TOPOGRAPHY OF THE FOOD-REINFORCED KEY PECK AND THE SOURCE OF 30-MILLISECOND INTERRESPONSE TIMES[1]

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High-speed photography of key pecking revealed that the arc described by the upper bill as a pigeon closes its beak is capable of operating a Lehigh Valley pigeon key set at 8 to 14 g. Arc-produced switch closure follows initial switch closure in less than 50 msec. When birds were trained on ratio schedules, the probability of interresponse times (IRTs) shorter than 50 msec exceeded 0.30. Interval-trained birds produced a much lower probability of short-IRTs. When the schedules were reversed, there was only weak evidence of a reversal in the probability of short IRTs. A temporal analysis of topographic features observed in the original photographs failed to reveal differences between ratio and interval pecking topography. It appeared that only the point of contact with the key differed between subjects trained on the two schedules. It was concluded that only the locus, but not the topography, of the food-reinforced key peck was modified by the schedule of reinforcement.

Several recent papers have questioned fundamental assumptions of reinforcement theory (e.g., Bolles, 1970, 1972; Garcia, Clarke, and Hankins, 1973; Moore, 1973; Seligman, 1970; Staddon and Simmelhag, 1971). Three questioned assumptions, relevant to the present study, may be stated as follows: (1) within methodological constraints, skeletal activities of the subject may be *arbitrarily* selected by the experimenter to serve as operants (Dinsmoor, 1966; Ferster, 1953; Ferster and Skinner, 1957, p. 7; Millenson, 1969, p. 160), (2) the key-peck response in pigeons is one such behavior (Ferster and Skinner, 1957), and (3) the topography of the operant (key peck) can be modified (differentiated) by the schedule of reinforcement (Ferster and Skinner, 1957, p. 9; Sidman, 1961, pp. 389-390; Skinner, 1938, pp. 309-310; Skinner, 1966, p. 17).

Questions regarding the arbitrary selection of the key peck stem from the difficulty with which pigeons learn this response in shock

avoidance and escape situations (Dinsmoor, 1968; Hineline and Rachlin, 1969; Hoffman and Fleshler, 1959; MacPhail, 1968; Rachlin and Hineline, 1967). When alternative escape or avoidance responses such as head-lifting, flying, general activity, running, or treadle-pressing are instrumented, pigeons successfully and often quickly learn to escape or avoid shock (Bedford and Anger, 1968; Foree and Lolordo, 1970; MacPhail, 1968; Smith and Keller, 1970). The difficulty in training key-peck escape appears to result from the incompatibility of the key-peck response with the pigeons' unconditioned response to shock (Smith, Gustavson, and Gregor, 1972). That is, the unconditioned response to shock involves near maximum flexion of the neck, while the key peck requires near maximum extension of neck. The Smith et al. data suggest that the key peck is *not* an arbitrary behavior that can be performed by a pigeon in all operant situations; rather, the key peck will be performed only in situations that normally elicit pecking behavior (e.g., where drinking, eating, preening, or attack behaviors are elicited by the reinforcer).

The second questioned assumption concerns the classification of the key peck as an operant. This classification derives from Skinner's (1938) statement that "the kind of behavior that is correlated with specific eliciting stimuli may be called *respondent* behavior . . . such behavior as is not under this kind of control I

shall call operant." (p. 20). The earliest data that casts doubt upon the classification of the key peck as an operant was provided by Wolin (reprinted, 1968) at the first conference for the Experimental Analysis of Behavior (1948). Wolin found that key pecks reinforced with water were topographically similar to drinking responses, while food-reinforced key pecks resembled eating responses. Recently, the study was replicated by Jenkins and Moore (1973) with improved controls and techniques that include autoshaping, concurrent schedules, and photography. Moore (1973) concluded his description of the Jenkins and Moore study by stating that "response topographies were indeed due to *associative* learning" (p. 161, italics mine). In general, Moore (1973) provided strong evidence from the autoshaping, cross-drive conditioning, and avoidance literature that indicates that the key peck in many "operant" situations is most closely described by Skinner's definition of *respondent* behavior. That is, the key peck is "correlated with a specific eliciting stimulus".

Perhaps questions regarding arbitrary selection and label (operant *versus* respondent) pose little threat to operant theorists so long as the key peck behaves as predicted under schedule control (*i.e.*, as long as its topography can be modified (differentiated) by the schedule of reinforcement). Unfortunately, few, if any, studies in the literature have clearly demonstrated schedule-controlled differentiation of the key peck. Although details of the study are lacking, Skinner (1958) successfully used contingent reinforcement to increase the force with which birds pecked keys. However, Cole (1965) concluded his paper on force and stimulus generalization by describing an earlier pilot study that appears to be similar to Skinner's. He reported that for each increase in the force requirement, birds previously trained on VI received a net reduction in reinforcement density and the consequence was that "the bird invariably spiralled into extinction". That is, Cole failed to differentiate the response.

The most systematic attempt to modify key-peck topography is found in Moore's (1971) dissertation. He described a study conducted by James Warren and himself in which six pigeons received water reinforcers and six received food reinforcers for key pecks of a particular duration. An attempt was made both to increase and decrease response duration for subjects in both reinforcement groups. Moore concluded that "in spite of the learning curves, then, our data did not demonstrate strong operant differentiation. The water-trained birds learned readily to take long draughts from the key but elsewhere the results were usually weak, nil, or ill-gotten." (p. 133.)

In general, then, there is little evidence for key-peck differentiation even when reinforcement is contingent upon some modification of the response topography. Perhaps the paucity of literature in this area is accounted for by a relative lack of techniques necessary to identify, monitor, and reinforce aspects of key-peck topography. In the present paper, Experiment I describes a photographic technique that was used to identify one aspect of response topography that can be monitored by high-speed recording devices. After the photographic analysis, Experiment II was designed to produce differentiation of the response as revealed through changes in the relative frequency of the topographical event (beak closing on the key). The design simply involved recording the event while pigeons were working under variable-ratio (VR) and variable-interval (VI) schedules of reinforcement. The beak-closing event, which can operate a typical response key (LVE 1348C set at 8 to 14 g), tends to occur about 30 msec after initial switch closure produced by striking the key. It was assumed that counting beak-closure responses would benefit the VR birds, but would produce little change in VI reinforcement density.

EXPERIMENT I: TOPOGRAPHY OF THE FOOD-REINFORCED KEY PECK

METHOD

Subjects and Schedules of Reinforcement

Seven adult, male Carneaux pigeons were photographed during pecking in Experiment I. Three of these birds were specifically used to develop the photographic technique and are referred to as the fixed-ratio (FR) birds. The FR birds were maintained under severe deprivation conditions (70% free-feeding weight) and were hand-shaped to key peck for mixed grain in a Lehigh Valley (1519C) pigeon chamber. Following shaping, the reinforcement schedule, arranged by solid-state (Massey Dickinson) modules, was ultimately set at FR

25². Reinforcement duration was 2.5 sec, session duration was 90 min, and the 1348 LVE pecking key was set to operate at 10 g. The remaining four birds performed as subjects in the Smith *et al.* (1972) experiment; the special L-shaped photographic chamber used for these birds is described in that paper. As before, the birds were hand-shaped to respond for mixed grain and the schedule, arranged with conventional electromagnetic equipment, was gradually increased from continuous reinforcement to VI 30-sec. Reinforcement duration for VI subjects was 5 sec, training sessions were 30 min long, and the final photographic session was 60 min long. The pecking key was set at 14 g and contained a modification of the standard LVE 1348 key. The modification involved glueing a 0.75-in. diameter disc to the face of the key. The disc extended $\frac{1}{16}$ in. into the chamber and, when photographed, provided the viewer with an estimate of key-displacement.

Photographic Technique

High-speed (100 or 200 frames per second) film strips showing detailed response topography were obtained with a 35-mm kymographic camera (Grass, C4). Tri-X film was moved past the continuously open shutter of the camera at a rate of one meter per second. Individual frames were exposed by strobing the bird at a rate of 100 or 200 flashes per second with a General Radio (1531) stroboscope. Flash off-time for the FR subjects was 4.85 msec, and flash off-time for the VI subjects was 9.85 msec; on-time for both groups was equal to 0.15 msec. The flashing strobe remained on throughout each session and, since its rate exceeded the experimenter's critical flicker frequency, it was assumed that the strobe provided general illumination for the birds as well. For FR birds, photographed at the rate of 200 frames per second, it was necessary to reduce overlap between frames by restricting the image on the film to a band of approximately 5 mm in its vertical direction. This was accomplished by photographing the bird through an aperture that restricted the image

to these dimensions. For VI birds, photographed at 100 frames per second, such restriction was unnecessary.³

RESULTS

Figures 1 and 2 show sample kymographic film strips of each of the birds. The three FR birds are shown in Figure 1, the four VI birds in Figure 2. In each filmstrip the earliest frame occurs at the bottom of the sequence and the arrows indicate estimated points of initial and final contact with the key. In Figure 1, successive frames were exposed at 5-msec intervals; in Figure 2 frames were exposed at 10-msec intervals. Since the VI 30-sec data were obtained from filmstrips exposed at 10 msec per frame, they provided improved photographic clarity but less topographical detail. For this reason, the arrows representing estimated points of initial and final contact with the key are sometimes interpolated between frames. In general, these figures reveal that at the moment of switch closure, the beak and eyes are open. Both begin to close immediately, however, with beak closure complete by 30 msec after switch closure. The time from switch closure to loss of contact with the key is about 50 msec (obvious retraction by 60 msec). The details of the photographic analysis may be explained by considering Figure 3. This figure shows a bar graph summarizing the topographical features visible from an analysis of filmstrips such as those shown in Figures 1 and 2. For example, the filmstrip showing Bird 430 in Figure 1 was analyzed for presentation in Figure 3 as follows: the estimated time from beak opening to key contact for this bird was 25 msec, as measured from the bottom frame of the filmstrip to the frame adjacent to the contact arrow; the beak opening and holding on the key time was judged to be 20 msec (from contact to the frame that just shows the upper bill moving away from the upper edge of the key). Beak

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²The FR birds were run for about two weeks on FR 15 or FR 35 schedules while a single lens reflex photographic technique was developed. Readers interested in the technique are directed to Smith, 1967, or should write for information. Specifics regarding film processing are also available.

³While the data are not included in the present paper, the technique also permits the simultaneous recording of quantitative data. This can be achieved by exposing only part of the film to the subjects and the remainder can be continuously exposed to the beam of a Tektronics oscilloscope. The route of exposure is through the accessory lens of the C4 camera. The oscilloscope can be used to monitor events of the experimenter's choosing. Such events included reinforcement, key-switch closure, or analog signals representing the displacement, force, or velocity of key movement.
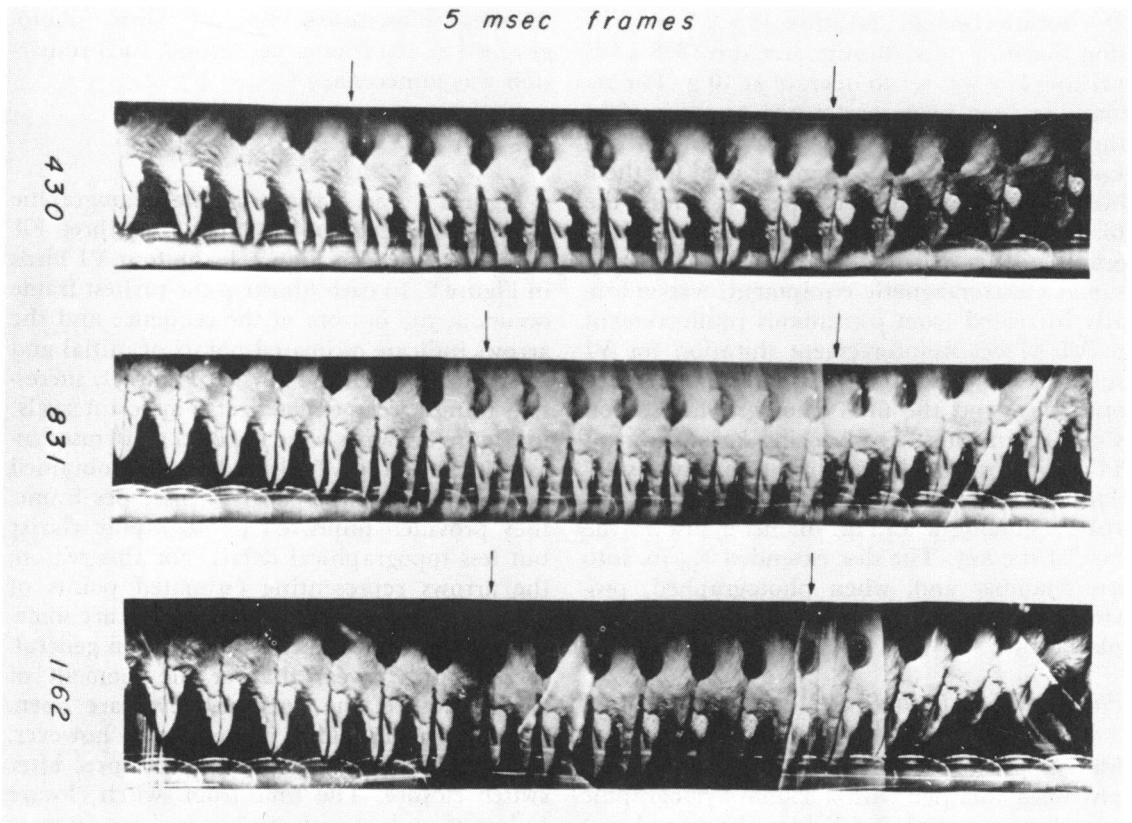
5 msec frames

Fig. 1. Kymographic pictures of single pecks made by the three fixed-ratio birds. The earliest frames appear at the bottom of the figure and successive frames were exposed at 5-msec intervals. The arrows indicate the estimated limits of contact with the key.

closing on the key was judged to take 10 msec; (this period ends with the frame just before the arrow indicating loss of contact with the key). The key contact to beak-closure time was estimated at 35 msec; that is, from the initial contact arrow to the frame preceding loss of contact with the key. Key contact to retraction was estimated at 40 msec, and beak closure to retraction was estimated at 5 msec.

Inspection of all filmstrips revealed that between 12 and 21 responses from each of the subjects recorded in Experiment I were of analyzable quality. Thus, each bar in Figure 3 represents an average of the temporal measures just described for 12 to 21 responses. The black bars reflect average data from the three FR 25 birds, and the shaded bars reflect the average data from the VI 30-sec birds. From visual analysis of the filmstrips, the following summary description of key-peck topography is possible: (1) the beak begins to open about

20 to 25 msec before contact with the key, (2) the upper bill encounters the key at an upward angle while the lower bill remains roughly horizontal (*i.e.*, perpendicular to the key), (3) beak opening continues for about 10 msec on the key, (4) the beak remains open for about 5 to 10 msec, (5) beak closure, on the key, requires about 15 msec, and is produced with a downward movement of the upper bill and, (6) retraction follows closure almost immediately and is accompanied by a slight downward tilt of the head. In general, the estimated time from key contact to beak closure was between 30 and 40 msec. In general, the temporal aspects of the response for VI 30-sec birds appear very similar to those produced by FR birds. In Figure 2, the filmstrip for Bird P6 represents the only significant departure from any of the other birds. The upper bill is "hooked" over the upper edge of the protruding disc and beak closure is produced by move-
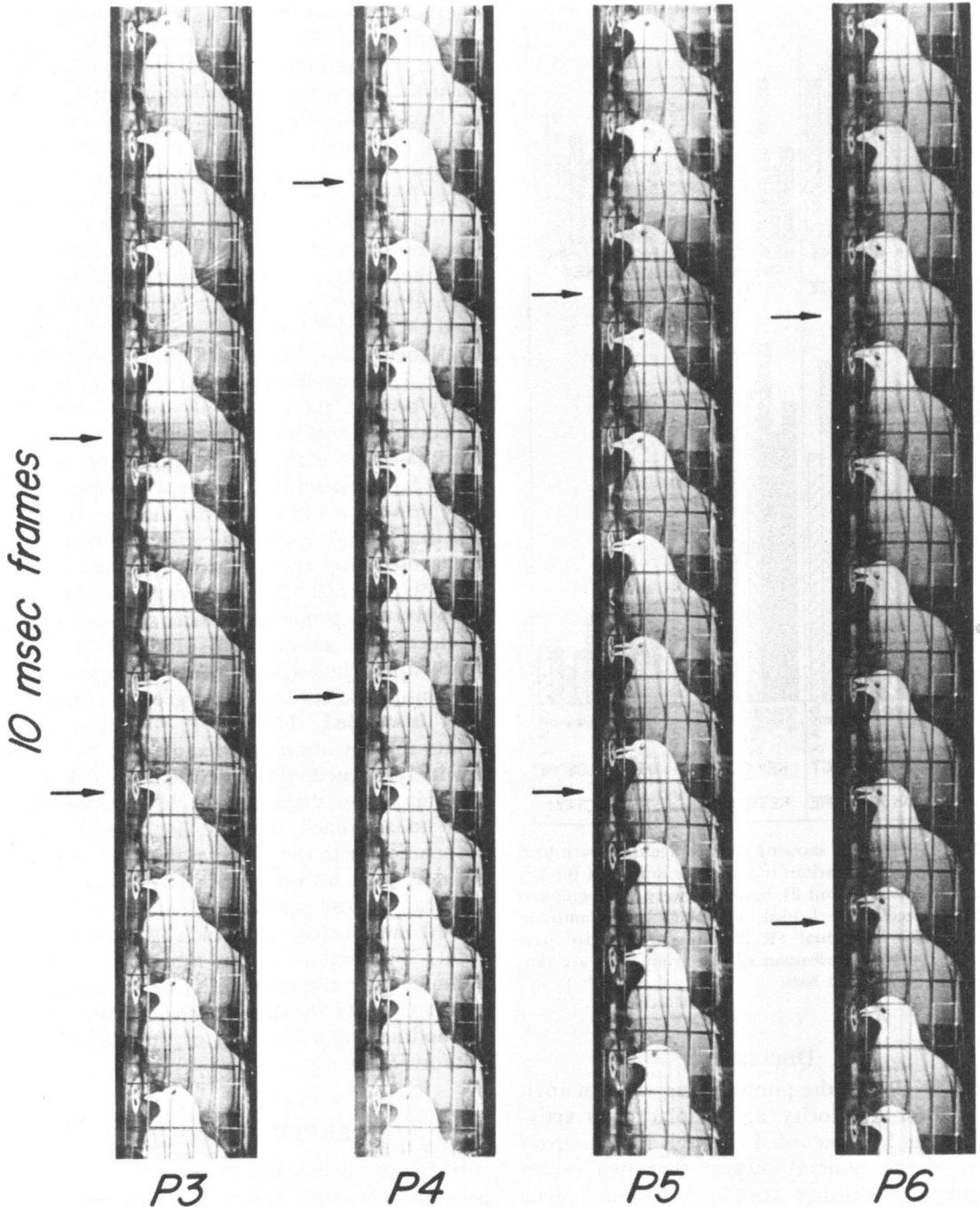
10 msec frames

P3 P4 P5 P6

Fig. 2. Kymographic pictures of single pecks made by the four variable-interval birds. The earliest frames appear at the bottom of the figure and successive frames were exposed at 10-msec intervals.

ment of the lower bill. We have concluded, through close visual inspection of the filmstrips, that this event is an artifact of the projecting key. That is, we believe that downward force was applied to the top of the key and since it was "hooked", it "pulled up" the lower bill. At any rate, the other features of the response remain unchanged.
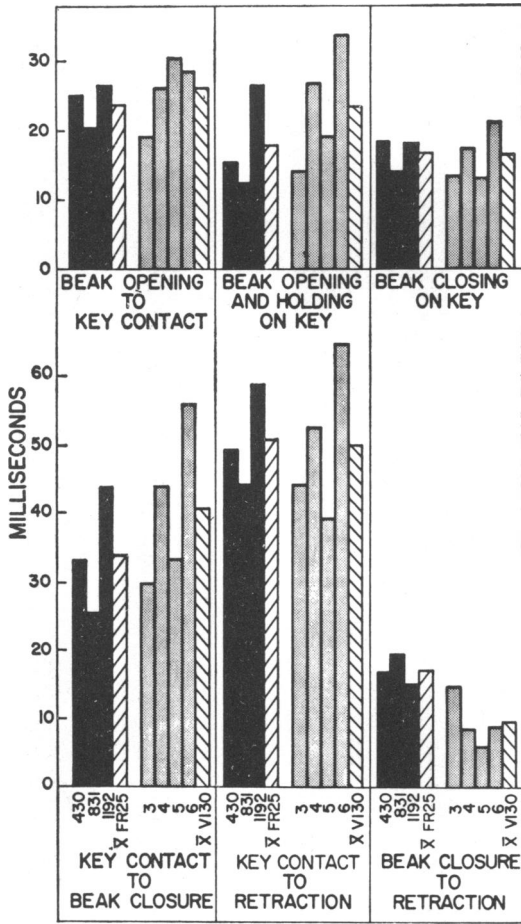
Fig. 3. Bar graph showing the average time each bird spent performing various topographic aspects of the key peck. Between 12 and 21 responses were photographed and analyzed for each bird. The black bars summarize pecking for individual FR 25 birds, the shaded bars show VI subject performance. The group data are represented by hatched bars.

DISCUSSION

Inspection of the photos along with an analysis of force, velocity, and displacement activity of the key (recorded through the accessory lens of the camera) suggest that two events capable of causing key-switch closure occur during pecking. The first occurs about 10 msec after contact, the second about 20 to 30 msec later. While the accessory lens data are not included in the present report, the effect is confirmed in interresponse times revealed in Experiment II. The second event seemed to provide the desired topographical feature that could be easily detected and used to determine

whether response topography was under the control of the reinforcement schedule.

The photographic records obtained in Experiment I suggest the following analysis of the behavioral origin of the second event.

The bird strikes the key with an open beak, the lower bill in a horizontal position and the upper bill at an acute upward angle. Although the upper bill is longer, its upward angle suggests either that the lower bill strikes first or that they contact the key at much the same time. Probably through an upward and forward thrust of the neck (Figures 1 and 2), the head then pivots downward until the beak is closed. Downward rotation of the head is necessary because the upper bill cannot move independently and the lower bill maintains a fixed position with vertical reference to the key. The arc described by the long upper bill as it moves downward across the key may result in a second operation of the key switch 30 to 50 msec after the initial contact and about 20 to 30 msec after the first switch closure. Presumably, the probability with which the arc produces the second key-switch closure depends upon the angle at which the upper bill encounters the key and the degree to which the beak is opened. That is, if the upper bill strikes the key at an acute angle and the beak is widely opened, the described arc will produce maximum displacement. If the upper bill were to approach the key horizontally (*i.e.*, perpendicular to the plane of the key) then the arc described by the upper bill would cause the beak to lose contact with the key and no second switch-closure would be expected to occur. Experiment II was designed to determine whether the probability of arc-produced switch closures (beak-closing responses) could be modified as a function of the schedule of reinforcement.

EXPERIMENT II

In Experiment I, the topography of the key peck was described and one feature of the topography, beak closing, was identified as an event that could be monitored with high-speed recording equipment. In Experiment II, a fine-grain analysis of interresponse times (IRTs) was undertaken while birds worked on VR and VI schedules of reinforcement. Beak-closing events were expected to produce IRTs shorter than 50 msec. The intent of the

experiment was to determine whether the probability of short IRTs was a function of reinforcement schedule, *i.e.*, whether response differentiation would occur.

VR and VI schedules were chosen because they are relatively uncomplicated schedules producing fairly smooth response rates, and because short IRTs were expected differentially to affect reinforcement density on the two schedules. That is, the inclusion of the beak-closing response for a bird under VR could nearly double reinforcement density, while inclusion of the response under VI should produce virtually no change in reinforcement density.

METHOD

Subjects

Four experimentally naive, male, Carneaux pigeons, approximately 3-yr old at the beginning of the study, were maintained at 80% of their free-feeding weights throughout the experiment.

Apparatus

The apparatus consisted of a standard Lehigh Valley (1519C) two-key pigeon chamber. The return spring in one of the Lehigh Valley (1348) keys was replaced with a spring made of beryllium copper in order to change the operate and return characteristics of the key. The key modification was included in order to determine whether detection of beak-closing depended upon precise characteristics of the commercial key. Schedules of reinforcement and data acquisition were controlled by a PDP-12 (Digital Electronics Corporation) computer. All computer and behavioral events were time-tagged by a data acquisition program to the closest 5-msec unit. Thus, the smallest accurate time bin for interresponse time analysis was 10 msec. No attempt was made to photograph birds in Experiment II.

Procedure

The four birds were hand-shaped according to the method of successive approximation to key peck for mixed grain in a single 1-hr session. Two of the birds, P 900 and P 905, were trained on the standard Lehigh Valley key; Subjects P 901 and P 903 were trained on the key with the replaced beryllium copper spring. One subject from each key condition was designated for VR training and one subject from

each key was designated for VI training. Both keys were set to operate with a force of 8 g (0.08N). The sequence of sessions used to bring each of the birds to the final VR or VI performance is shown in Table 1.

Table 1

Session 1	900 Shape (CRF)	901 B.C. Shape CRF	903 B.C. Shape CRF	905 Shape CRF
2	CRF	VI 6-sec	VR 2	VI 6-sec
3	VR 2	VI 12-sec	VR 4	VI 9-sec
4	VR 4	VI 18-sec	VR 4	VI 9-sec
5	VR 4	VI 24-sec	VR 4	VI 12-sec
6	VR 4	VI 30-sec	VR 10	VI 18-sec
7	VR 10		VR 20	VI 24-sec
8	VR 20		VR 40	VI 30-sec
9	VR 40		VR 50	
10	VR 50			

(B.C. = beryllium copper spring used in key)

Following 16 days on the VR 50 schedule, Birds P 900 and P 903 were transferred without additional training to the VI 30-sec schedule; similarly, after 22 days on the VI 30-sec schedule, Birds P 901 and P 905 were transferred to the VR 50 schedule. The experiment was ended after 25 sessions on the final schedules. All session durations were 60 min, and reinforcement durations were 3 sec.

RESULTS

Each bird's terminal performance on the two schedules is shown as an IRT distribution in Figure 4. The left panels show performance on the initial schedules; the right panels show the final schedules. Table 2, to be referred to while considering these distributions, contains each bird's mean IRT, standard deviation of the mean IRT, the probability of a 30-msec IRT, and the total probability of an IRT between 0 and 50 msec. Several thousand responses were used in calculating each distribution.

The upper-left panel shows the initial performance of Bird 900 on the VR 50 schedule. This bird produced a very high probability of 20- and 30-msec IRTs along with a clean distribution of about 300-msec IRTs representing new "strike" responses. When shifted to the VI schedule (upper-right panel), there was a large and unexpected increase in the probability of short IRTs, and the strike-response distribu-
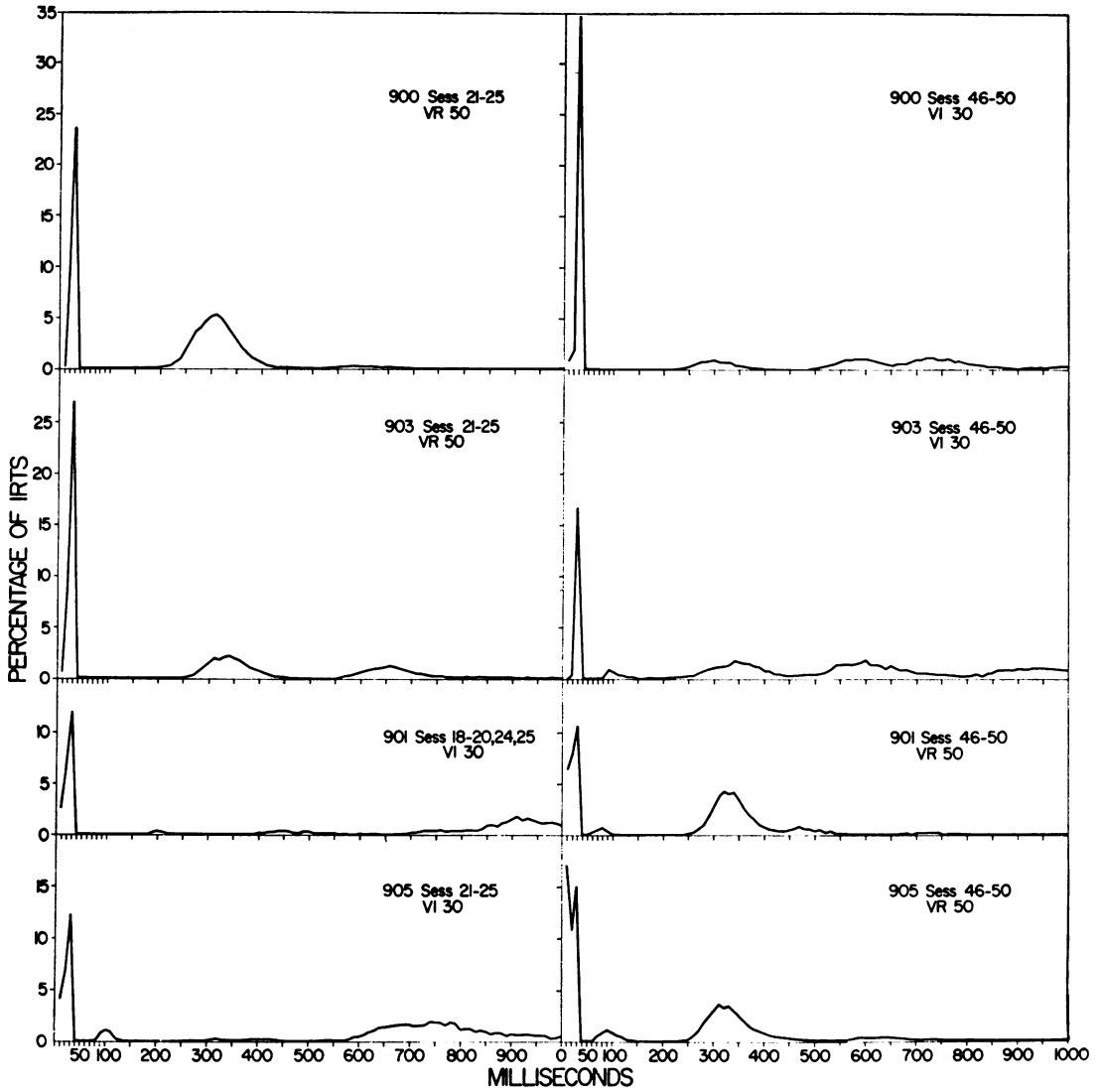
Fig. 4. IRT distributions showing terminal behavior on the initial (left panels) and final reinforcement schedules (right panels). The two upper rows show the behavior of subjects initially trained on VR and the low two rows show subjects initially trained on VI. The distributions are plotted in 10-msec bins.

Table 2

| | Initial Schedule | | | | | Final Schedule | | | | |
Subject	Schedule	Mean IRT* <1 sec	SD**	Prob. 30 msec IRT	Prob. IRT <50 msec	Schedule	IRT* Mean <1 sec	SD**	Prob. 30 msec IRT	Prob. IRT <50 msec
P900	VR 50	235	21.6	23.58	33.17	VI 30-sec	342	23.3	34.68	37.36
P903	VR 50	291	54.2	26.94	36.99	VI 30-sec	462	23.2	16.67	17.12
P901	VI 30	497	70.7	11.93	21.29	VR 50	285	9.2	10.77	25.21
P905	VI 30	505	36.3	12.41	23.82	VR 50	205	28.5	14.80	42.83

*Mean in msec for IRTs equal to or less than 1000 msec.
**An analysis of variance resulted in an $F < 1$ across sessions.

tion becomes irregular with new modes at about 600 and 725 msec.

The short IRT distribution for P 903 is similar to P 900's; it reflects a high probability of response at 30 msec. The strike-response modes are peculiar, as though the bird had previously received VI training. When this bird was shifted to VI (right panel), the probability of 30-msec IRTs was reduced and a new response mode formed around 950 msec.

The third panel shows 901's performance on the initial VI schedule. The probability of 30-msec IRTs from this subject is about half as great as from the VR birds. The bird's strike-response mode on VI was about 900 msec and shifted nicely to about 325 msec when the schedule was changed to VR (right panel). There was, however, only a minor increase in the probability of short IRTs associated with the schedule change.

P 905 also produced relatively few short IRTs during VI training, but did show substantial increase in short IRT probability after it was switched to the VR schedule. Much of this increase occurs in the 0- to 10-msec bin. Again, the effect of the schedule change appears nicely in the strike-response distribution shift.

In general, birds trained on VR showed, as expected, high short-IRT probabilities as compared to birds trained on VI. However, the effect of schedule reversal is unclear. Three of the birds evidenced some change in short-IRT probability in the expected direction, although this effect was clear in the 30-msec bin for only Birds 903 and 905. Bird 900 evidenced a large shift in the unexpected direction. Lack of reversal evidence is surprising in view of overall rate stability, as evidenced by the standard deviations and small F ratio over sessions reported in Table 2.

Modification of ·the operate and return properties of one key did not appear to affect the probability of short-IRTs.

DISCUSSION

It seems clear that during early key-peck training, the probability of short IRTs produced by beak closing was under schedule control. At best, there is only weak evidence that the beak-closing feature of the response remains sensitive to schedule changes. Presumably, introduction of the second schedule

sooner, or continued experience on this schedule, would enhance reversal effects if they are present.

These data, then, seem to support the position that key-peck response topography can be controlled by the schedule of reinforcement. However, it will be recalled that no apparent differences were observed in the microanalysis of response topography conducted with the VI 30-sec and FR 25 filmstrips analyzed in Experiment I and summarized in Figure 3. Except for perhaps the last category (beak-closure to retraction) there was considerable overlap between subjects in the ratio and interval groups. While the data are not available in Figure 3, there was also no difference observed in the variability of interval subjects (*e.g.,* the VI birds were not bimodal in any category).

After plotting Figure 3, we returned to the films in search of topographical differences between VI and FR responding that had not been included in the figure. While we were unable to find any new topographical events that could be measured from the filmstrips, it appeared that the interval birds strike the key with the upper bill more nearly horizontal than the ratio birds. This characteristic can be seen in Figures 1 and 2 (*i.e.,* the VI birds strike the key more nearly in the center). To report this effect with certainty would require vertical calibration of the key. However, if our impression is correct, the reduced frequency of beak-closing events produced by VI birds probably results from reduced arc as the upper bill moves across the key. Thus, the topography of the response is probably identical for subjects studied under interval and ratio schedules. In general terms, we would say that only the locus and not the topography of the key peck is conditioned. Just as a bird on a concurrent schedule optimized reinforcement by changing the locus of its response (left to right key), so our birds struck the key at different locations in order to maximize reinforcement.

The reader may object to our analysis for three reasons: (1) the ratio schedule (FR 25) used in Experiment I differed from the ratio schedule (VR 50) used in Experiment II; (2) the subjects photographed were not the same as the subjects showing differential IRT distributions in Experiment II; (3) in Experiment I, the key used for ratio birds differed from the key used for interval birds both in

terms of design and operate force. We do not believe these differences invalidate our conclusions.

The subject and schedule differences between the experiments resulted from an attempt to "tidy up" the IRT data presented in Experiment II. In fact, IRT data were recorded during Experiment I, but these data were not obtained systematically and did not contain a schedule reversal. Nevertheless, we were able to compare the FR 25 distributions from the first experiment with the VR 50 distributions produced by different subjects in the second experiment. These distributions were very similar and differed from the VI 30-sec distributions obtained in both experiments. Even, however, if the FR 25 distribution had failed to resemble the VR 50 distribution, it would be difficult to explain why topographical differentiation was not visible in the photographic comparison of FR and VI birds.

The third design problem, the difference between the keys used in Experiment I, would be expected to oppose our conclusion of no difference in topography. That is, differences between keys should support differences in topography. None were observed. Thus, we must conclude that under schedule control, birds do indeed respond in such a way as to maximize reinforcement. However, it is not the topography of the response that changes under schedule control; rather, it is the locus of the response on the key that is changed. That is, the food-reinforced peck may well represent a species-specific eating response, and during training its locus is *associatively* changed from hopper to key.

A final note of caution. High-speed equipment (*e.g.*, solid-state modules and mini-computers) will not distinguish between key-striking and beak-closing events produced on Lehigh Valley keys set to operate around 10 g. This means that reinforcement density and recorded response rates may not agree with data collected from (a) "paddle" switches (*e.g.*, Grason-Stadler), (b) equipment with input pulse formers set above 50 msec, or (c) slower speed electromagnetic equipment. Whether the beak-closing event should be accepted as a legitimate response must be decided by the investigator. However, if it is accepted, the keys should receive daily calibration checks; if it is rejected, input pulse-formers set at 100 msec should be included in the circuitry.

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