A PRELIMINARY ANALYSIS OF THE DYNAMICS OF THE PECKING RESPONSE IN PIGEONS[1]

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The pecking response of pigeons is usually measured by a transducer that senses the presence or absence of a response. Typically, the response force as a function of time has not been accurately measured. Data were collected using a transducer specially designed to record the waveform of the pecking response in pigeons. Each response on the target surface of the transducer was reinforced and followed by a blackout. The response was stored on an oscilloscope screen and the peak force and duration of the response were recorded manually from the oscilloscope screen. The mean peak force of the response substantially exceeded the minimum criterion for reinforcement of 35 g (0.343 Newtons) of force. Photographs of the waveform of pecks on the transducer showed great variability in response force and demonstrated that the waveform produced by pecking the target surface was complex. The responses were frequently asymmetrical with the rise time shorter than the fall time, although no single verbal description could be applied to all of the waveforms. Bimodal peaks and double responses were observed and the first peak or response was usually larger than the second. A disadvantage of the transducer was that pecking produced oscillation of the transducer at its resonant frequency. In spite of this deficiency, the waveform of the peck was easily recognizable.

In much instrumental conditioning research, the experimenter is interested in the amount of time between responses. A transducer that senses the presence or absence of a response is appropriate for such research. With pigeons, most investigators employ the transducer developed by Ferster and Skinner (1957). A peck of sufficient force on the plastic armature of the key opens it and provides an electrical signal for the recording and scheduling apparatus. The key is usually adjusted so that the lightest peck that is expected will operate the switch. Variation in the force of the peck is undoubtedly present and the conventional key was not designed to measure such variation. To compare the force of different responses, it is necessary to measure the change in the force of the response as a function of time. The rationale for an experimental analysis of response dynamics has been expressed by Notterman and Mintz (1965) who said: "Are there significant experimental or theoretical questions best answered by examina-

tion of the dimensional characteristics of the response itself rather than by study of the time interval between responses (p. 3)?"

Several different types of transducers have been used to measure the dynamics of the pecking response in the pigeon. Some transducers were designed to measure the force of the response; others were designed so that the required force could be experimentally manipulated. Hefferline, Birch, and Gentry (1961) employed a pressure transducer. They found a substantial error in the output of the transducer depending on where the pigeon pecked the target area. The major disadvantage of their transducer was that the amount of force with which the pigeons struck the key far exceeded that required to produce reinforcement; the birds began to bleed around the beak and eventually stopped responding. Chung (1965) mounted an extension spring on the conventional response key so that the minimum force required to operate it could be adjusted. The key provided an ingenious and inexpensive technique for detecting when a response exceeded the minimum force criterion, but it had the disadvantage of not sensing the minimum force criterion. Chung varied the minimum effective force of a response and found that, beyond a certain force value, the response rate decreased with increas-

ing force requirements. However, Chung's results are difficult to interpret because the decrease in response rate may have been due to unregistered responses emitted with less force than required by the criterion at the higher force levels. Hake and Azrin (1969) varied the minimum force necessary to operate the key (Ralph Gerbrands Co.) by varying the amount of resistance in series with an electromagnet that held the key in a normally closed position. This transducer cannot detect responses that fail to meet the minimum force level. Cole (1965) used a phonograph crystal to record the dynamics of the peck in an experiment that attempted to determine how stimulus generalization affected response force. Cole's data are difficult to interpret because calibration data for the transducer were not provided. This survey indicates that a transducer that can be used to measure accurately the force of the peck and the output of which can be used to manipulate experimentally the force required for contingencies of reinforcement has yet to be developed.

In designing an ideal transducer for measuring the dynamics of the peck, the following factors should be considered: (1) The transducer should produce an accurate, continuous analog representation of the instantaneous force at the manipulandum. As Notterman and Mintz (1965) have shown, the force-time record of the response can be quantified along three dimensions: the peak force, the duration, and the time integral of force or impulse. The peak force is the maximum force reached during a response. The duration is the time between the beginning and the end of a deviation from zero force at the manipulandum. The time integral of force is the area under the force-time curve during the response. (2) The transducer should have a linear output over the range of forces produced by a peck. (3) The resonant frequency of the transducer, the frequency at which the transducer oscillates, should be high enough that a response does not induce ringing, *i.e.*, oscillation of the transducer at the resonant frequency. (4) The output of the transducer should be independent of the location of the force on the target area of the transducer. (5) The target area of the transducer or its surround should be translucent so that it could be illuminated from behind. (6) The displacement of the transducer by the response should be as small as

possible. Notterman and Mintz (1965) a[...] that the time integral of force is a better i[...] of energy expenditure by the organism [...] work, which is the product of force times [...] tance. The state of the art of transducer [...] sign does not permit all of these criteria t[...] met by a single transducer; so the investig[...] is forced to decide which factors he consi[...] most important.

The purpose of the present research wa[...] collect preliminary data using a transd[...] that was designed specifically for measu[...] the pecking response of the pigeon. Ph[...] graphs of the output of the transducer sho[...] the actual changes in force that occurred [...] ing the response. Data from the photogr[...] could be used to establish some paramete[...] the force of the pigeon's peck for a more [...] plex control and recording system.

METHOD

Subjects

Four experimentally naive adult fe[...] White Carneaux pigeons were maintaine[...] 80% of their free-feeding weight.

Apparatus

Mechanical properties of the transd[...] system. The force transducer was a load [...] designed to meet our specifications by Le[...] Associates (21820 Wyoming Ave., Oak P[...] Mich. 48227). A load cell is a transducer t[...] measures force due to a compressive [...] (Perry and Lissner, 1962). A load cell con[...] of strain gauges bonded to a metal surface [...] connected electrically in an arrangement t[...] is sensitive to the strain of interest to the [...] perimenter. The transducer was a model [...] 3108-113 load cell and the cost was $950. [...]

A photograph of the transducer is show[...] Fig. 1. The transducer was 3 ¹⁄ in. long [...] 1½ in. wide by 1¾ in. (7.98 cm by 3.81 cm [...] 3.49 cm) thick. The sensing end of the tr[...] ducer was a metal semicircle with a radiu[...] 0.5 in. (1.27 cm) which is shown at the bott[...] of Fig. 1. The strain gauges were bonded [...] two metal beams attached to the sensing [...] of the transducer. A plastic window 1.5 [...] long by 1.5 in. wide (3.81 cm by 3.81 cm) m[...] of Polacoat Lenscreen was rigidly attached[...] the sensing end of the transducer with [...] screws; hence, the plastic window did not h[...] the displacement upon impact of the conv[...] tional pigeon key.
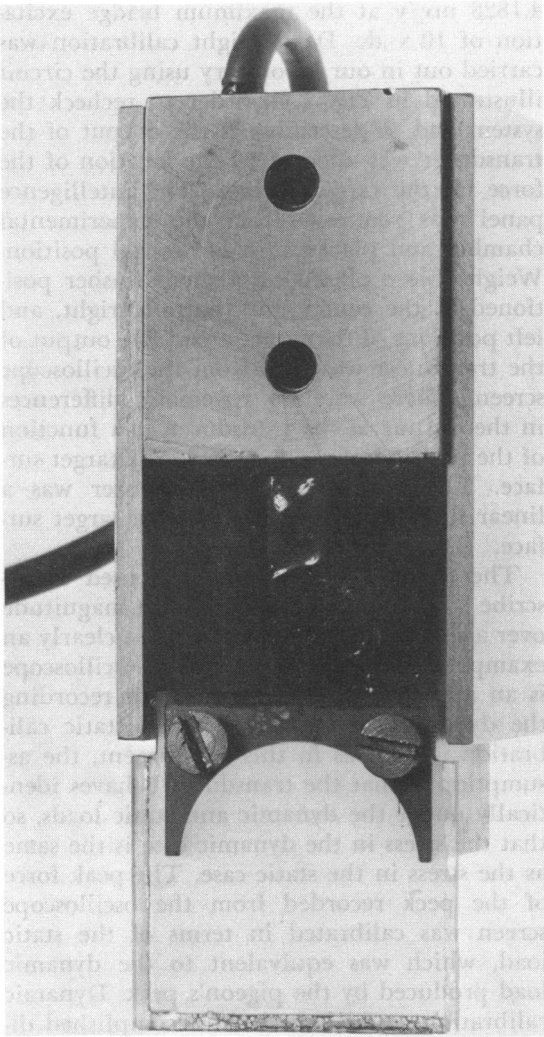
Fig. 1. A photograph of the transducer.

The force transducer replaced the conventional center key in a Lehigh Valley Electronics 1519 three-key pigeon test chamber. The houselight above the center key was removed to make room for the transducer. The transducer was mounted behind the intelligence panel above the hole for the center key so that the metal semicircle was aligned with the hole for the center key, which had a diameter of 1 in. (2.54 cm). From the bird's eye view, the transducer was a 1 in. (2.54 cm) diameter screen. The entire surface of the screen was illuminated from behind by a Lehigh Valley Electronics tricolor stimulus light. Shape or pattern stimuli also could be projected on the screen.

The output of the transducer was the input

for Tektronix type 546 oscilloscope with storage using a type 2A63 differential amplifier and a type 2B67 time base. A Polaroid camera was mounted on the frame and could be swung into position for photographing the screen of the oscilloscope. Some of the features of this oscilloscope proved quite valuable. A sweep across the oscilloscope screen could be triggered by an input voltage from the transducer. Once a single sweep occurred, all other input stimuli were locked out until the triggering device was reset. In addition, any sweep could be stored on the screen until manually erased.

Electrical properties of the transducer system. Electrically, the transducer was a Wheatstone bridge composed of four resistors connected in the pattern shown in Fig. 2. In a load cell, the four arms of the Wheatstone bridge are strain gauges in which resistance changes when a force is applied to the sensing end of the transducer. The strain gauges were bonded to the metal surface of the transducer in a configuration such that the output of the transducer would be independent of the location of the peck on the target surface. The bridge was designed for a maximum excitation with 10 v ac or dc. In this experiment, an 8-v battery provided the excitation voltage.

A simplified circuit diagram of the transducer and its auxiliary circuits is presented in Fig. 2. The Wheatstone bridge of this transducer is called a "hybrid bridge" because it is formed of semiconductor gauges (S.C. in Fig. 2) in two arms and foil gauges (F. in Fig. 2) in two arms. The hybrid bridge has the advantage of compatibility with conventional bridge balancing and shunt calibration circuits and the disadvantage of reduced output as compared with a full semiconductor bridge. A semiconductor gauge consists of semiconductor materials in which resistance changes when force is applied to the surface of the material to which the gauge is bonded. A foil gauge is a grill of extremely thin resistance wire. When force is applied to the structure to which the gauge is bonded, the resistance of the wire changes due to changes in its length and diameter.

The transducer was theoretically designed so that with no force on the target surface of the transducer, the bridge would be balanced and the output would be zero. In practice, it was necessary to balance the bridge before and during each session because balance changed
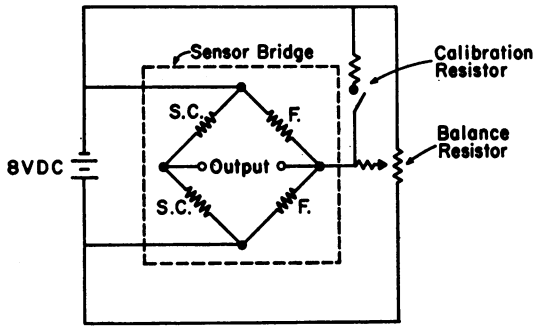
Fig. 2. A simplified schematic diagram of the sensor bridge, "T" bridge balance network, and shunt calibration network.

slightly from day to day and the amplifier of the oscilloscope drifted slightly within each session. The bridge was balanced by means of a "T" bridge-balance network, which was simply a 10K potentiometer attached to the three arms of the bridge as illustrated in Fig. 2. The vertical position control of the oscilloscope was used to position the oscilloscope trace vertically at the desired position on the oscilloscope screen.

Calibrating the transducer. A transducer may be calibrated electrically by shunt calibration or mechanically by dead-weight calibration. In shunt calibration, a precision resistor of considerably higher value than the resistance of an arm of the bridge is placed in parallel with one arm of the bridge. The shunt calibration network in Fig. 2 was a precision resistor rated at 112,375 ohms with an accuracy of 0.05%. This precision resistor produced a bridge unbalance equivalent to 500 g of dead weight on the transducer when placed in parallel with one arm of the bridge by closing the switch shown in Fig. 2. The synthetic strain produced by the precision resistor appeared as a vertical displacement of the trace on the oscilloscope screen. The transducer was shunt calibrated before each session and was checked within the session during the blackout after reinforcement. Shunt calibration is more convenient than dead-weight calibration because it can be carried out while the pigeon is in the experimental chamber and does not require removal of the transducer from the experimental chamber.

Dead-weight calibration by the manufacturer rated the linearity of the transducer at 0.1% of the two-pound rated capacity of the cell and the output of the transducer was

4.1828 mv/v at the maximum bridge excitation of 10 v dc. Dead-weight calibration was carried out in our laboratory using the circuit illustrated in Fig. 2 in order to recheck the system and to determine if the output of the transducer was affected by the location of the force on the target surface. The intelligence panel was removed from the experimental chamber and placed in a horizontal position. Weights were placed on a small washer positioned at the center, top, bottom, right, and left positions of the target area. The output of the transducer was read from the oscilloscope screen. There were no systematic differences in the output of the transducer as a function of the position of the weight on the target surface. The output of the transducer was a linear function of the force on the target surface.

The term "dynamic strain" is used to describe strain that varies rapidly in magnitude over a short time interval. A peck is clearly an example of dynamic strain, and an oscilloscope is an appropriate null detector for recording the dynamics of the peck. When static calibration is used as in this experiment, the assumption is that the transducer behaves identically under the dynamic and static loads, so that the stress in the dynamic case is the same as the stress in the static case. The peak force of the peck recorded from the oscilloscope screen was calibrated in terms of the static load, which was equivalent to the dynamic load produced by the pigeon's peck. Dynamic calibration could have been accomplished directly by dropping ball bearings on the surface of the transducer. The resonant frequency of the transducer was approximately 1600 to 1900 Hz.

Procedure

The birds were run six days a week. The center key, behind which the transducer was mounted, was illuminated with green light, and the two side keys were illuminated with white light to provide general lighting in the chamber. All birds were habituated to the chamber on the first day, magazine trained on the second, and shaped to peck the green center key on the third. Whenever the magazine was in the feeding position, the center key was dark. During magazine training, termination of access to grain was occasionally fol-

lowed by a timeout of from 5 to 15 sec. During a timeout all lights in the chamber were out and the chamber was completely dark. On the day of shaping and thereafter, each of 50 pecks on the center key was reinforced with 6-sec access to grain. A 20-sec timeout followed each reinforcement. Each peck that exceeded approximately 35 g (0.343 N) of force triggered a sweep of the oscilloscope and the resulting force-time function was stored on the screen. During the timeout period the peak force and duration of the peck were recorded. The duration of the peck was operationally defined as the length of time from the triggering of the sweep to the first return of the trace to the baseline. The peak force was defined as the highest point of the trace from the onset of the response to the first return to the baseline. In many instances multiple peaks occurred, but only rarely was any later peak higher than the first. In most cases, the amplifier and time base were set such that the maximum peak force that could be recorded on the oscilloscope was 480 g (4.70 N) and the maximum response duration was 45 msec. The peak force and duration were recorded in tenths of the major divisions on the scope graticule.

At the beginning of each session, the bridge balance network and vertical position control of the oscilloscope were adjusted so that the baseline of no force on the transducer was centered at the first horizontal line of the graticule. Just before the end of the timeout period, the baseline on the oscilloscope was checked and the bridge balance network was adjusted if necessary. As soon as the keylights came on, the oscilloscope was set to trigger on the next peck. Once it was triggered it could not again be triggered until it was reset. As soon as the investigator saw the peck appear on the screen, reinforcement was started using a hand microswitch. All other scheduling was accomplished with electromechanical switches and timers located in another room. Manual, rather than automatic, recording and reinforcement were employed because we do not as yet have equipment to provide control over the feeder by the waveform. Hence, our data are preliminary.

All animals were given 15 daily sessions of 50 reinforcements each followed by the 20-sec timeout. On the next two days, each peck was followed immediately by a 20-sec timeout but reinforcement was eliminated (extinction).

These sessions were terminated after 50 pecks or any latency to peck of 20 min. The birds were returned to the schedule including reinforcement and timeout for two more sessions after extinction.

In addition to recording the duration and peak force for each response, two pecks from each bird during each of the 15 sessions were photographed from the screen of the oscilloscope. In order to select and present sample photographs of each bird's pecking behavior, the following procedure was used. The pecks to be photographed were determined randomly before each session. Four photographs for each bird were selected from the 30 photographs taken during the 15 days of continuous reinforcement. The photographs were sorted into four piles. Three of the piles were based on the peak force of the peck and a fourth pile was reserved for "atypical pecks". The high peak-force pile contained pecks that were at least one standard deviation above the mean, the medium-force pile contained pecks that were between one standard deviation
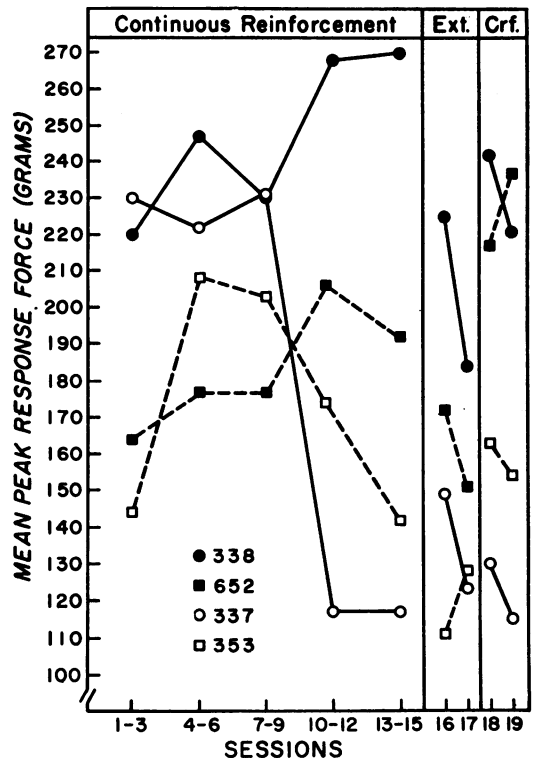

Fig. 3. Mean peak response force as a function of successive sessions. (The metric for the vertical axis may be converted to Newtons (N) by means of the relationship: 1 gram-force = 0.009807 N.)

above and below the mean, and the low peak-force pile contained pecks that were at least one standard deviation below the mean. One peck was selected from each of the three typical piles using the criterion of which peck was the most characteristic in terms of the total waveform of the response. The atypical peck was selected using the criterion of the peck that was most uncharacteristic of all 30 pecks in terms of the total waveform of the response.

RESULTS

The results are presented in Fig. 3 to 6 in terms of means and standard deviations across sessions for each of the four subjects. Figure 3 shows that the mean peak response force for the four animals was substantially greater than the 35-g (0.343 N) criterion, but no trends consistent for all four birds were apparent during the 15 sessions of continuous reinforcement. A comparison of the mean peak response force during the two sessions of extinction with the average of the three preceding sessions of continuous reinforcement shows a decrease during extinction for Birds 338, 652, and 353, but an increase for Bird 337. In Session 18, when continuous reinforcement was reintroduced, all four birds showed an increase in the mean peak force over the level that prevailed during the previous sessions of extinction.

Figure 4 shows the standard deviations of the means presented in Fig. 3. As is the case with the means, no systematic trends are ap-
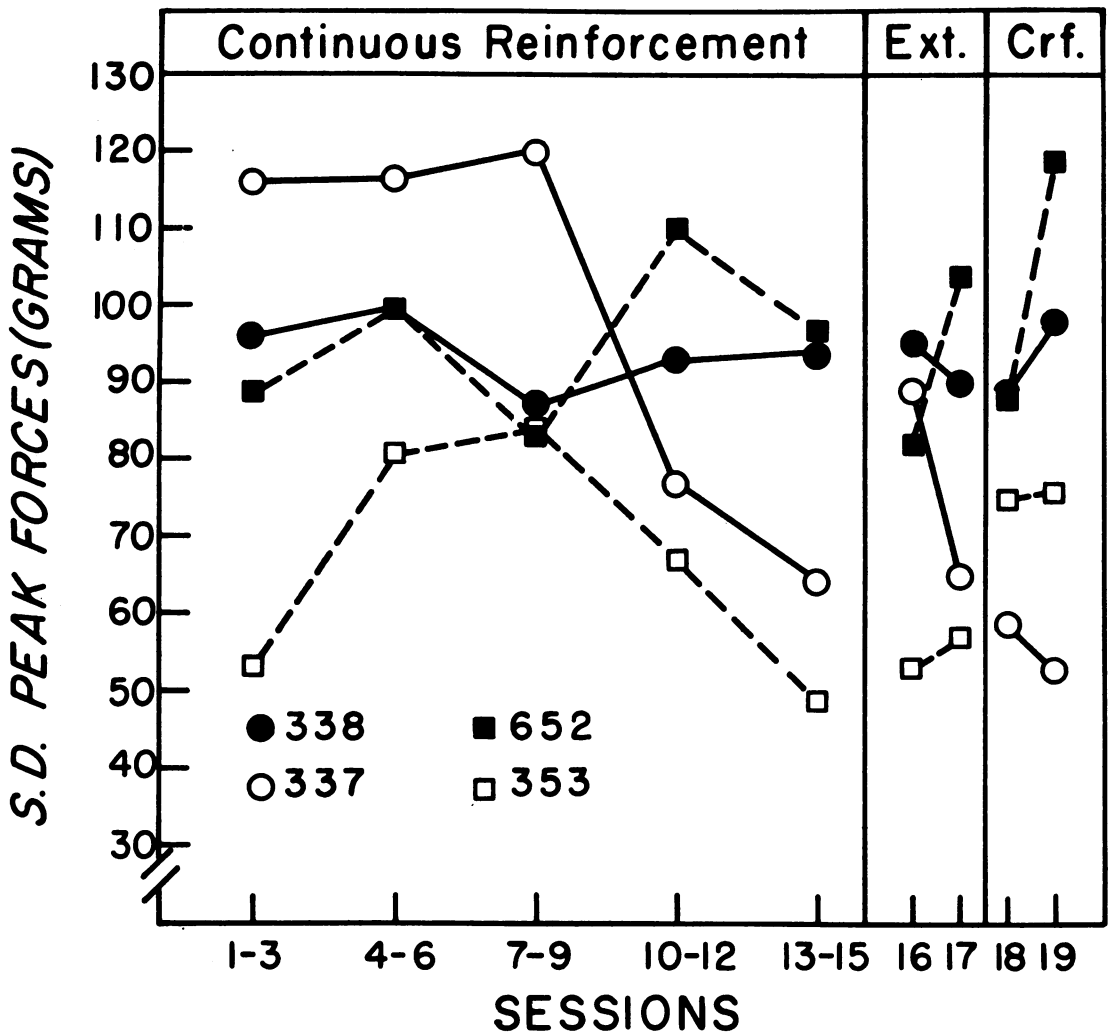

Fig. 4. Standard deviation of mean peak response force as a function of successive sessions. (The metric for the vertical axis may be converted to Newtons (N) by means of the relationship: 1 gram-force = 0.009807 N.)
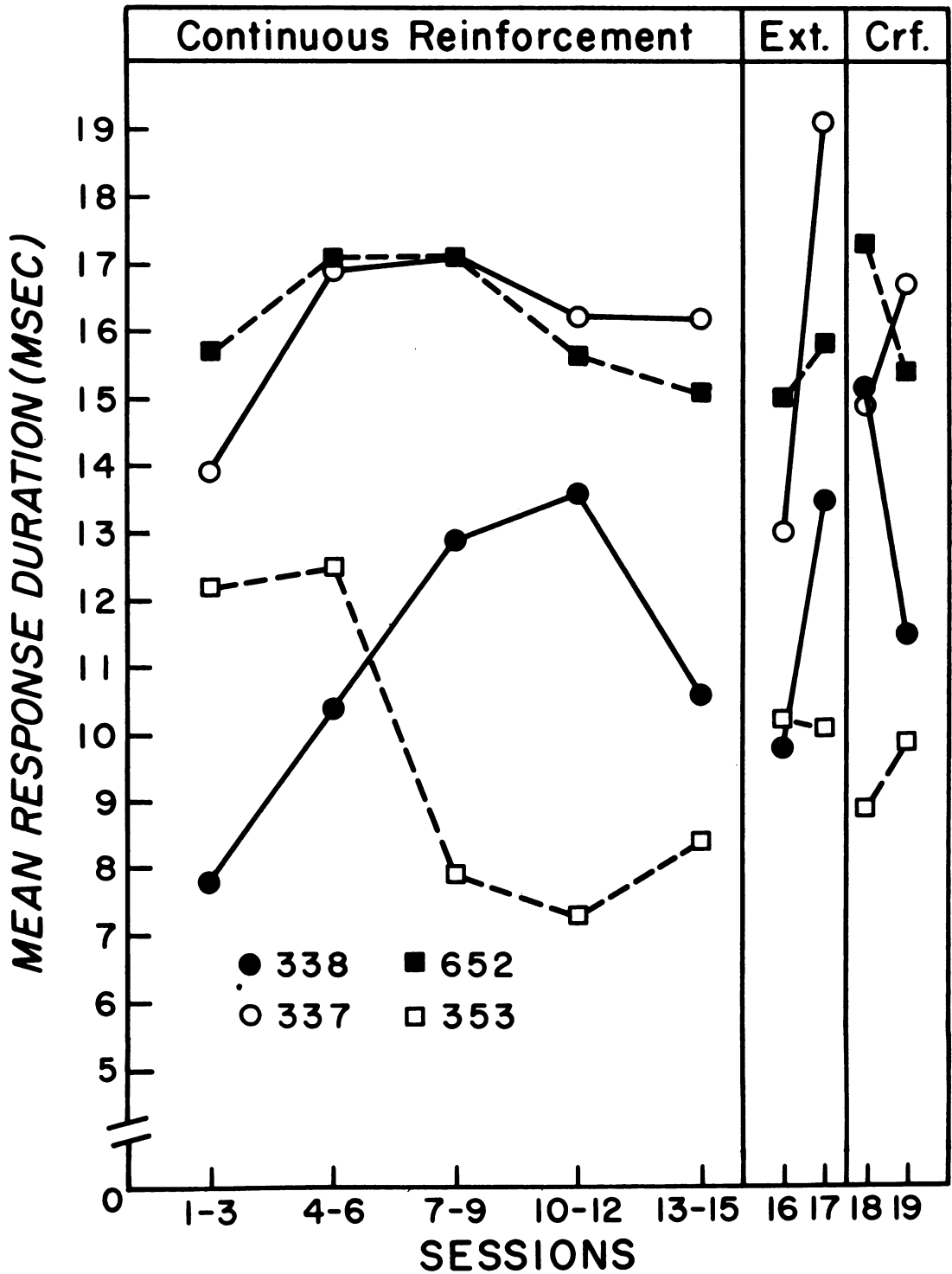
Fig. 5. Mean response duration as a function of successive sessions.

parent during the 15 days of continuous rein-
forcement. The standard deviations illustrate
the substantial variability in the mean peak
force that was obtained with this procedure.

Figure 5 shows no consistent trends in the
mean response duration during the 15 sessions
of continuous reinforcement. Extinction did
not have a consistent effect on response dura-
tion, and reconditioning produced about the
same response durations as were obtained dur-
ing Sessions 13 to 15 of original conditioning.

Figure 6 shows the standard deviations of
the means presented in Fig. 5. For each ani-
mal, the variability was greatest during Ses-
sions 4 to 6 and decreased during Sessions 7 to
15. The second day of extinction produced an
increase in the variability of the response du-
ration as compared with the first session of
extinction and the last three sessions of con-
tinuous reinforcement.

Figure 7 presents the photographs of the
individual responses selected from the 15 days
of continuous reinforcement. In Fig. 7, each
row shows the four responses for each bird.
The columns in Fig. 7 are arranged from left
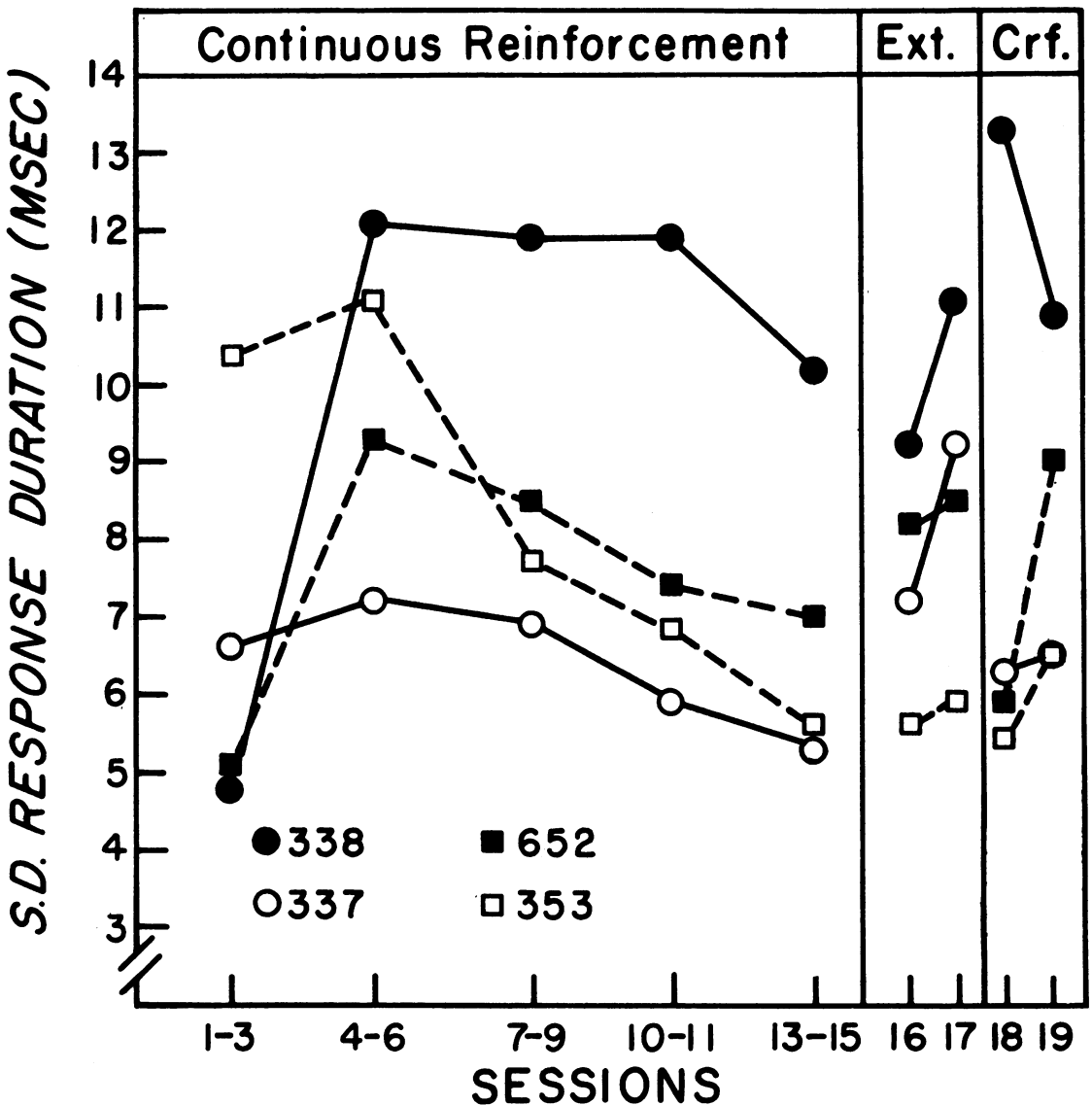to right with high, medium, low-peak force,

Fig. 6. Standard deviation of mean response duration as a function of successive sessions.

and atypical responses respectively. Each large division on the horizontal axis of the graticule equals 5 msec and each large division along the vertical axis equals 70 g of force (0.685 N). The horizontal sweep was adjusted so that the response began at the first large vertical line. The sweep triggered when the force of the response exceeded half a large division, or about 35 g of force (0.343 N), so the initial deflection from the baseline to the criterion does not show on the photograph of the oscilloscope trace.

For the responses with a high peck force shown in Fig. 7, the largest was 425 g (4.16 N) for Bird 338. For Birds 337, 652, and 353 the responses with a high peak force were asymmetrical with the rise time shorter than the fall time, while the response for Bird 338 was symmetrical. For all four birds, the rise time to the peak was 3 msec or less and the average

fall time to the baseline was 8 msec. The bimodal response shown for Bird 337 was typical of the high-force pecks of this bird. The photographs for Birds 338 and 353 show multiple responses since the trace crossed the baseline before the second major peak occurred. When multiple responses occurred, the peak force of the second response was usually lower than that of the first. The time between the peaks of the two responses was 13 msec for Bird 338 and 10 msec for Bird 353.

For Bird 338, the response of medium peak force shown in Fig. 7 was bimodal with the second peak larger than the first. This response rose rapidly to a peak, dropped toward, but did not reach the baseline, and then rose to a second larger peak and finally dropped to the baseline. For Birds 337 and 353, each response of medium peak force reached the peak in less than 2 msec and then
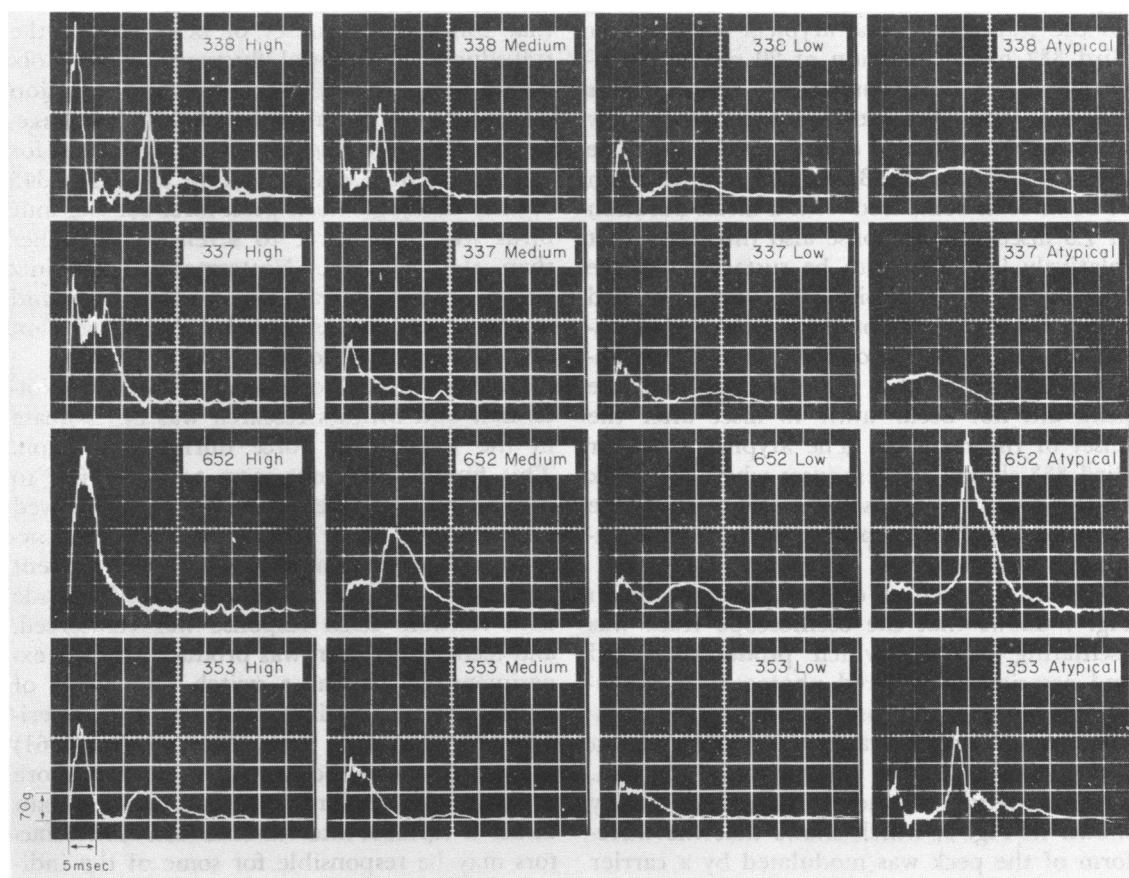

Fig. 7. Photographs of typical responses of high, medium, and low peak force and an atypical response for each of the four birds. Each photograph shows the output of the transducer during the 45 msec after the onset of a response. Each large division of the horizontal axis equals 5 msec and each large division of the vertical axis equals approximately 70 g of force (0.685 N).

dropped to the baseline in 20 msec for Bird 337 and 10 msec for Bird 353. For Bird 652, the medium-force response was more symmetrical than those of the other birds, since the duration of the response was 20 msec and the peak occurred 10 msec after the onset of the response.

The responses of low peak force for the four birds shown in Fig. 7 were all asymmetrical with the rise time shorter than the fall time. Double responses are shown for Birds 338 and 337 and the peak of the first response was larger than the second. The low-force response for Bird 652 was bimodal with the first peak larger than the second.

Atypical responses are shown in the right-hand column of Fig. 7. For Bird 338, the mean response duration for the 15 sessions was 10 msec. The atypical response for this bird shows a response that had a duration of 35 msec and that was sustained with a relatively low force on the transducer. The atypical response for Bird 337 had a duration of 20 msec as compared with a mean duration of 7.3 msec; this response also illustrates that relatively low force can be sustained on the transducer. The atypical response for Bird 337 had a duration of 20 msec as compared with a mean duration of 7.3 msec; this response also illustrates that relatively low force can be sustained on the transducer. The atypical response for Bird 652 had a peak force of 425 g (4.16 N), an unusually large peak force for this bird. An unusual feature of this response was that the peak did not occur until 15 msec after the onset of the response. The atypical peck for Bird 353 shows two responses where the peak of the second response was larger than the peak of the first response; such double responses were unusual.

Careful inspection of the photographs in Fig. 7 shows that the oscilloscope trace was oscillating rapidly, which produced jagged and occasionally blurred photographs. In order to observe this oscillation of the transducer, several photographs were taken with a sweep speed of 2 msec per horizontal division. The oscillation of the transducer is clearly shown in Fig. 8, which shows that the waveform of the peck was modulated by a carrier frequency of about 1600 Hz. The duration of the response was evidently short enough to produce oscillation of the transducer at its resonant frequency of 1600 Hz. This oscilla-

tion or ringing of the transducer introduced an error into the measurement of the peak force, since the oscillation of the transducer could either add to or subtract from the waveform of the response.

Observation of the birds after each session revealed no damage to or bleeding around the birds' beaks.

DISCUSSION

The pecking response is not a simple ballistic impact relatively invariant from response to response. The photographs of the force-time record showed that the waveform produced by pecking was complex and variable. The responses were frequently asymmetrical with the rise time shorter than the fall time. Bimodal peaks were observed and the first peak was usually larger than the second. Two responses were sometimes observed during the 45 msec that followed the onset of behavior on the transducer. Substantial fluctuations were observed in the mean peak force and duration during the 15 sessions of continuous reinforcement. Although the minimum criterion for reinforcement was a peak force of 35 g (0.343 N), the observed mean peak force for the four birds was from three to seven times higher than the criterion. Notterman and Mintz (1965), in their research with rats, also found that the mean force exceeded a low criterion of minimum peak force.

One of the most consistent findings in Notterman and Mintz's research was an increase in the mean peak force during extinction. This finding does not seem to generalize to pigeons; in fact, three of the four birds showed a decrease in mean peak force during extinction. However, comparisons of the present data with previous research should be made with caution. Each response was reinforced, and feeder operation was produced by the experimenter operating a switch, so a delay of reinforcement was introduced by the experimenter's reaction time. Herrnstein (1961) showed that the location of a peck is more variable when each response is reinforced than under a variable-interval schedule. These factors may be responsible for some of the individual differences and variability that were obtained.

An examination of the waveforms of the peck suggests that a portion of the transducer
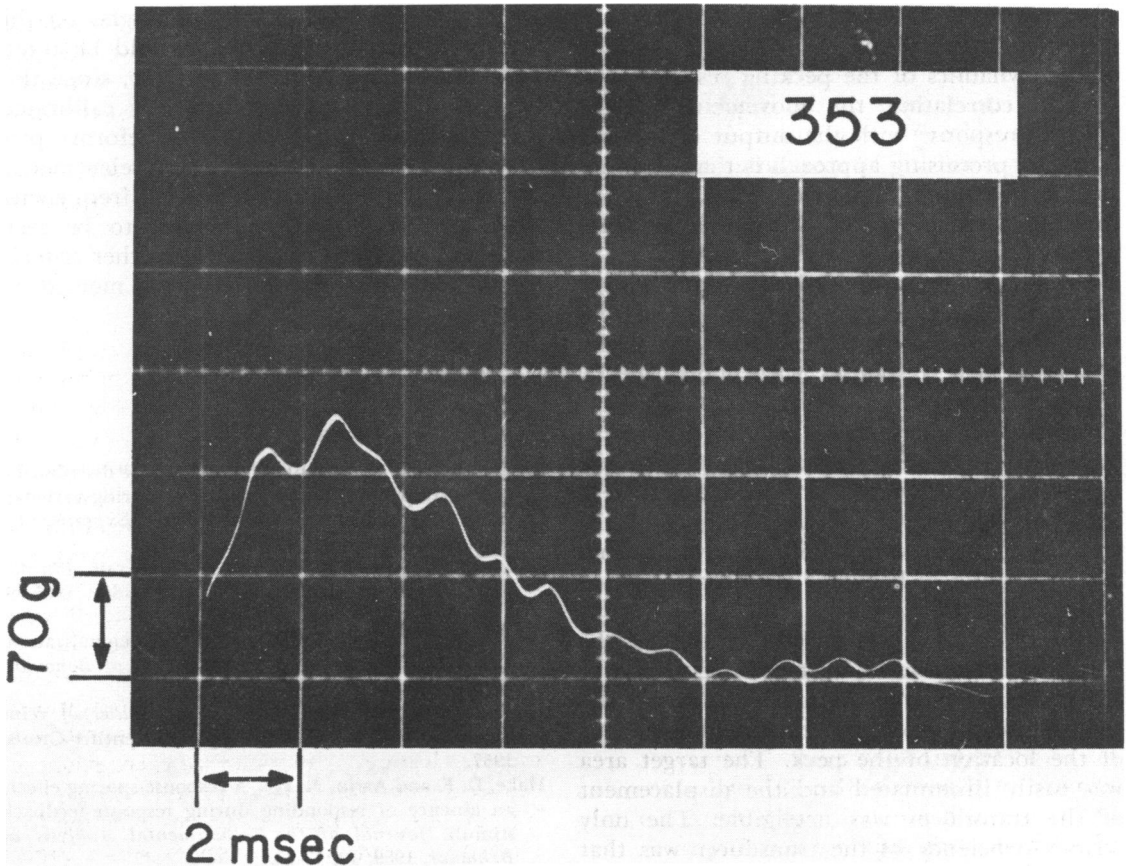
Fig. 8. A photograph of a single force-time record for Bird 353 taken to illustrate oscillation of the transducer at its resonant frequency. Each large division on the horizontal axis equals 2 msec and each large division on the vertical axis equals approximately 70 g of force (0.685 N).

output is due to artifacts produced by the resonant frequency of the transducer or oscillation of the plastic window when struck by the pigeon's beak. Such artifacts could be reduced by filtering. For example, a low pass filter could be employed, particularly if the experimenter was not interested in measuring the peak force. A computer of average transients such as the CAT could also be employed to extract the signal produced by the peck from background random noise. If filtering techniques are necessary, the time integral of force or impulse would be a more appropriate dependent variable for measuring the dynamics of the peck than the peak force.

In the experimental chamber the pigeon was free to emit any sequence of movements as long as the minimum force on the transducer exceeded the criterion. The animal is probably reinforced for standing in one position in the chamber and moving its head toward the key at a certain rate. Different birds will be rewarded for different movement patterns, which may account for some of the individual differences observed here. It is interesting to note than when Hake and Azrin (1969) wanted to shape a discrete pecking response, they reinforced a downward movement of the head toward the key. When the pigeon pecks the target surface, the output of the transducer is a product of the mass that strikes the transducer times the acceleration of the pigeon's beak. Thus, the experimenter may also be reinforcing the rate at which the bird moves its beak toward the key, since the more rapid the beak's acceleration at impact, the greater will be the output of the transducer. Observation of the birds by the experimenter demonstrated that pecking was not always a rapid discrete movement; sometimes the animal appeared to push the key and sometimes it worked its beak back and forth in the

crevice between the intelligence panel and the target surface. Ultimately, an understanding of the dynamics of the pecking response will require correlating the movements of the pecking response with the output of a transducer. A promising approach is that of Smith (1968), who used high-speed photography to correlate specific aspects of the peck sequence with changes in the force-time records.

Several investigators, Blough and Blough (1968) and Smith (1968), have suggested that short interresponse times are multiple pecks. Whether these responses with short interresponse times should be viewed as topographic variants of a single peck remains to be determined. However, the photographs of the force-time records reported here are consistent with this interpretation: they show that the force may cross the baseline several times after the onset of behavior within an interval of 45 msec.

The design, calibration, and output of the transducer indicated that it possessed many of the characteristics of an ideal transducer. Its output is continuous, linear, and independent of the location of the peck. The target area was easily illuminated and the displacement of the transducer was negligible. The only serious deficiency of the transducer was that its resonant frequency of 1600 Hz was not high enough, so that pecking the target area produced oscillation of the transducer at its resonant frequency. This deficiency principally affected the measurement of the peak force and would have less effect on the measurement of duration or time integral of force. Despite this deficiency, the waveform of the peck was easily recognizable. Future transducers for measuring response dynamics in the pigeon should be designed with a resonant frequency substantially higher than 1600 Hz. In addition, a future transducer should be calibrated dynamically by dropping a ball bearing from various heights and at various angles on the surface of the transducer. It would be interesting to employ an accelerometer, since this type of transducer is dynamically calibrated for measuring the complex waveforms produced by transient impacts. Accelerometers typically have higher resonant frequencies than load cells, but it remains to be seen whether accelerometers meet the other criteria for an ideal transducer that were mentioned earlier.

REFERENCES

Blough, Patricia M. and Blough, D. S. The distribution of interresponse times in the pigeon during variable-interval reinforcement. *Journal of the Experimental Analysis of Behavior*, 1968, 11, 23-28.

Chung, S-H. Effects of effort on response rate. *Journal of the Experimental Analysis of Behavior*, 1965, 8, 1-8.

Cole, J. L. Force gradients in stimulus generalization. *Journal of the Experimental Analysis of Behavior*, 1965, 8, 231-242.

Ferster, C. B. and Skinner, B. F. *Schedules of reinforcement*. New York: Appleton-Century-Crofts, 1957.

Hake, D. F. and Azrin, N. H. A response-spacing effect: an absence of responding during response-feedback stimuli. *Journal of the Experimental Analysis of Behavior*, 1969, 12, 17-26.

Hefferline, R. F., Birch, J. D., and Gentry, T. Simple transducers to detect or record operant amplitude. *Journal of the Experimental Analysis of Behavior*, 1961, 4, 257-261.

Herrnstein, R. J. Stereotypy and intermittent reinforcement. *Science*, 1961, 133, 2067-2069.

Notterman, J. M. and Mintz, D. E. *Dynamics of response*. New York: John Wiley & Sons, 1965.

Perry, C. C. and Lissner, H. R. *The Strain Gage Primer*. 2nd ed.; New York: McGraw-Hill, 1964.

Smith, R. F. *Behavioral events other than key striking which are counted as responses during pigeon pecking*. Paper presented at the meeting of the Eastern Psychological Association, Washington, D.C., April, 1968.