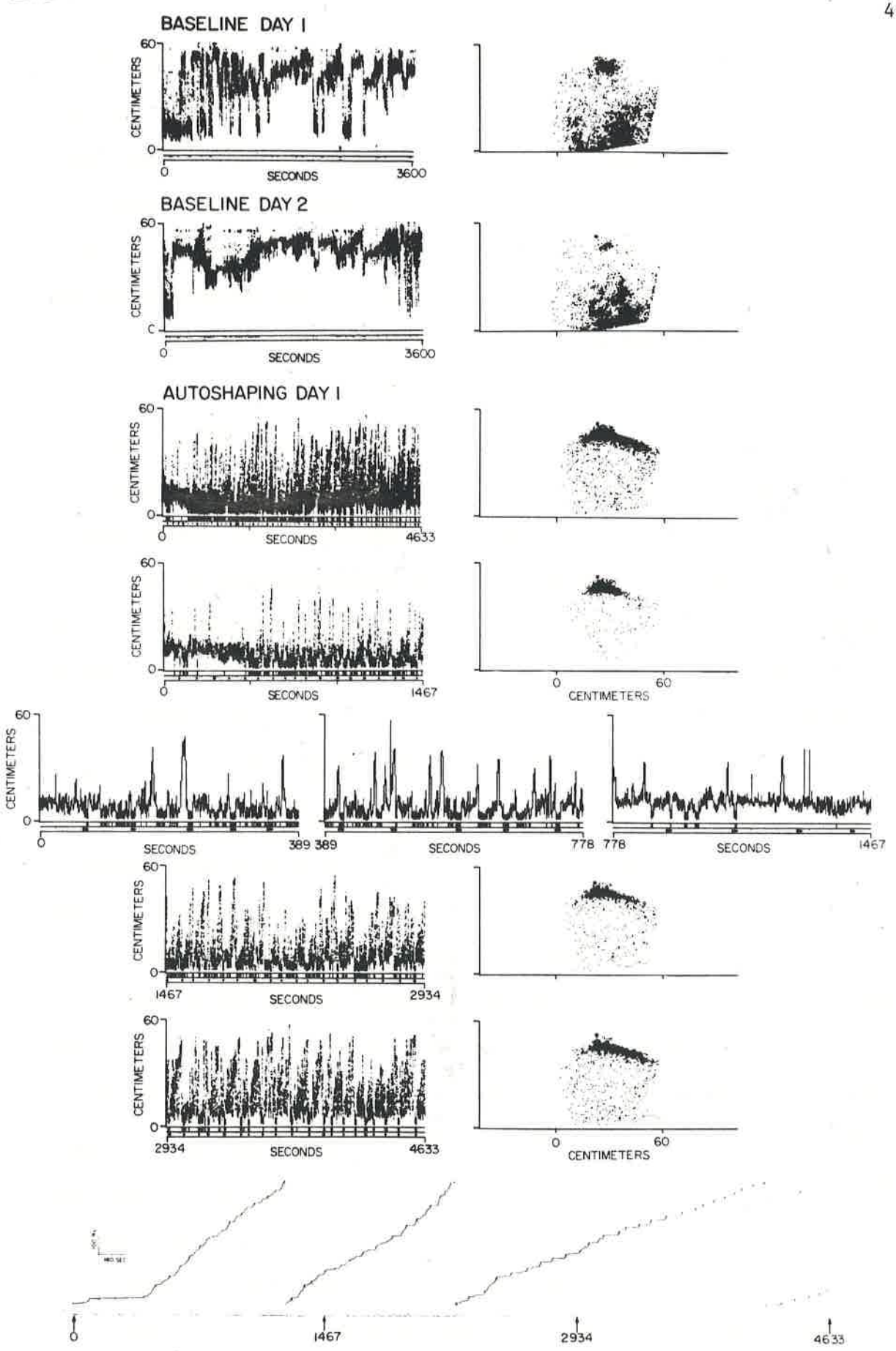
The lower five rows of graphs and the cumulative recording at the bottom of Figure 10 illustrate the development of pecking to the white and the red keylight, and the subsequent reduction in pecking to the white keylight during session 1 of autoshaping. The graphs in the left column and the middle row show distance from the key. The graphs in the right column show overhead plots corresponding to the distance graphs to the left.

Unlike Bird #5052, who pecked the red keylight on trial #20, Bird #1134 approached and pecked the white keylight and then the red keylight on the first trial before any reinforcers had been delivered. Following delivery of the first reinforcer, #1134 pecked both the white and the red keylight on the next trial, and then moved from the key to the feeder. The bird sat in front of the feeder, making repeated head movements toward the key during both the CS and the ITI for two trials. In trial #5, high-rate pecking resumed to both the red and the white keylights, and continued until trial 44. After trial 44, pecks occurred only to the red key. During this reduction in pecking to the white key, abortive pecking directed at the white key and circling to the rear of the chamber occurred during the ITI. By the end of session 1, the bird circled away from the area of the key and the feeder to the rear of the chamber during the ITI, and returned to the key at CS-onset and pecked rapidly throughout the CS-interval.

This rapid reduction in pecking to the white key and withdrawal from

Figure 10. Response topography for Bird #1134 for baseline days 1 and 2, and the first session of autoshaping. Graphs in the left column, and in the fifth row show absolute distance of the bird's head from the key. Absolute distance in cm is indicated on the vertical axis, and session time in sec on the horizontal axis. Time during reinforcer presentations is not graphed. Pecks are indicated by vertical marks between the upper pair of horizontal lines beneath each graph, and CS-presentations by long vertical marks between the lower pair of horizontal lines. Errors in tracking are indicated by the short marks between this lower pair of lines. Cursors on each graph indicate areas expanded in lower graphs. The graphs in the right column show X vs. Y or overhead plots of the path of the bird's head as it moves around the chamber. These plots are located to the right of corresponding distance graphs. The key is indicated by the small dark square; the feeder is not shown, but is located to the immediate right of the key. The extent of the chamber is indicated by the cursors on the vertical and horizontal axes, but is rotated 15 degrees to the right of perpendicular. One discrete point is plotted per sec of session time. On the cumulative recording at the bottom of the page, CS-presentations are indicated by upward deflections of the lower event pen, and US-presentations by downward deflections of the upper pen.

BIRD 1134


BASELINE DAY 1
60
CENTIMETERS
0
0
SECONDS
3600
BASELINE DAY 2
60
CENTIMETERS
0
0
SECONDS
3600
AUTOSHAPING DAY 1
60
CENTIMETERS
0
0
SECONDS
4633
60
CENTIMETERS
0
0
SECONDS
1467
0
60
CENTIMETERS
60
CENTIMETERS
0
0
SECONDS
389
389
SECONDS
778
778
SECONDS
1467
60
CENTIMETERS
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1467
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the white key during the ITI is similar to Bird #5052 during the first session of autoshaping. Unlike #5052, however, pecking to the white key reappeared for increasingly brief periods early in both the second and third sessions of autoshaping for Bird #1134. Figure 11 shows the transition between patterns of responding early in autoshaping (see Figure 10) and stable patterns of responding later in autoshaping (see Figure 12). Graphs in the left column show distance from the key, and in the right column, corresponding overhead plots. The first five pairs of graphs show details from the second session of autoshaping, followed by the cumulative recording for that day. The final pair of graphs and the cumulative recording beneath show the overall session from day 3 of autoshaping.

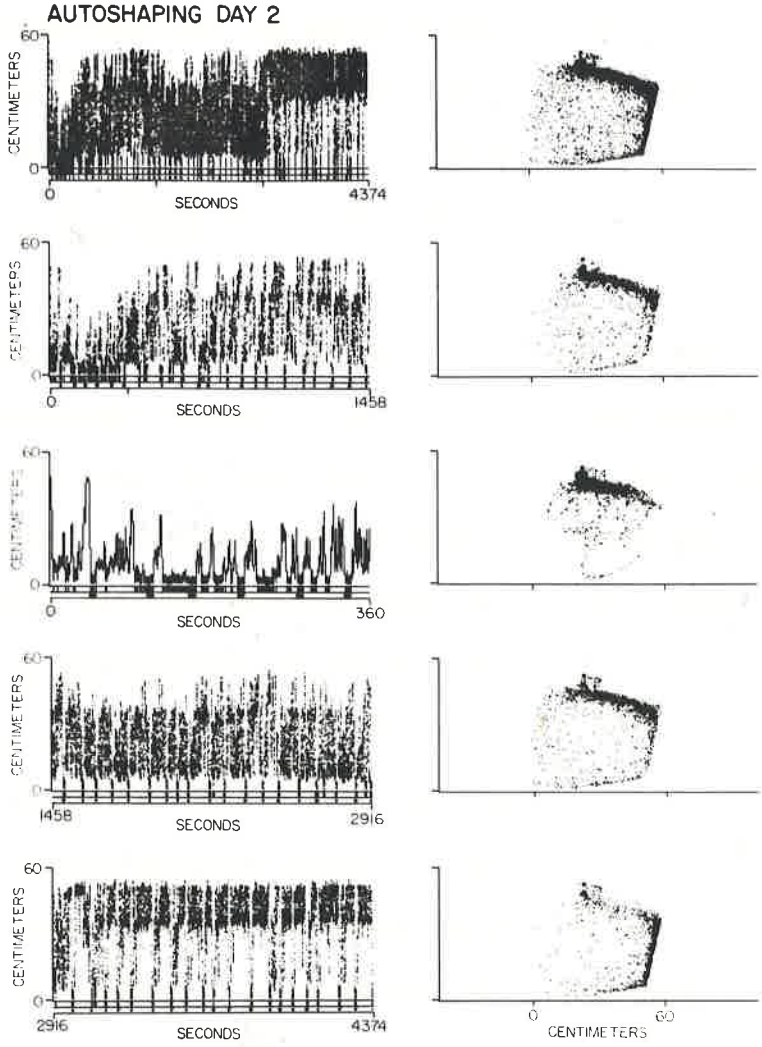
Early in the second session, high rates of key-pecking occurred during both the CS and the ITI; however, by the twelfth trial, key-pecking occurred only during the CS. Following each feeder presentation, the bird circled away from the key and the feeder, and returned to pace along the feeder wall from the right corner to the key during the remainder of the ITI. At CS-onset, the bird approached the red key and pecked rapidly throughout the CS-interval. The ITI pattern changed abruptly at approximately 3000 sec into the session. Rather than pacing the feeder wall during the ITI, the subject repetitively paced back and forth along the right wall of the chamber, oriented outside the chamber. On day 3, some key-pecking during the ITI occurred early in the session, but by the third trial, stable patterns of approaching the red key and key-pecking during the CS, and pacing the right wall of the chamber during the ITI appeared. These patterns persisted throughout the remaining sessions of autoshaping in Phase 1.

Figure 12 shows stable patterns of responding for Bird #1134 during the sixth day of autoshaping in Phase 1. These patterns were typical of

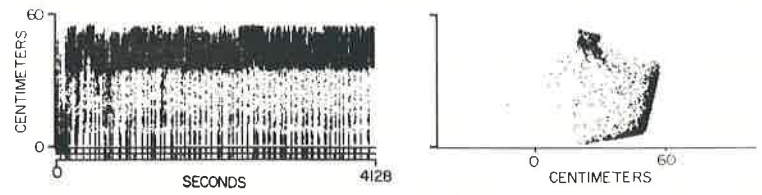
Figure 11. Transition to stable patterns of responding for Bird #1134 during autoshaping in Phase 1. Graphs in the left column show absolute distance of the bird's head from the key. Absolute distance in cm is indicated on the vertical axis, and session time in sec on the horizontal axis. Time during reinforcer presentations is not graphed. Pecks are indicated by vertical marks between the upper pair of horizontal lines beneath each graph, and CS-presentations by long vertical marks between the lower pair of horizontal lines. Errors in tracking are indicated by the short marks between this lower pair of lines. Cursors on each graph indicate areas expanded in lower graphs. The graphs in the right column show X vs. Y or overhead plots of the path of the bird's head as it moves around the chamber. These plots are located to the right of corresponding distance graphs. The key is indicated by the small dark square; the feeder is not shown, but is located to the immediate right of the key. The extent of the chamber in cm is indicated by the cursors on the vertical and horizontal axes, but the chamber is rotated 15 degrees to the right of perpendicular. One discrete point is plotted per sec of session time. CS-presentations are indicated by upward deflections of the lower pen, and US-presentations by downward deflections of the upper pen on the cumulative recordings.

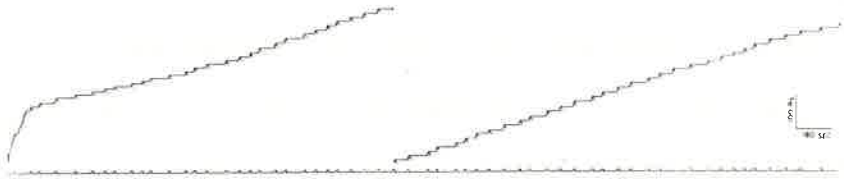
BIRD 1134

AUTOSHAPING DAY 2



AUTOSHAPING DAY 3





sessions 5 to 7 of autoshaping. The first row shows distance from the key and the overhead plot for the entire session. The second row shows details from the center area marked by cursors in the upper left graph. The three lower graphs show greatly enlarged details from that same segment. The cumulative recording shows the pattern of key-pecking during the entire session.

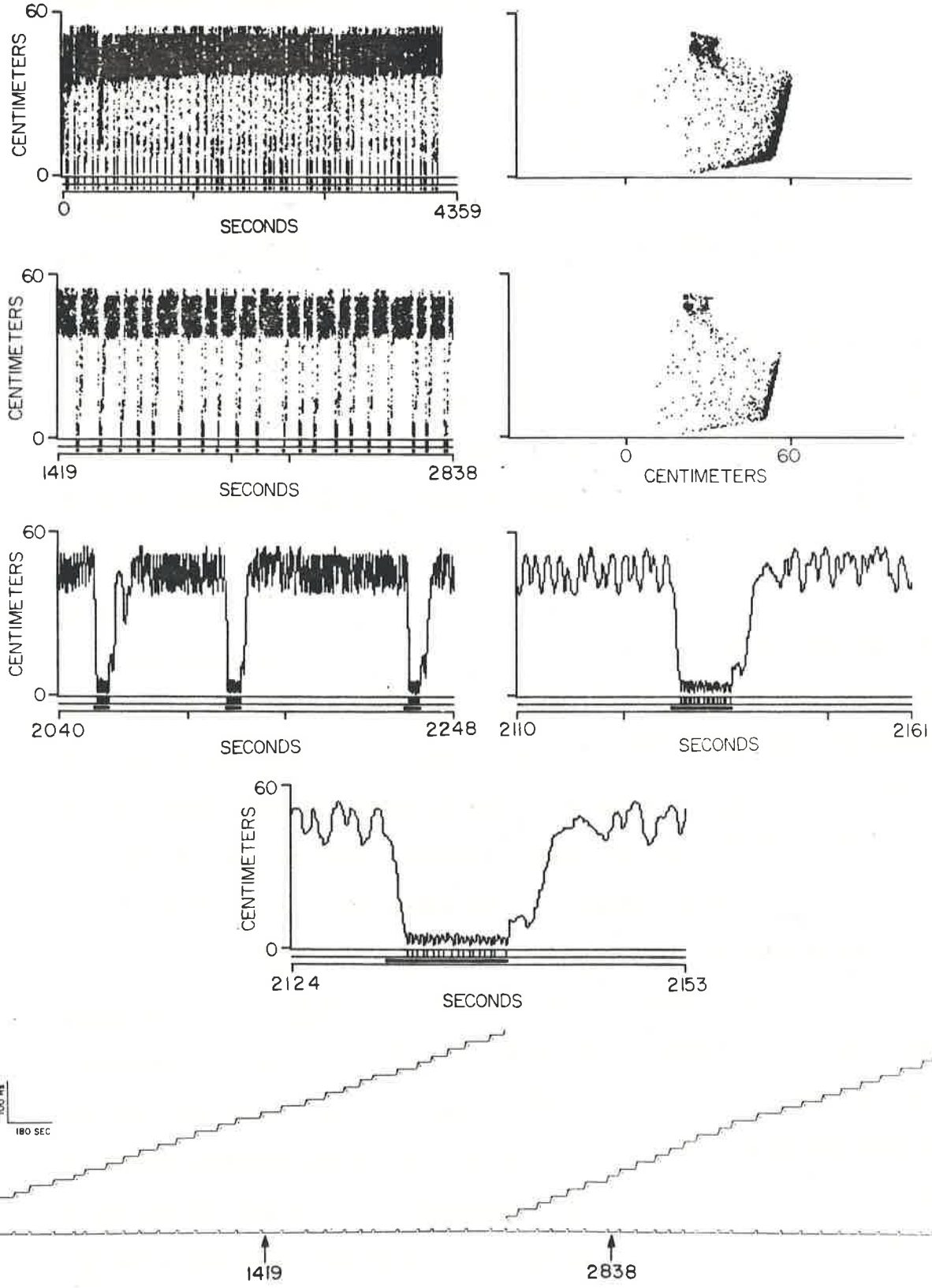
This figure clearly illustrates: (1) withdrawal from the feeder and key following feeder presentations; (2) repetitive pacing of the right wall during the ITI; (3) rapid approach to the key at CS-onset; and (4) rapid key-pecking throughout the CS-interval. The detail in row 4 shows that occasional abortive pecks directed at the key occurred during the CS. However, with the exception of day 4, when abortive pecks were frequent, and the rate of key-pecking was low (see Figure 3), abortive pecks occurred rarely during autoshaping for this subject. The cumulative recording shows clearly that key-pecks occurred only during the CS. The stable autoshaping patterns illustrated here for Bird #1134 are highly similar to the stable autoshaping patterns for Bird #5052 shown in Figure 6.

For Bird #1134, the response patterns described above were not altered during day 1 of omission training, although response rate during the CS declined slightly and mean latency to the first key-peck during the CS increased slightly (see Figure 3). Occasional abortive pecks occurred during CS-presentations, but these did not appear to be more frequent than during autoshaping. However, similar to Bird #5052, changes in the ITI pattern occurred prior to changes in the CS pattern. From the first trial of session 2 of omission training, the previous ITI pattern of pacing the right wall of the chamber was completely disrupted, and was replaced by random patterns of circling the chamber, approaching the white key and the feeder, pacing the rear wall of the chamber, agitated preening at the rear

Figure 12. Stable CS and ITI response patterns during the sixth session of autoshaping in Phase 1 for Bird #1134. All graphs other than the two in the upper right column show absolute distance of the bird's head from the key. Absolute distance in cm is indicated on the vertical axis, and session time in sec on the horizontal axis. Time during reinforcer presentations is not graphed. Pecks are indicated by vertical marks between the upper pair of horizontal lines beneath each graph, and CS-presentations by long vertical marks between the lower pair of horizontal lines. Tracking errors are indicated by the short marks between this lower pair of lines. Cursors on the graphs indicate areas expanded in lower graphs. The two remaining graphs show X vs. Y or overhead plots of the path of the bird's head as it moves around the chamber. These plots are located to the right of corresponding distance graphs. The key is indicated by the small dark square; the feeder is not shown but is located to the immediate right of the key. The extent of the chamber in cm is indicated by the cursors on the vertical and horizontal axes, but the chamber itself is rotated 15 degrees to the right of perpendicular. One discrete point is plotted per sec of session time. CS-presentations are indicated by upward deflections of the lower pen, and US-presentations by downward deflections of the upper pen on the cumulative recording.

BIRD 1134

AUTOSHAPING DAY 6



of the chamber, and sitting in the center of the chamber, oriented away from the key. Approaches to the key at CS-onset occurred on all but two trials.

On these two occasions, the bird preened at the rear of the chamber throughout the CS and omitted pecking, but also missed the reinforcer when it was delivered. On six other trials, the bird omitted pecking by making very slow approaches to the key at CS-onset. However, slow approaches, which were reinforced on six trials, did not increase greatly in frequency, while abortive pecks directed at the red key did increase, although they were reinforced on only one trial. This increase in abortive pecking is reflected in the reduction in response rate during the CS and the increase in mean latency to the first key-peck during the CS for this session (see Figure 3), although key-pecks were successfully omitted on only nine trials.

Throughout all sessions of omission training, the subject continued to approach the key at CS-onset. However, response patterns during the CS-interval and the ITI changed. High-rate abortive pecking directed at the key during the CS continued until session 17. Figure 3 indicates that this was not an efficient omission topography, as both mean latency to the first key-peck, and rate during the CS remained variable, and the number of CS-presentations with a key-peck remained high throughout that period, particularly in comparison to Bird #5052 (see Figure 2). On day 17, the frequency of abortive pecking declined and the frequency of pecks directed onto the right rim of the key increased. (It was not possible to discriminate abortive pecks directed at the key from pecks directed to the right rim of the key by examination of the wave-forms produced by each behavior; however, visual observations during all sessions indicated that the topography had changed. In addition, the pigeon's beak could be

heard striking the rim of the key, and over several sessions, the paint in that area of the chamber was chipped away). This redirection of pecking signalled the beginning of a gradual decline in response rate and the number of trials with a key-peck, and a slight increase in mean response latency during the CS (see Figure 3).

Throughout this period (from session 2 to 17), ITI behaviors remained disrupted and extremely variable both within and across sessions. In addition, visual observations indicated that behaviors which might be labelled "emotional," such as agitated pacing, agitated preening, wing-flapping, and ruffling of chest feathers and swelling of the crop occurred during the ITI's.

Figure 13 illustrates both this disruption in ITI behavior and also the persistence of approaching and pecking at or around the key during the CS-interval. In addition, Figure 13 shows the reacquisition of the stereotyped ITI pacing pattern seen during autoshaping. The two left columns show distance from the key and overhead plots of each entire session. The two right columns show details (both distance from the key and overhead plots) of two CS-presentations sampled from the center of each session shown. For these latter overhead plots only, data was not averaged and one point was plotted for each 1/10 sec of session time shown. The points were connected to yield a continuous line, which, at this small time scale was more informative than a scattered few unconnected points. The sessions shown (prior to session 20) were selected randomly to illustrate the great variability in ITI behavior both within and across sessions.

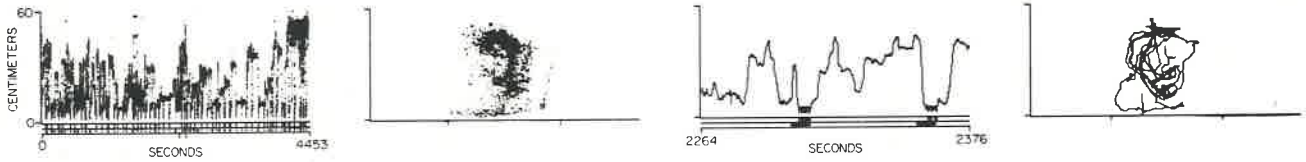
On day 20, pacing the right wall of the chamber, which had occurred only briefly and sporadically during omission training, reappeared and increased in frequency until session 23, when it once again occurred throughout each ITI. This redevelopment of the stereotyped pacing pattern seen

Figure 13. Changes in ITI patterns during omission training for Bird #1134. Graphs in columns 1 and 3 show absolute distance of the bird's head from the key. Absolute distance in cm is indicated on the vertical axis, and session time in sec on the horizontal axis. Time during reinforcer presentations is not graphed. Pecks are indicated by vertical marks between the upper pair of horizontal lines beneath each graph, and CS-presentations by long vertical marks between the lower pair of horizontal lines. Tracking errors are indicated by the short marks between this lower pair of lines. Cursors on the graphs in column 1 indicate areas expanded in the graphs in column 3. Graphs in columns 2 and 4 show X vs. Y or overhead plots of the path of the bird's head as it moves around the chamber. These plots are located to the right of corresponding distance graphs. The key is indicated by the small dark square; the feeder is not shown, but is located to the immediate right of the key. The extent of the chamber in cm is indicated by the cursors on the vertical and horizontal axes; however, the chamber is rotated 15 degrees to the right of perpendicular to these axes. For graphs in column 2, one discrete point is plotted per sec of session time. For graphs in column 4, one point is plotted for each 1/10 sec, and the points are connected to produce a continuous line.

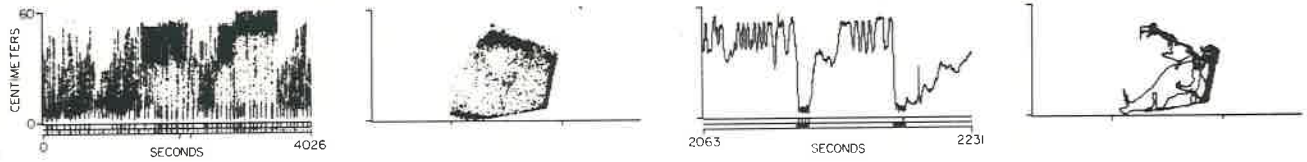
BIRD 1134

OMISSION DAY 2

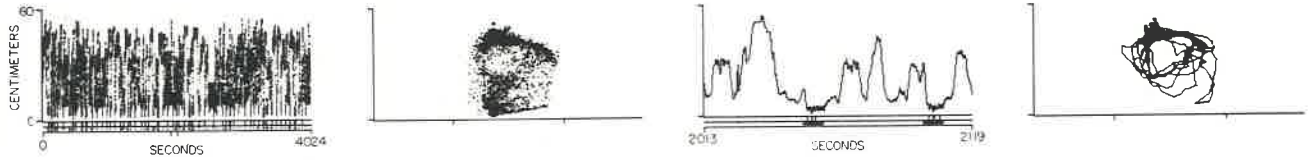
OMISSION DAY 6



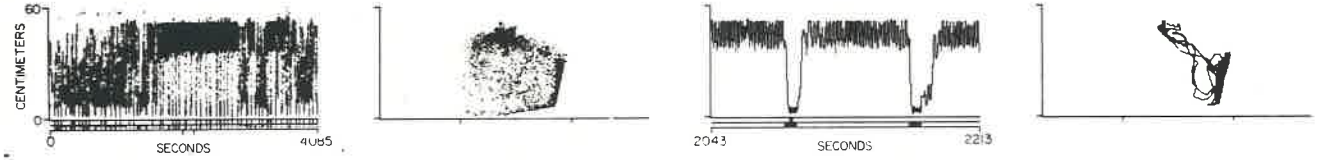
OMISSION DAY 11



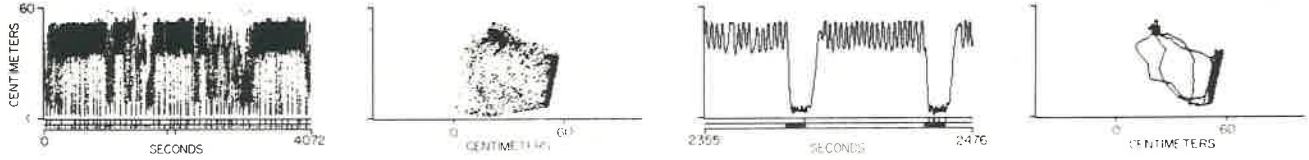
OMISSION DAY 17



OMISSION DAY 20



OMISSION DAY 21

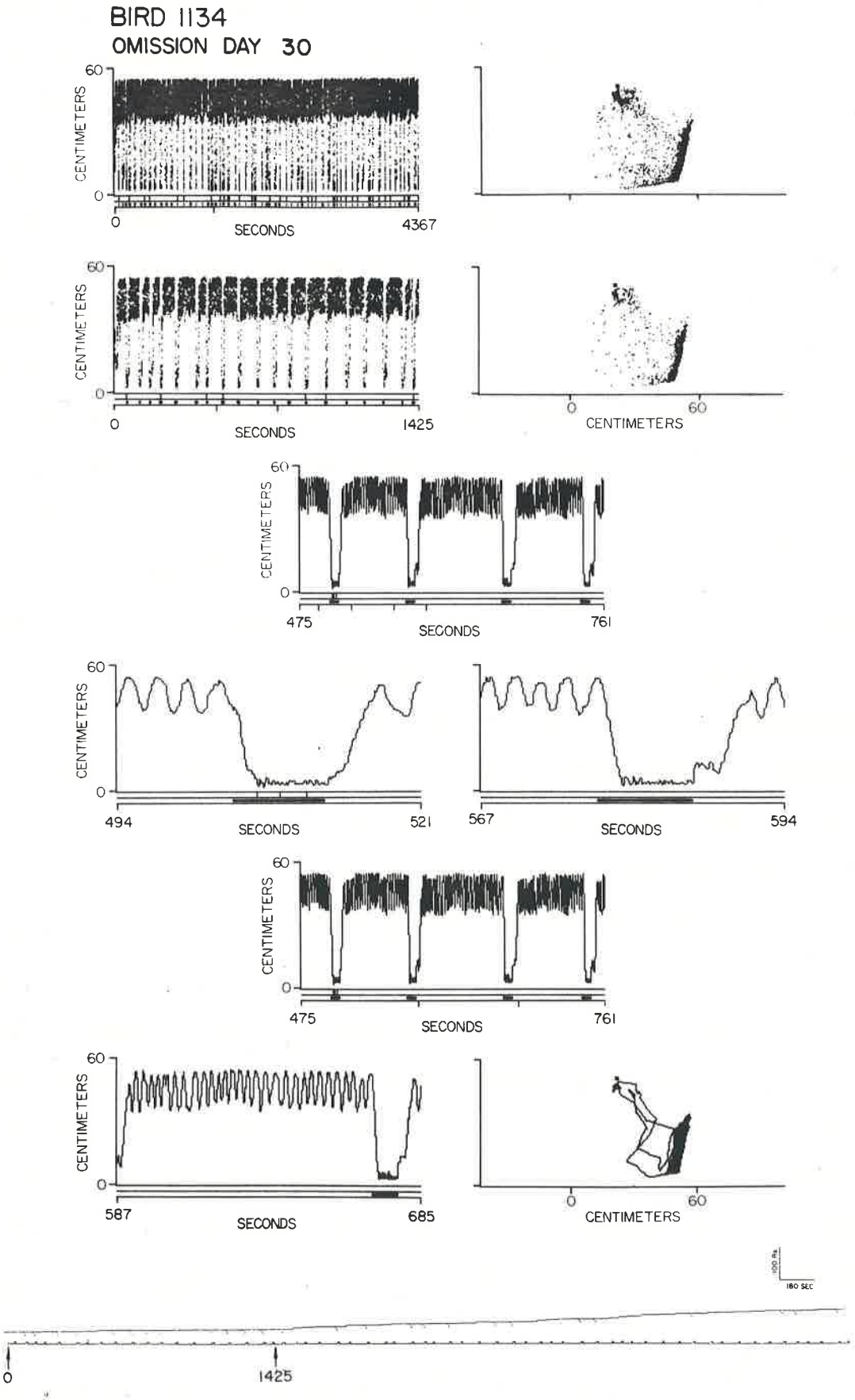


during autoshaping occurred after abortive pecks directed at the key declined and pecks directed onto the right rim of the key increased. This redirection of pecking coincided with an increase in the efficiency of omission performance. Following reestablishment of this repetitive ITI pattern, response latency, response rate during the CS, and the number of trials with a key-peck all decreased (see Figure 3).

Figure 14 shows in detail the pattern of omission responding which persisted from session 23 to session 30 for Bird #1134. The first row shows distance from the key and the overhead plot for the entire session. The second row shows an expanded detail of the first third of the session. Rows 3 to 6 show expanded views of segments of the session marked by the cursors in the graph immediately above. These graphs clearly illustrate: (1) the stereotyped ITI pattern of pacing the right wall of the chamber; and (2) rapid approaches to the key at CS-onset. The expanded details in rows 5 and 6 show rapid pecks to the rim of the key during each CS, as well as occasional key-pecks. The frequency of pecks to the rim of the key does not appear to differ from the frequency of key-pecks during autoshaping, which suggests that, similar to Bird #5052, the omission contingency did not alter the rate of pecking during the CS, but simply redirected the pecks to another area near the key.

The distance graph of the entire session in the top row of this figure, and the cumulative recording at the bottom of the figure illustrate a typical pattern of successful omission trials for this subject: a large number of reinforced trials early in the session followed by more key-pecks and fewer reinforced trials as the session progressed. Visual observations suggested that pecking the rim of the key was a successful omission topography, until several unreinforced trials (i.e., trials with key-pecks) had occurred. With repeated unreinforced trials, the subject

Figure 14. Stable CS and ITI response patterns during omission training for Bird #1134. With the exception of the top two, and the lower graph in the right column, all graphs show absolute distance of the bird's head from the key. Absolute distance in cm is indicated on the vertical axis, and session time in sec on the horizontal axis. Time during reinforcer presentations is not graphed. Pecks are indicated by vertical marks between the upper pair of horizontal lines beneath each graph, and CS-presentations by long vertical marks between the lower pair of horizontal lines. Tracking errors are indicated by the short marks between this lower pair of lines. Cursors indicate areas expanded in lower graphs. The remaining graphs show X vs. Y or overhead plots of the path of the bird's head as it moves around the chamber. These plots are located to the right of corresponding distance graphs. The key is indicated by the small dark square; the feeder is not shown, but is located to the immediate right of the key. The extent of the chamber in cm is indicated by the cursors on the vertical and horizontal axes; however, the outline of the chamber is rotated 15 degrees to the right of perpendicular. For the two upper overhead plots, one discrete point is plotted per sec of session time. For the lower overhead plot, one point is plotted for each 1/10 sec, and the points are connected to produce a continuous line. CS-presentations are indicated by upward deflections of the lower pen, and US-presentations by downward deflections of the upper pen on the cumulative recording at the bottom of the figure.


BIRD 1134
OMISSION DAY 30
CENTIMETERS
60
0
0
SECONDS
4367
1425
CENTIMETERS
475
761
494
521
567
594
587
685
100 Rs
180 SEC

began to peck more forcefully at the wall, and more rapidly, which appeared to increase the likelihood of pecks striking the key.

Upon removal of the omission contingency, the pattern of pacing the right wall during the ITI and approaching and pecking during the CS remained unchanged; however, over the course of five sessions, all pecks were redirected from the right rim of the key to the key itself, with a commensurate increase in the rate of key-pecking during the CS, and the number of trials with a key-peck (see Figure 3).

In summary, Bird #1134, as well as Bird #5052, developed stable patterns of CS and ITI behavior in each phase. During Phase 1 of autoshaping, #1134 developed a stereotyped pattern of withdrawal from the key and feeder following feeder operations, and repetitive pacing of the right wall of the chamber throughout each ITI. At CS-onset, the subject approached the key and pecked rapidly throughout the CS-interval. Occasional abortive pecks directed at the red key occurred during autoshaping.

Similar to Bird #5052, the first change during omission training was a pronounced disruption of this ITI pattern, followed by an increase in abortive pecks directed at the red key, and a decrease in pecks contacting the key. Similar to #5052 as well, the omission contingency did not affect approaches to the CS. On day 17, abortive pecks directed at the key decreased and were replaced by pecks contacting the right rim of the key. This signalled the start of an increase in the efficiency of omission responding. From day 2 to day 19 of omission, ITI patterns showed great variability both within and across sessions. On day 20, repetitive pacing of the right wall during the ITI reappeared and increased over sessions. Stable omission patterns included rapid approach to the key at CS-onset, rapid pecking directed at the right rim of the key during the CS, and repetitive pacing along the right wall of the chamber during ITI's.

Following removal of the omission contingency, approach to the CS and pacing during the ITI remained unchanged, but pecks were redirected from the right rim of the key back to the red key itself. Mean latency to the first key-peck during the CS stabilized at a level above that of autoshaping in Phase 1, although response rate during the CS recovered to near Phase 1 levels (see Figure 3).

The fact that Bird #6859 did not key-peck during 18 sessions of autoshaping would have led him to be discarded as a conditioning failure if dependent measures were limited to trials with a key-peck, or response rate during the CS. However, an examination of response topography during autoshaping for this subject indicates great similarity between his performance and the response patterns of both #5052 and #1134 during autoshaping.

Figure 15 illustrates response patterns for Bird #6859 during days 1 and 2 of baseline, and during autoshaping. Graphs in the left column show distance from the key, and in the center column, corresponding overhead plots for the entire sessions. Graphs in the right column show Z vs. X views, or front elevations of the feeder wall similar to those described in Figure 7. However, each graph in Figure 15 shows head movements parallel to the feeder wall for an entire session, and data for these graphs are averaged and one point is plotted for each sec of session time. The key is indicated by the small dark square in the body of the graph. The feeder is not indicated, but is located to the lower right of the key. The 0 to 60 cm scale on the horizontal axis includes the entire length of the feeder wall.

Row 1 shows baseline day 1. At the start of the session, the bird sat near the feeder, oriented toward the key, and approached and made one peck to the white key. The bird then withdrew to the rear of the chamber

and preened, making several further approaches to the key and the feeder, but no further pecks. On day 2, shown in row 2, the bird did not approach either the feeder or the key; it remained in the center or at the rear of the chamber, oriented away from the key.

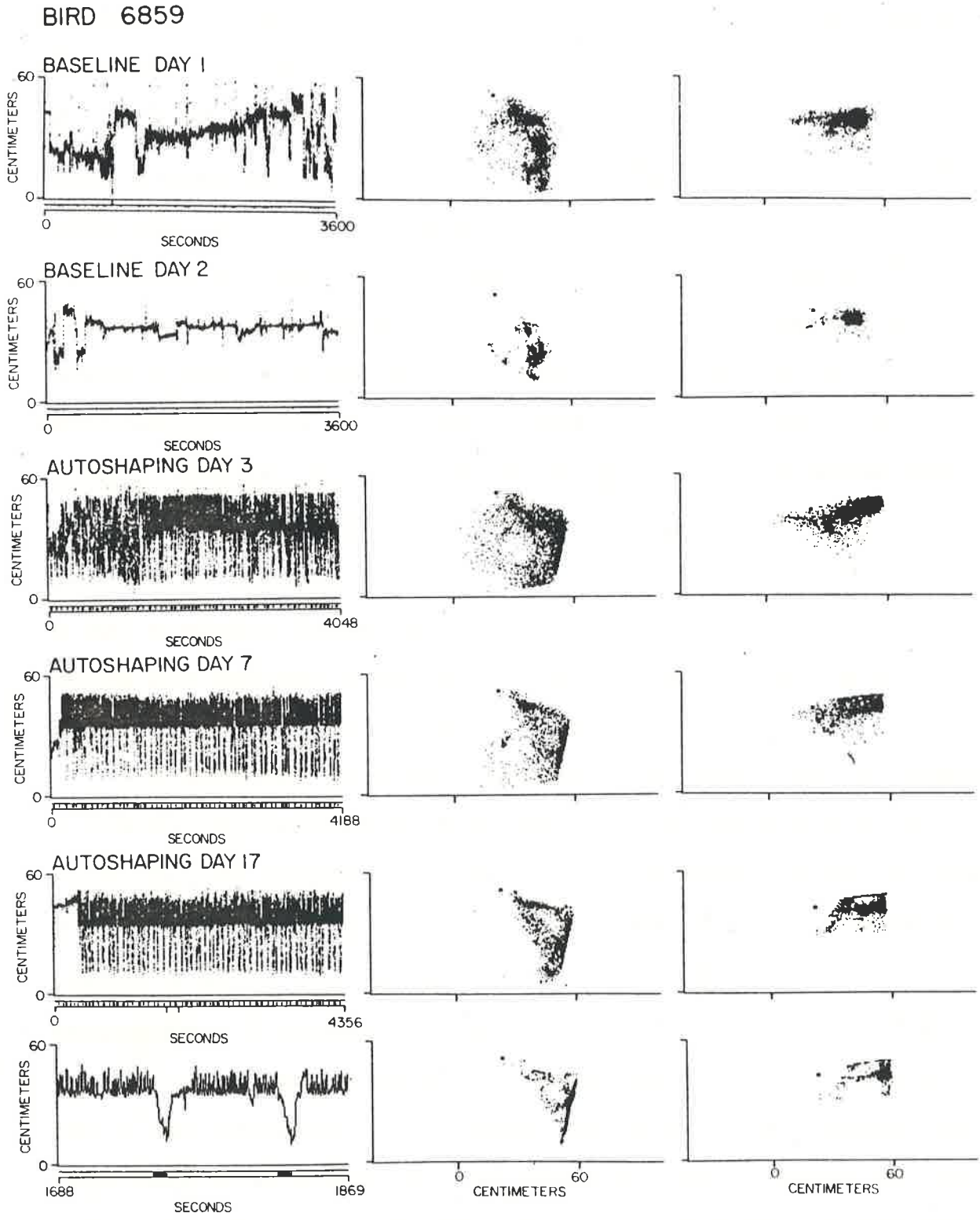
During day 1 of autoshaping, the subject approached the feeder wall during the first ITI, but startled and withdrew rapidly to the rear of the chamber at the onset of the red keylight. He remained at the rear of the chamber during the remainder of session 1, and for most of session 2, making only occasional tentative approaches to the feeder when it operated. These approaches were very slow, however, and the bird was unable to reach the feeder in time to consume any of the reinforcers during the first two sessions of autoshaping. Consequently, reinforcer duration was increased to 4 sec on day 3 of autoshaping and remained at that value for the final 15 sessions of autoshaping.

Graphs in the third row of Figure 15 show the third day of autoshaping. During the first 19 trials, the bird consumed 17 reinforcers. During ITI's, he made random circling movements of the chamber, and during CS-presentations stopped and oriented toward the feeder wall. On trial #20, a repetitive pattern of pacing the right wall of the chamber appeared. This persisted throughout most of the remaining ITI's in this session. At CS-onset, the bird ceased pacing and oriented to the feeder wall.

This CS pattern developed over subsequent sessions. By day seven, shown in the fourth row of Figure 15, the subject paced the right wall during each ITI, and at CS-onset, approached the right feeder wall, making repeated head movements toward the key at key-height, but never approaching past the left edge of the feeder. This pattern of head movements along the feeder wall toward the key is shown in the Z vs. X view in the right column of row 4 in Figure 15.

These CS and ITI patterns persisted during the remaining sessions of autoshaping for this subject, although from day 8 to day 17, part of all of each session was spent either sitting at the right wall of the chamber, or pacing the right wall during CS, ITI, and reinforcer presentations. The fifth and sixth rows of Figure 15 show both the entire session and expanded details of day 17. Early in the session, the bird sat motionless at the rear of the chamber for several trials, and then resumed pacing the right wall during each ITI, and approaching the key during each CS. The sixth row shows an expanded detail of one segment of that session, clearly illustrating both pacing during the ITI's, and head movements along the feeder wall toward the key during CS-intervals. Sessions were discontinued after day 18 for this subject.

Figure 15. Response topography for Bird #6859 for baseline days 1 and 2 and autoshaping. The graphs in the left column show absolute distance of the bird's head from the key. Absolute distance in cm is indicated on the vertical axis, and session time in sec on the horizontal axis. Time during reinforcer presentations is not graphed. Pecks are indicated by vertical marks between the upper pair of horizontal lines beneath each graph, and CS-presentations by long vertical marks between the lower pair of horizontal lines. Tracking errors are indicated by short marks between this lower pair of lines. Cursors indicate areas expanded in lower graphs. The graphs in the center column show X vs. Y or overhead plots of the path of the bird's head as it moves around the chamber. These plots are located to the right of corresponding distance graphs. The key is indicated by the small dark square; the feeder is not shown, but is located to the immediate right of the key. The extent of the chamber in cm is shown by the cursors on the vertical and horizontal axes; however, the outline of the chamber is rotated 15 degrees to the right of perpendicular. One discrete point is plotted per sec of session time. The graphs in the right column show Z vs. X or front elevations of the key and feeder. The height of the chamber in cm is shown on the vertical axis, and the entire width in cm on the horizontal axis. These plots are located to the right of corresponding overheads and distance graphs. Key position is indicated by the small dark square. One point is plotted for each sec of session time.


BIRD 6859
BASELINE DAY 1
BASELINE DAY 2
AUTOSHAPING DAY 3
AUTOSHAPING DAY 7
AUTOSHAPING DAY 17
CENTIMETERS
SECONDS
0
60
3600
4048
4188
4356
1688
1869
CENTIMETERS

DISCUSSION

The most striking feature of the data from this study was the demonstration of control exerted by the red keylight (the CS) over approach to the key in all three subjects, and over approach and pecking behavior for two of the subjects. Within few pairings of the keylight and food during autoshaping, all subjects began to approach the red keylight immediately after its onset. For example, Bird #6859 missed all reinforcer presentations for days 1 and 2 of autoshaping, and did not approach the red key during those sessions. However, on day 3, after consuming reinforcers on only 15 trials, he began to orient toward the key and make head movements toward the key area during the CS. These head movements gradually developed into approaches to the red key, which persisted during most CS-presentations for the remaining 15 days of autoshaping for that subject. For #1134, and #5052, the red keylight controlled pecking as well as approach to the key. For both subjects, approach to the CS and pecking persisted despite the introduction of a negative contingency placed on key-pecking during omission training.

The main issue addressed in this study was a description of changes in response topography during the CS which occurred when a negative response-reinforcer dependency was added to an autoshaping paradigm. As described earlier, during autoshaping both #1134 and #5052 rapidly developed patterns of approach to the red key at CS-onset, with key-pecks occurring throughout the CS-interval. For both birds, abortive pecks directed at the key also occurred during the CS. During omission training, this pattern of approaching the key at CS-onset remained unchanged. However, both birds showed an increase in abortive pecking directed at the red key, and a decrease in key-pecks. This increase in abortive pecking may have reflected sensitivity to changes in the response-reinforcer relationship

or a weakening of the response produced by changes in the stimulus-reinforcer relationship caused by a shift to partial reinforcement. Trials with a key-peck were not followed by reinforcement, which meant a reduction in the number of CS-US pairings. Without controls for these shifts in reinforcement density, which this study did not employ, it is impossible to attribute topographical changes to either the response-reinforcer or the stimulus-reinforcer relationship.

Abortive pecking was not an efficient omission topography for either subject, as many pecks continued to contact the key, resulting in the omission of reinforcers. Within five sessions of omission training for Bird #5052, abortive pecking disappeared and was replaced by pecking the chamber wall to the left of the key. Over subsequent sessions, pecks shifted farther down the wall during the CS, and the efficiency of omission performance increased until few, if any, reinforcers were omitted.

In contrast, Bird #1134 continued to make abortive pecks directed at the red key for 16 sessions before redirecting pecks to the right rim of the key. Rapid abortive pecking persisted in this subject despite its inefficiency as an omission response. During the first 16 sessions of omission training, #1134 received a maximum of 11 reinforcers in any one session.

There are a number of possible reasons why abortive pecking and key-pecking persisted for so many sessions for #1134 compared to #5052. If response rate is an index of response strength, then key-pecking was a much stronger response for #1134 during autoshaping, as rate was much higher, mean latency to the first key-peck shorter, and fewer abortive pecks occurred. In addition, Bird #5052 had a history of approaches to the area of the key during the ITI which did not culminate in key-pecks. In contrast, during autoshaping, Bird #1134 approached the key only at the onset

of the CS, and each approach was immediately followed by rapid key-pecks. Therefore, for #1134, the response chain of approach and peck the key was less variable than the response chain for Bird #5052, which included frequent sequences of approaches with no pecks. Some possible support for this argument is that during autoshaping #5052 frequently made head movements to the left of the key during the ITI, and the successful omission topography which emerged for that subject consisted of pecks to the wall to the left of the key. This combination of a high-strength response and a rigid approach-and-peck chain coupled with intermittent reinforcement may have maintained abortive pecking and key-pecking for many sessions for #1134 compared to #5052.

Similar to #5052, however, abortive pecking was eventually replaced by pecks to the right rim of the key for #1134. This was a somewhat more efficient omission topography, however, unlike #5052, #1134 did not shift the location of pecks farther away from the key in subsequent sessions, continuing instead to peck close to the key. This meant that frequent key-pecks still occurred, resulting in omitted reinforcers.

These results support the findings of Barrera (1974), Woodruff and Williams (1976), and Williams and Williams (1969), who reported that pecking was maintained during omission training, but that pecks were redirected from the key to other areas close to the key. Interestingly, Lucas (1975) reported that the frequency of prekeypecking (abortive pecking) increased during omission training, and in the present study, both subjects displayed increased abortive pecking prior to redirecting pecks to other areas around the key.

Woodruff and Williams (1976) argued for a "learned-release" account of autoshaped responding. Biologically preorganized appetitive responses are released by stimuli signalling impending reinforcers. Applying this

account to the present study, the red keylight which signalled food presentations would release pre-consummatory patterns of approach and pecking directed at the CS. However, as Barrera (1974), Lucas (1975), Wessells (1974) and Woodruff and Williams (1976) suggest, responses initially controlled by a stimulus-reinforcer relationship may be modified by changes in the existing response-reinforcer relationships. This suggests that although approach to the CS and pecking may be under control of the stimulus-reinforcer relationship, the location of the pecks may be modified by the negative response-reinforcer relationship in omission training.

Lucas (1975) and Wessells (1974) reported that an omission contingency suppresses only that component of behavior which it contacts. When an omission contingency is placed on key-pecking, key-pecking decreases and orientation and approach to the CS remain. When the omission contingency is expanded to include approach behaviors, then approach decreases and orientation to the CS remains. In the present study, approaches to the red key occurred immediately at CS-onset in all phases. The fixed-trial procedure, in which reinforcers are delivered or omitted only at the end of the 8-sec CS-interval, meant that approaches to the key were removed in time from the negative response-reinforcer dependency. Therefore, the negative contingency would impact most powerfully on responses occurring later in the CS interval, in this case, key-pecking.

Woodruff, Connor, Gamzu, and Williams (1977) demonstrated that autoshaped responding is jointly controlled by stimulus-reinforcer and response-reinforcer relationships, and that, in any given situation, the strongest relationship exerts greatest control over the behavior. Extending this analysis to the fixed-trial omission paradigm, the response-reinforcer relationship would be at its strongest and exert greatest control at the end of the CS-interval because of the close temporal contiguity

between responses occurring at that time, and reinforcer presentations or omissions. At CS-onset, however, the response-reinforcer contingency would be less powerful because of the effect of a delay on reinforcement. During autoshaping, the stimulus-reinforcer relationship would be at its most powerful at CS-offset, due to the immediate delivery of the reinforcer at that time. However, during omission training, the strength of that relationship would likely be weakened by the occurrence of unreinforced trials (a shift to partial reinforcement). Therefore, during omission training, the response-reinforcer relationship might be relatively stronger at that point than the stimulus-reinforcer relationship. This suggests that responses occurring at CS-onset might be controlled by the more powerful stimulus-reinforcer relationship, resulting in the persistence of approach to the CS and the release of pecking behaviors, while responses occurring close to CS-offset might be controlled by the more powerful response-reinforcer relationship, resulting in the displacement of pecking from the key to areas around the key.

Following removal of the omission contingency, key-pecking increased in both subjects, although for Bird #5052, it did not recover to its original autoshaping level. For this subject, the omission topography of pecking to the left of the key persisted despite removal of the negative contingency on key-pecking. This could again reflect joint control by the stimulus-reinforcer and response-reinforcer relationships. In autoshaping, Phase 2, mean latency to the first key-peck during the CS decreased, perhaps reflecting an increase in the relative strength of the stimulus-reinforcer relationship once reinforcers were again delivered following each trial. However, pecks to the left of the key occurred later in the CS-interval and may have been maintained by adventitious reinforcement from feeder presentations at CS-offset.

For #1134, key-pecking recovered to its previous autoshaping levels, perhaps due to a large increase in the number of reinforced trials and a consequent increase in the strength of the stimulus-reinforcer relationship when the omission contingency was removed. For this subject, the number of reinforcers delivered per session more than doubled when the negative contingency was removed. In addition, key-pecking remained relatively frequent during omission training, which would have made it more likely that it would be adventitiously reinforced following the return to autoshaping.

This study replicated the observations of Schwartz and Williams (1972) and Williams and Williams (1969) that latency to the first key-peck following CS-onset increased during omission training compared to autoshaping. For Bird #5052, mean latency increased early in omission training due to the increase in the number of abortive pecks or pecks to the left wall which occurred prior to key-pecks. For Bird #1134, mean latency increased during omission training, but was extremely variable compared to #5052, reflecting the increased likelihood of striking the key at any time during the interval when pecking in front of the key, or very close to the side of the key. This confirms Barrera's suggestion (1974) that changes in latency are related to changes in response topography.

Mean latency to the first key-peck during the CS in autoshaping appeared to be related to the speed of approach to the CS, which was, in turn, related to the pattern of behavior during the ITI, and the bird's position in the chamber at the moment of CS-onset. Mean latency is a very gross measure, however, for assessing small changes occurring early in the acquisition of autoshaped key-pecking. It would be more informative in subsequent studies to analyze latencies trial by trial, similar to the way in which IRT distributions are plotted and analyzed.

During ITI's for both #1134 and #5052, frequent key-pecking occurred early in Phase 1 of autoshaping, but rapidly declined to zero. Following the reduction in key-pecking during the ITI, stereotyped repetitive patterns of behavior developed, which, for all birds in all phases, included withdrawal from the key and feeder following feeder operations. (This was also true for Bird #6859, who did not key-peck during the CS). Since the keylight correlated with nonreinforcement satisfies the requirements for the development of an inhibitory stimulus (Hearst, 1972), this reduction in key-pecking and withdrawal from the key suggests that these birds may be withdrawing from an inhibitory stimulus, as described by Hearst and Jenkins (1974) and Wasserman, Franklin, and Hearst (1974).

In addition to withdrawal from the key, all birds showed stereotyped repetitive patterns of behavior during ITI's. Since these patterns were not evident during baseline sessions, and since in both cases they were disrupted early in omission training when few reinforcers were delivered, they may represent supersitious behaviors maintained by adventitious reinforcement by CS-onset. Consequently, this suggests that ITI performance, as well as CS performance, may be under the joint control of stimulus-reinforcer and response-reinforcer relationships: inhibitory control over withdrawal from the white key, and adventitious reinforcement of repetitive patterns occurring during the remainder of the ITI. Adventitious reinforcement could account for the difference in patterns seen in Bird #1134 and Bird #5052 during the ITI's.

However, the invariant nature of the patterns once established suggests that perhaps adventitious reinforcement cannot account solely for their maintenance. Subsequent studies should examine response patterning in the presence of an inhibitory stimulus (a discriminated autoshaping paradigm might be suitable) using appropriate tests (e.g., reacquisition

and summation) to ensure that the stimulus actually is inhibitory.

The results of this study suggest that autoshaped key-pecks are sensitive to and modifiable by their consequences. Autoshaped responses are under the joint control of both stimulus-reinforcer and response-reinforcer relationships. Unfortunately, the omission paradigm is unable to separate the relative effects of one relationship from the other, since both are altered by the omission contingency. A second step in this research program would be to replicate the present study using yoked controls to equate for changes in reinforcement density. This would allow a more detailed analysis of whether topographical changes during omission training can be attributed to changes in the response-reinforcer relationship, or in the stimulus-reinforcer relationship.

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