ACQUISITION AND EXTINCTION OF A CONDITIONED RESPONSE UNDER THREE DIFFERENT PATTERNS OF PARTIAL REINFORCEMENT

by

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PREFACE

The research on which this thesis is based was conducted in the laboratory of Dr. B. F. Skinner in the Department of Psychology at Harvard University. The author is deeply indebted to Dr. Skinner and the Harvard Psychology department for the use of space and valuable apparatus without which this study could not have been carried out. Dr. Skinner designed the new apparatus required by the study and provided wise counsel as the research progressed. Dr. Charles Ferster, who was in charge of the laboratory, rendered invaluable service by assuming major responsibility for the construction and maintenance of the apparatus.

The author is also greatly indebted to Dr. William O. Jenkins, who made available his apparatus in the Department of Social Relations at Harvard for preliminary work and with whom the author had many fruitful discussions in the course of planning the experiment.

Dr. Edward L. Walker, chairman of the thesis committee, read several early drafts of the manuscript and offered many valuable suggestions related to the theoretical discussion and the analysis and presentation of the experimental results. Dr. Donald G. Marquis made major contributions in the design of the experiment.

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INTRODUCTION

It is possible to give reward for every occurrence of a response to be learned, or to give the reward only intermittently. It has been shown that regularity of reward is of considerable importance in determining how easily a habit can be broken. When a response has been learned under conditions of so-called "partial" reinforcement, it persists longer after reinforcement is discontinued than when it has been reinforced 100% of the time. This superiority of partial reinforcement in producing resistance to extinction has aroused much interest among workers in the field. There is another question of great importance both theoretically and practically: What effect does partial reinforcement have on behavior during a period in which reinforcement is still being given? Jenkins and Stanley in their review of the literature on partial reinforcement (6) have discussed separately the effects of partial reinforcement upon (1) acquisition of a habit, (2) "performance" of the learned response after the asymptote of the learning curve has been reached but while reinforcement is still being given, and (3) extinction. They draw the empirical generalization that the level of performance under partial reinforcement is characteristically low. There is one finding which is an outstanding exception to this generalization, however. Skinner reports exceedingly high rates of response under reinforcement at a fixed ratio, where animals are reinforced for every N'th response. When animals are reinforced every N'th minute, on the other hand, Skinner reports low rates even when such factors as drive, number of reinforcements, etc., are the same as for the fixed ratio schedule. It is evident, then, that the level of performance which will result from

a schedule of partial reinforcement is dependent upon the particular kind of reinforcement schedule which is employed, and the significant question becomes: What are the characteristics of a reinforcement schedule which govern the rate of response?

This question is clearly of practical significance. If an organism will sometimes work at a high level of performance for a given amount of reward, and sometimes work at a low level for the same amount of reward, it is important to know under what circumstances these two different results may be expected.

BACKGROUND OF THE PROBLEM

Terminology

Several patterns of partial reinforcement have been employed by investigators in this field, and the terminology used in designating the different patterns has not been uniform. Jenkins and Stanley (6) have attempted to standardize the terminology, and their usage will be followed in the subsequent discussion. Four kinds of partial reinforcement schedules will be referred to, and they are defined as follows:

I. Time-correlated schedules:

In time-correlated reinforcement schedules, the organism is reinforced for the first response he makes after a specified period of time has elapsed. Reinforcement is never given in the absence of a response.

A. Periodic: Reinforcement regularly every N'th minute.

B. Aperiodic: Reinforcement irregularly, after varying intervals of time. In aperiodic reinforcement the time intervals between reinforcements is sometimes long, sometimes short, and reinforcements may sometimes occur for two successive responses.

II. Response-correlated schedules:

A. Fixed ratio: Reinforcement regularly for every N'th response.

B. Random ratio: Reinforcements given after a varying number of intervening responses. Sometimes reinforcement may be given for two successive responses, sometimes after a large number of responses have been given since the last reinforcement.

A fifth variety of reinforcement schedule to be discussed is a variant of aperiodic reinforcement, and will be described in detail later under the designation: "reinforcement coincident with rapid responding."

Some details of Skinner's exploratory finding:

Skinner has employed periodic reinforcement schedules with rats as subjects (9, p. 282 ff.). The periodic schedule Skinner used provided a reinforcement every fifth minute. After a sufficient period of training each animal settled on a fairly constant rate of responding. Skinner then determined the number of responses which each animal made per reinforcement (the "extinction ratio"). Then he shifted the animals to a schedule which gave them a reinforcement as soon as they had completed the number of responses they had been giving per reinforcement under the periodic schedule. Thus, if an animal had been responding at a rate of 50 responses every five minutes (50 responses per reinforcement) under periodic reinforcement, he was shifted to a schedule which gave him a reinforcement every 50 responses. Under this new fixed ratio schedule the animals ultimately increased their rates of responding, although in some cases the increase did not occur until the fifth experimental hour under the new schedule. Skinner did not report continuing the training under the fixed ratio schedule beyond the point at which an increase in rate was first observed. For this reason we do not know what the magnitude of the increase would have been, nor even whether it would have been maintained. There is the further problem that no control group was employed, and it is possible that there would have been a comparable increase in rates if the animals had remained on periodic reinforcement instead of being shifted to fixed ratio.

Assuming, however, that the increase was actually due to the change in schedule, his procedure gives us a very important datum: namely, that even when the factors of:

drive,
total number of reinforcements,
total number of responses,
ratio of responses to reinforcements, and
time interval between reinforcements

are held constant, an increase in rate is observed when animals are shifted from a time-correlated (periodic) to a response-correlated (fixed ratio) schedule of reinforcement.

The fifth factor in the above list perhaps requires some elaboration. The time interval between reinforcements in the fixed-ratio schedule is the same as that in the periodic schedule before the animal increases his rate of responding. Once his rate begins to increase, he is reinforced sooner, a factor which might itself be responsible for a further increase in rate. But the initial increase in rate cannot be attributed to any change in the time interval between reinforcements.

Theoretical implications of this finding:

The original finding that partial reinforcement increased resistance to extinction (9, p. 133 ff.; also 4) was felt to be theoretically significant because it suggested that habit strength was not simply a function of the number of reinforcements, as Hull's theory holds. Humphreys' results appeared to constitute an instance in which greater habit strength was observed with fewer reinforcements than for a 100% reinforcement group.

Similarly, on first glance, Skinner's finding (described above) does not seem to be consonant with Hull's theory. Although Hull does not deal specifically with rates of response in a free-responding situation such as the Skinner box, rate should be an increasing function of habit strength, other things being equal. For rate of

response is an inverse function of latency, and response latency is a decreasing function of habit strength in Hull's system. (3, Postulates IX and XV). Skinner observed a faster rate of responding for response-correlated than for time-correlated schedules; since other factors (such as drive) which affect latency are constant, this should indicate greater habit strength for the response-correlated situation, from Hull's point of view. But what could be the source of a difference in habit strength when all factors presumed to affect habit strength are constant under the two conditions?

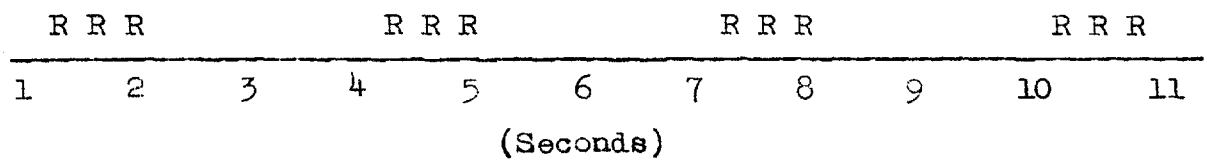
Similar difficulties are raised for Skinner's own system. He has posited a constant response output for a given input of reinforcements -- his "extinction ratio". His empirical result (described above) is an instance in which the output changes with no change in input. As Skinner himself points out, this would at first appear to refute the whole notion of an extinction ratio (9, p. 286).

How does a response-correlated schedule of reinforcement differ from a time-correlated one?

Skinner solves this problem by reference to the fact that there exists in the two schedules a basis for a discrimination. For both Hull and Skinner, if certain stimuli are differentially reinforced, the tendency of the response to occur (reaction potential for Hull, operant strength for Skinner) in the presence of these stimuli will be increased. Also, of course, the tendency of the response to occur in the presence of stimuli which are differentially non-reinforced will be diminished.

In the response-correlated schedule reinforcement is more likely to coincide with rapid responding than is true in time-correlated

reinforcement. To borrow an illustration from Skinner, let us assume that responses are occurring according to the following pattern (R indicates a response):



In a time-correlated schedule a reinforcement might "come due" at any of the time periods marked along the time line, and the animal would actually receive the reinforcement for the first response which followed this point in time. It will be seen that the first response in any of the triplets of responses illustrated has a much greater chance of being reinforced than the second or third member of the triplet, since it will receive any reinforcements which were set up during the relatively long time period since the last response. Reinforcement of the first response of the triplet would favor slow responding, since no other response has immediately preceded the "pay-off" response. On the other hand, reinforcement of the second or third member of a triplet would tend to favor more rapid responding. In the above illustration it is clear that with a time-correlated schedule an animal will be rewarded more often for slow responding than for fast responding.

With a response-correlated schedule reinforcement has an equal probability of occurring for any of the responses, regardless of its temporal position. Two out of three of the responses in the above illustration follow another response immediately. Therefore, two thirds of the reinforcements should favor fast responding, one-third slow.

In the situation illustrated, there exists the basis for a discrimination. It may be seen, however, that this discrimination can be formed only if the rate of responding is variable. If the responses were equally spaced along the time line, there would be no difference between the two schedules of reinforcement.

Expected consequences of the difference between the two schedules:

Assuming that there is enough variability so that rapid responding would be differentially reinforced under a response-correlated schedule, one result should be an increase in rate. This should be expected for two reasons. First, a "response" is not just a press of a lever of a peck at a key. It is all the muscle movements and all the autonomic reactions which are occurring at a given moment. Rapid responding may be thought of as a different response (to a degree) than slow responding. It may be that more muscle groups are involved, or that different visceral "states" underly it -- but in any case, it is this particular behavior which is being conditioned under a response-correlated schedule of reinforcement. Rate of responding, while it is responsive to changes in drive level and amount of habit strength, can also be considered an important aspect of the topography of the response itself. It should be possible to manipulate it independently of drive and habit strength through differential reinforcement of different rates.

The second reason that an increase in rate might be expected under response-correlated reinforcement is that under this schedule, reinforcement tends to occur when the animal has just given several responses. Therefore, the movement-produced cues from previous

responses will themselves become conditioned to the response, and will tend to produce further responding. This process has been described by Guthrie in his discussion of movement-produced cuess as integrators of behavior (2, pp. 127-28). In time-correlated reinforcement the cues from a previous response tend to be differentially non-reinforced, and such cues tend to reduce the probability of the occurrence of a response until they have dissipated. This factor thus favors a low rate of responding under a time-correlated schedule.

In brief, then, Skinner's explanation for the higher rates of response he observed under fixed-ratio reinforcement (as compared with periodic reinforcement) is that under a response-correlated schedule, reinforcements tend to coincide with rapid responding. Now in a response-correlated schedule, if the above-mentioned factor does cause an animal to speed up, he begins to get reinforcements sooner. More frequent reinforcements will in themselves tend to produce higher rates (9, p.119 ff). Thus we have the interaction of two factc tending to accelerate rates of responding, once the speed-up has begun.

Resistance to extinction

The greater resistance to extinction following partial reinforcement has had several kinds of explanation. One of these is the so-called "response-unit" hypothesis. This hypothesis was discussed by Skinner, (9, p. 300) and was later made the subject of an experiment by Mowrer and Jones (7). The hypothesis is, briefly, that the response (in the Skinner box) which is being reinforced is not a

single press of a lever but a multiple press. This hypothesis suggests that if one counts responses groups in extinction, rather than individual responses, the superiority of partial reinforcement in producing resistance to extinction will disappear.

Mowrer and Jones tested this hypothesis over a limited range of fixed ratios (1/1, 1/2, 1/3, and 1/4) and for one random ratio schedule. The random ratio schedule employed by Mowrer and Jones gave reinforcement on the average every 2 1/2 responses, but the number of responses between reinforcements varied around this average. They found that when they counted response units in extinction the 100% reinforcement group showed slightly greater resistance to extinction, and the higher ratios successively less. The random ratio schedule gave extinction performances which were between those of the 1/2 and 1/3 groups, suggesting that the matter of irregularity of the reinforcements did not make an important difference in this experiment.

It should be pointed out parenthetically that there is a problem in the definition of the response unit. Mowrer and Jones define it simply as the number of responses occurring between reinforcements -- if an animal must give four responses for each reinforcement, then his response unit is four responses. As Skinner has pointed out, however, the situation may be more complex than this, particularly when a large number of responses intervene between reinforcements. The integration of responses into a "unit" would be a gradual process, depending as it does in Skinner's formulation on the development of a discrimination based upon stimuli from preceding responses, and the discrimination might never be complete.

The response-unit hypothesis, as an explanation of the greater resistance to extinction after partial reinforcement, seems to demand that the units which should be counted in extinction are those sets of responses which become integrated in training and behave, in some respects, as one response. But it is difficult to identify and define the response-unit which is formed in the Skinner-box situation. If a schedule of 100 responses per reinforcement is employed, for example, it is quite possible that some animals develop as their response-unit bursts of ten or fifteen responses, rather than runs of 100. What should be counted, then, as the unit in extinction? It would be desirable to have some measure of the unit which is actually formed, instead of assuming it to be identical with the number of responses intervening between reinforcements.

Mowrer and Jones did not employ any independent measure of their response unit. They considered their unit to be whatever number of responses the animal made per reinforcement. When treated in this way, the response-unit hypothesis gives identical predictions with Humphreys' hypothesis that the crucial factor in extinction is the number of <u>responses</u> which have occurred during training, rather than the number of reinforcements. (5). Humphreys relates the total number of individual responses during training to the total number of individual responses during extinction. Mowrer and Jones relate:

$$\frac{\text{Individual responses in training}}{k} \text{ to } \frac{\text{Individual responses in extinction}}{k}$$

where the constant k is the ratio of responses to reinforcements during training. It is evident that the two procedures are in effect the same, so that the Humphreys and Mowrer and Jones results can

each be explained in terms of the other's hypothesis.

There is another reason why the Mowrer and Jones results are difficult to interpret: as Jenkins and Stanley point out, they did not control the speed of responding at the time extinction was started. It is possible that the animals with the larger response units were responding more rapidly at the end of their training session than animals receiving 100% reinforcement or animals having smaller response units. Rate of responding and the size of the response unit tend to be confounded in many experiments which employ partial reinforcement. Ferster found, for example, (1) in using aperiodic schedules that there was a correlation of .63 between the speed of responding during training and the number of responses in extinction. In aperiodic reinforcement, of course, the faster the animal responds, the larger is his number of responses per reinforcement, so that it is impossible to tell whether Ferster's correlation is due to speed as such or to the size of the response-unit. The writer knows of no report in the literature on the correlation between rates of responding under fixed ratio reinforcement and the number of responses to extinction. Mowrer and Jones did not report the rates of response under the different schedules they employed, but it is possible that their results are more a function of rate <u>per se</u> than of ratio.

OBJECTIVES OF THE PRESENT STUDY

The first objective will be to determine whether rates of responding will increase when animals are switched from an aperiodic schedule to a random ratio schedule which is the same with respect to the ratio of responses to reinforcements. The present study differs from Skinner's experiment in that irregular rather than regular schedules will be used. Thus the situation which permits animals to learn to pause after reinforcements (because responses immediately following a reinforcement are never reinforced) will be minimized and it will be possible to study the effects of response-correlated as compared with time-correlated schedules free from this complicating factor. Furthermore, in the present study, a control group will be used, from which it will be possible to determine whether the increases in rate of responding under response-correlated reinforcement (if such increases occur) would have occurred anyway without the change in schedules. There is evidence that there is an upward drift in response rates with prolonged training under time-correlated reinforcement schedules, so that this control is necessary.

The explanation of the increased rates which have been observed under response-correlated reinforcement posits a learned discrimination based on the differential reinforcement of rapid responding. The second main objective of the present study, therefore, is to test this assumption by determining whether animals can learn to increase their response rates when they are explicitly rewarded for rapid responding, even when speeding up does not bring reinforcements any sooner in time.

The present study will provide a comparison between a response-correlated schedule (in which the probabilities are that reinforcement will coincide with rapid responding more often than with slow), and a schedule in which every reinforcement coincides with rapid responding. The latter schedule should produce an increase in rate more quickly, and the increase should be more consistent from animal to animal.

To meet the above two major objectives, the present study will include three groups:

1. A group trained first on aperiodic reinforcement, and then shifted to a random ratio schedule in which the number of responses per reinforcement is initially the same as that under the preceding aperiodic schedule. Where necessary these ratios will be readjusted to match any trends in the control group.
2. A group trained first under an aperiodic schedule, and then shifted to a schedule which maintains the same time intervals between reinforcements as under the aperiodic schedule, but which gives these reinforcements only when the animal is responding rapidly.
3. A control group, remaining on the basic aperiodic schedule throughout.

The third major objective has to do with extinction. First of all, it will be of value to learn something about the nature of the extinction curves yielded by the three schedules of reinforcement, since reports of such curves are not so far available in the literature. Then, too, the study will permit the separate examination of the time interval

between reinforcements and ratio of responses to reinforcements, in their effects on resistance to extinction.

APPARATUS

During experimental sessions pigeons were placed in a circular drum (about three feet in diameter) with nine compartments, each bird in a separate compartment. One compartment was in the experimental position at any given time. The drum was rotated 1/9th of a full rotation by each impulse from a stepping relay, so that compartments 1, 2, 3, etc., successively were in the experimental position. With a single impulse from the stepping relay, one bird was moved out of the experimental position and the next bird moved in. For most of the work in this experiment the stepping relay was activated by a one-hour timer, so that each bird was in the experimental position for one hour. Compartment 9 was always empty, and the stepping relay did not move the drum from compartment 9 to compartment 1 unless the mechanism was reset. Thus the drum would move to the empty compartment and remain there indefinitely after the birds had each had an hour's experimental session.

The drum and feeding mechanism were enclosed in a large box, about 5' x 3-1/2' x 2' in size, set up from the floor on stilts. This box was lined with celotex to render it relatively sound-proof. In the roof of this box was a periscope (a mirror fixed at the top of a tube) through which it was possible to see the key and the magazine and to observe the bird's behavior when he was in the region of the key or magazine. (See Appendix, photograph of apparatus)

In the wall of the experimental compartment, 10" above the floor, there was a circular hole, 1" in diameter, covered with plexiglas and illuminated from behind. Below this translucent disc (henceforth called the "key") was a recess (2" x 2" x 1-1/2")

in which was located the portion of the food magazine from which the bird could eat.

The food magazine was a round dish, three segments of which were covered with aluminum covers. When the food magazine was not operating, the dish rested in such a position that a covered segment was in the experimental chamber. When the food magazine was operated, the dish rotated one-third of a full rotation and an uncovered segment would move through the experimental chamber. The pigeon would eat about half a gram of grain during the four seconds when the uncovered segment was moving by.

When the magazine was activated, there was a characteristic click, and a light went on in the recess; when the magazine came to rest in a covered position, the light went out.

The piece of plexiglas covering the circular hole in the wall of the experimental compartment was attached to the outside of the wall, fastened at the top and loose at the bottom, so that it could move outward a short distance when pressure was applied to it from inside the experimental compartment. If it moved outward 1/32", it would close a contact and an impulse would be transmitted to the keying relay.

Continucus reinforcement

In continuous (100%) reinforcement the keying relay operated the food magazine. Every time the pigeon pecked the key with enough force to close the contact, the food magazine turned and gave a reinforcement.

Aperiodic reinforcement

For this stage of the experiment a timer was used. A strip of

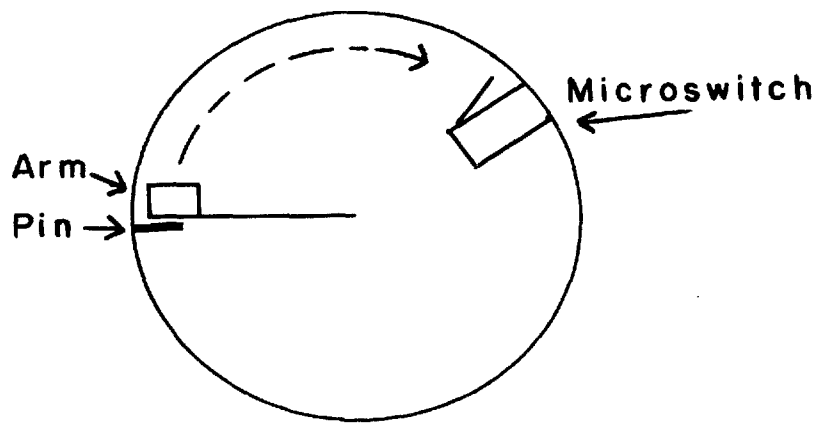
film moved at a constant rate of speed with the armature of a microswitch riding on it. Holes were punched at intervals along the film strip and whenever a hole passed the armature, the microswitch sent an impulse to a silent holding relay. The holding relay, when closed, put current through the keying relay, so that the bird's next response after the holding relay had been closed by the timer would operate the magazine.

A microswitch was attached to the food magazine in such a way that the switch would be operated as the magazine came to rest after a reinforcement. The impulse from this switch reopened the holding relay so that no further reinforcements would be given until the timer again activated the holding relay.

The holes in the film strip were spaced to give reinforcements at the desired temporal intervals.

Reinforcement coinciding with rapid responding

Under this schedule reinforcements were set up aperiodically by the timer as described above. However, the magazine was not operated by the first response after the holding relay had been closed. Instead, the impulses from the key went to the following mechanism:



A motor turned the disc at a constant speed. An arm rested against a pin attached to the disc and when the bird was not responding, the arm was carried around by the pin. The arm was activated by impulses from the key so that with each response it moved forward (away from the pin). But since the pin was moving around at a constant speed, it would catch up with the arm unless responding was fast enough to keep the arm moving forward faster than the disc itself. Two and one-half responses per second were enough to keep the arm moving just ahead of the pin. If the bird responded more rapidly than this, the arm would move forward and catch up with the microswitch. The microswitch impulse was carried to the keying relay, and if this relay was "hot" (because the holding relay had been closed by the timer), the impulse from the microswitch on the disc would operate the food magazine. If the timer had not closed the holding relay, however, a burst of responses fast enough to activate the microswitch would not result in a reinforcement.

It will be noted that the mechanism described above does not control exactly the rate of responding which will result in a reinforcement. It requires that the rate must be faster than 2 1/2 responses per second, and that this rate must be sustained long enough for the arm to catch up with the microswitch. A rate of four responses per second will close the microswitch in 4 seconds, while a rate of 3 responses per second does so in 12 seconds; the differential between the speed of the arm and the speed of the disc is greater with the faster rate.

A rate of responding greater than 2 1/2 responses per second is reinforced aperiodically by the above apparatus.

Random ratio reinforcement

The impulses from the key were transmitted to a counter. When the counter showed that the proper number of responses (less 1) had been given, a hand switch was closed by the experimenter, and this switch operated the holding relay. Then, as in aperiodic reinforcement, the bird's next response would result in a reinforcement.

The recorder

In the recorder a pen moved laterally across a strip of paper when the bird responded. The pen moved a distance of one inch for 207 responses. The pen was equipped with an automatic reset so that when it had moved all the way across the paper to the edge of the strip (1100 responses would move it the width of the strip), it would reset to the other edge of the paper and begin a new excursion.

The paper strip moved at a constant rate of speed (7-7/8 inches per hour) over a roller and under the pen. If the bird was not responding, the pen made a straight line parallel with the edge of the paper strip. If the bird was responding rapidly, the line was almost perpendicular to the paper's edge. A moderate rate of responding (1500 responses per hour) yielded a line at approximately a 45 degree angle from the edge of the paper. Variations in rate of responding produced changes in slope of the line. Since the pen moved only a very small distance laterally with each response, individual responses cannot be counted from the record produced. It is possible, however, to measure from it the number of responses which have been made in any time interval of one minute or longer.

The reset mechanism was operated not only when the pen came to the edge of the paper but also by the impulse from the one-hour timer

which rotated the drum so that every time a new bird was brought into the experimental compartment, a new record was started by the pen.

The impulse from the food magazine, set off as it came to rest after a reinforcement, went to the pen and caused it to move a short distance in a direction perpendicular to that of its normal movement across the paper. Thus the pen made a distinctive mark whenever a reinforcement had been administered.

EXPERIMENTAL PROCEDURE

Subjects: 21 male pigeons, varying in normal (ad libitum) body weight from 300 to 500 grams. Ages unknown, but all fully grown.

Upon arrival at the laboratory each bird's wings were clipped, a numbered band was attached to one leg, and he was put in an individual cage. For three days his food cup was kept filled and he was weighed daily to establish his ad libitum weight.

The birds were then deprived of food. They were given only five grams of food every 3 days during the starving-down process. They were weighed daily and after each bird reached 80% of his ad libitum weight, he was fed a daily ration sufficient to maintain his weight at this level. The maintenance ration varied from bird to bird, the lowest being 10 grams, and the highest 18 grams, daily. The length of time required to lose the requisite amount of weight also varied -- from 7 days to 13 days.

Training step 1:

After reaching 80% weight, the birds were habituated to the apparatus. The food magazine was propped open and grains were scattered on the floor in front of it. Each bird was allowed to eat his day's ration of grain from the open magazine.

Training step 2:

The next step was to allow the magazine to move continuously. On two different days each bird was put in the apparatus until he had eaten his day's ration from the moving magazine.

Training step 3:

During this stage of training the food magazine was operated by

a hand switch outside the experimental box. At irregular intervals the experimenter operated this switch and the birds learned to approach the magazine and eat when they heard the click of the magazine and saw the light over the food magazine go on. At this stage the experimenter observed the birds through the periscope and continued the click training until each bird had responded approximately 25 times to the magazine click and light. Two birds never learned to respond consistently to these cues, and were discarded.

Training step 4:

A grain was attached to the key with scotch tape in such a way that it could be seen but could not be dislodged or eaten, and the magazine was set to operate whenever the key was pecked. Each bird was left in the apparatus until he had pecked the key and eaten from the magazine 25 times. Two birds did not learn this step and were discarded. Thus, out of an original group of 25 birds, 21 were used for the full experiment.

Training step 5:

The grain was removed from the key and the birds were given 50 trials on each of two days. Thus each bird had 100 reinforced responses before being switched to a partial reinforcement schedule.

Aperiodic reinforcement:

All animals were then switched to a schedule of three-minute aperiodic reinforcement. Under this schedule the reinforcements were given on the average every three minutes. The longest interval between reinforcements was six minutes, the shortest was short enough so that reinforcements were given for two successive responses. The reinforcements through an hour's experimental session were spaced as follows:

3 minutes	2 minutes 40 seconds
5 minutes 40 seconds	3 minutes 40 seconds
40 seconds	4 minutes 20 seconds
2 minutes 20 seconds	1 minutes
4 minutes 40 seconds	3 minutes 20 seconds
successive (5 seconds)	20 seconds
3 minutes	1 minute
6 minutes	5 minutes 20 seconds
1 minute 20 seconds	1 minute 40 seconds
2 minutes	4 minutes

The order of these intervals was determined by a random drawing. Animals were started at varying points in the series in different hourly experimental sessions. It will be noted that, except for the fact that two 3-minute intervals were included, the distribution of these time intervals is rectangular -- the shortest and longest intervals came up just as frequently as the intervals nearer the average.

All animals were given nine hour-long sessions of three-minute aperiodic reinforcement. The reinforcements were set up by the timer when the proper interval of time had elapsed and the bird was reinforced for the next response he made after a reinforcement had been set up. During the first six of the nine sessions of aperiodic reinforcement the drive level (% body weight) of the animals was varied so as to produce as great a uniformity as possible among birds in their rate of responding under this schedule. Birds which responded rapidly at 80% body weight were fed enough to increase their body weight by two or three percent, and birds which responded more slowly than the others at 80% body weight were fed smaller rations until their body weight fell somewhat. During the last three days of aperiodic reinforcement the body weights were held constant -- each bird being maintained at the base weight which had been found to produce a rate of responding near to the average for the whole group.

The variation in base weights was from 77% to 84% and animals were maintained at these base weights throughout the experimental and extinction periods.

Group I: Random ratio

Eight of the birds were switched to a random ratio schedule. For each bird the schedule was devised as follows: His average rate of response (number of responses per reinforcement) was computed for his last three days under aperiodic reinforcement. Ten percent was added to this average to take into account the fact that response rates under aperiodic reinforcement were still increasing a little at the end of nine hours of this schedule and it could be predicted that the rate of response on the day following the ninth day of aperiodic reinforcement would be approximately 10% above the average rate of the last three aperiodic days. The intention was to match the random ratio schedule to the ratio which most probably would have been observed if the animals had not been switched to a new schedule.

For each bird a random ratio schedule was then matched to his corrected aperiodic rate. The random ratio schedules are shown in Appendix table 1A. Let us take bird 66 as an example to illustrate the procedure which was followed. Bird 66 averaged 1635 responses per hour during his last three days of aperiodic reinforcement. Adding 10%, it would be expected that on his next day of aperiodic training he would have averaged 1800 responses per hour; he had been receiving reinforcements on the average every three minutes or 20 reinforcement per hour; therefore, on this day he would have been working at the rate of 90 responses per reinforcement. This bird's random ratio schedule should, therefore, give him a reinforcement every 90th response on the average.

The highest interval between reinforcements was set at 180 responses (to correspond to 6 minutes, the largest time interval under aperiodic reinforcement), and other intervals were established likewise to correspond exactly to the aperiodic schedule. Thus if he did in fact respond at the predicted rate (1800 responses per hour) on his first day of random ratio reinforcement, his reinforcements would be spaced in time exactly as they would have been under aperiodic reinforcement, except for the effects of momentary spurts or lags within the hourly period.

Using the procedure described above a random ratio schedule was devised for each bird. The aperiodic timer was disconnected and the eight random ratio birds were shifted to the new schedules of reinforcement. A further change in the procedure was introduced at this point: the experimental sessions were no longer uniformly one hour in length. Each bird was allowed to remain in the apparatus only long enough to complete the number of responses which it was predicted he would have given in an hour if he had remained on aperiodic reinforcement. Thus bird 66, described above, remained in the experimental compartment until he had made 1800 responses and received 20 reinforcements. If he responded more rapidly than the predicted rate (10% above the average rate of the last three days under aperiodic reinforcement) he would be moved out of the experimental compartment in less than an hour. If he responded more slowly than the predicted rate, the experimental session would be more than an hour long. The purpose of this procedure was two-fold: (1) to equate the number of reinforcements with that given to the control group, who continued to receive 20 reinforcements per hour, and (2) to equate the total number of responses with

the control group, as nearly as possible. It will be noted that while total reinforcements are the same for random ratio birds and the control group, the time intervals between reinforcements are not necessarily the same. If the response rate of the random ratio birds increases, the time interval between reinforcements decreases, whereas for the control group, the interval continues to be three minutes on the average.

Under the procedure described above for determining random ratio schedules, it is evident that the random ratio birds were matched not only to their own performance under aperiodic reinforcement but to that of the control group as well. As will be seen later, birds were assigned to groups in such a way that, on the average, the control group birds and the Group I birds were giving the same number of responses per reinforcement at the end of the nine days of training on aperiodic reinforcement. We have seen that random ratio schedules were devised so that the birds received a reinforcement for the same number of responses (plus 10%) as during aperiodic training. If, as predicted, the control birds increased their rate by 10% after the other birds were switched to their new experimental conditions, then the Group I and Group 3 birds would be matched with respect to the ratio of responses to reinforcements. If the control group increased more than 10%, however, their ratios would be larger than those of the random ratio group. Successful matching of ratios between these two groups is important primarily for extinction comparisons, where the intention was to compare birds which had been giving the same number of responses per reinforcement but which had been responding at different rates of speed.

With this matching in mind it was necessary to observe any changes in rate in the control group, so that if any substantial changes occurred,

the ratio of responses to reinforcements among the random ratio group could be readjusted to bring them into better consonance with the control group. One such readjustment was in fact made: after the third day of running on experimental conditions, it was clear that the control group had speeded up beyond the predicted 10%. Therefore, on the fourth day of running under random ratio schedules, the ratios of Group I birds were increased by 20% -- that is, the number of responses between reinforcements was increased by this amount. Thus, bird 66, whose average number of responses per reinforcement had been 90, now had to give 108 responses for each reinforcement. These new schedules (shown in Appendix table 1B) were employed during the last six of the nine random ratio sessions.

Group II: Reinforcement coincident with rapid responding

Five of the birds were switched to this schedule. The timing of the reinforcements was established by the 3-minute aperiodic timer, but when the timer set up a reinforcement, the bird could get it only if he responded rapidly. The daily experimental sessions were an hour long under this schedule. This schedule differs from the random ratio schedule in several ways: an increased rate of response will not bring reinforcements any sooner in time; the coincidence of reward with rapid responding occurs on every reinforcement, not merely better than chance; and while the number of reinforcements in an experimental session remains the same as under aperiodic reinforcement (20), the number of responses does not, assuming that the rate of responding increases.

The device controlling the reinforcements under this schedule was set so that the animal had to respond at a rate greater than 2 1/2

responses per second in order to get a reinforcement. This rate is higher than the mean rate at which any of the five birds on this schedule were responding under aperiodic reinforcement, although short bursts at this speed would of course occur under simple aperiodic reinforcement also. Group II birds were given nine hourly sessions with the above schedule.

Group III: Control: Three-minute aperiodic reinforcement

Eight birds were assigned to the control group and remained on three-minute aperiodic reinforcement for nine additional hourly sessions.

Summary of experimental design

The conditions to which the three groups were subjected after their preliminary training on three-minute aperiodic reinforcement are summarized in Table I.

Extinction

In the first extinction session the birds were given two reinforcements according to their normal experimental schedule and then reinforcements were discontinued. During subsequent extinction sessions no reinforcements were given. Extinction sessions for all groups were one hour long and each bird had 7 such sessions.

Conditions were maintained during extinction exactly as they had been in the experimental sessions except for the omission of reinforcements. Thus, for Group II, the device which controlled the presentation of reinforcements only for a certain minimum rate of response remained in operation. It made a characteristic noise, and on the chance that the birds could hear it in the semi-sound-proof experimental box, it was not disconnected, although, of course, the connection from this device to the food magazine was disconnected.

Table I. Summary of design

Group	Conditions of Reinforcement	Length of experimental sessions	Number of reinforcements per session	Time interval between reinforcements	Total responses per session	Ratio of responses to reinforcements	Number of cases
I. Random ratio	I. Reinforcement every N'th response (the N being variable around an average)	Variable; long enough to complete fixed number of responses	20	Variable; decreases with increasing rate of response	Fixed, on basis of bird's own aperiodic performance and that of control group	Fixed, matched to that of own aperiodic performance and that of control group	8
II. Reinforcement coincident with rapid responding	II. Reinforcement every N'th minute, on the average, provided bird is responding rapidly	1 hour	20	Fixed; 3 minutes on the average (aperiodic)	Variable; increases with increasing rate of response	Variable; more responses per reinforcement with increasing rate of response	5
III. Control; 3-minute aperiodic reinforcement continued	III. Reinforcement every N'th minute, (the N being variable around an average)	1 hour	20	Fixed; 3 minutes on the average (aperiodic)	Variable; increases with increasing rate of response	Variable; more responses per reinforcement with increasing rate of response	8

Assignment of birds to groups

Fifteen birds (five for each of the three groups) went through the five steps of training and their training under the three-minute aperiodic schedule together. Six birds were started later and held in reserve for use only as they should be needed.

When the original fifteen birds had completed their aperiodic training, they were divided into three groups on the basis of their rate of responding under aperiodic reinforcement and their base weights. As nearly as possible the three groups were matched so that they would have the same average rate of responding and the same average base weights. Individual birds were matched in triplets -- the three fastest responders being matches for one another, the three slowest likewise, etc. (See Appendix table 2). The matching had little value in the middle of the range as far as response rates were concerned, for the manipulation of drive levels had resulted in a high degree of uniformity of rates under aperiodic reinforcement. After the fifteen birds had been divided into three groups, a random selection was made of one group for each of the three experimental conditions.

When the experimental training of the first three groups of birds was well advanced, it was apparent that while the behavior of the birds in Group II (reinforcement coincident with rapid responding) was consistent from bird to bird, the behavior of the birds in Groups I and III was more variable, and that the additional birds in the group held in reserve could most profitably be used to supplement these groups. Three birds were therefore used as a replication for Group I and three to replicate Group III, the new birds being matched and then

assigned at random in the same way as their predecessors. Group I and its replication, then, ultimately included eight birds, Group II five, and Group III eight. The six additional cases, having had every stage of their training later than the original groups of five, may have been subject to some slightly different conditions than the original birds (due to changes in weather, etc.), but such changes are balanced between Groups I and III.

Change in rate when birds are shifted from aperiodic to random ratio schedules

The effects of the change from aperiodic to random ratio reinforcement can be examined in two ways: the performance of birds under random ratio reinforcement can be compared to their own performance under the preceding aperiodic schedule, and their random ratio performance can also be compared to the performance of the control group, which remains on aperiodic reinforcement. The first comparison will tell whether there has been an increase in rate, and the second will tell whether the increase (if any) can be attributed to the change in schedule or whether a comparable increase might be expected with continued aperiodic reinforcement.

The comparisons must be made with respect to rates of response -- that is, number of responses per unit time. Rates will be reported as responses per hour in the subsequent pages, since records for Group 2 and Group 3 birds were originally accumulated by hourly experimental sessions and need no conversion if an hourly figure is used. As pointed out earlier, however, birds under random ratio schedules of reinforcement were allowed to stay in the experimental chamber only until they had completed their quota of responses and received twenty reinforcements. As their rates increased from day to day, the time spent in the experimental chamber for each session decreased. In order to compute a random ratio bird's rate of responding it was necessary to divide his total responses during a session by the fraction of an hour which he required to complete the responses. For example, bird 68's ratio of responses to reinforcements was set

at 110 (Appendix table 1-B), and he was taken from the experimental compartment when he had completed 2200 responses. If he completed this quota in half an hour, his rate per hour would be 4400.

It is necessary, however, to correct this rate for additional time which the random ratio birds spent in eating. A bird completing his responses in half an hour would receive twice as many reinforcements during this time as a control bird remaining on aperiodic reinforcement, and the rates would not be comparable, because the time period used as a denominator in computing the random-ratio rates includes extra time in which the bird was eating and not responding. The following correction was made: five seconds[1] were subtracted from a bird's total time in the experimental chamber for each reinforcement he received over and above the number which a control bird would have received in the same period of time. Thus for a bird who completed his quota of responses in half an hour, there would be ten extra reinforcements, and 50 seconds would be subtracted from his time score. In computing his rate per hour his number of responses would be divided by .486 hours instead of by .500 hours. It will be seen that the magnitude of the correction is small. All hourly response rates reported for random ratio birds have been corrected in this manner.

Figure 1 shows that, on the average, birds which were shifted to random ratio schedules of reinforcement increased their rates of responding beyond the levels they had previously reached and beyond the levels reached by the birds remaining on aperiodic schedules. The largest part of the increase occurred during the second and third

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[1] The food magazine turned for four seconds, during which the birds usually ate continuously. One second was required for the bird to return to the key

FIGURE 1

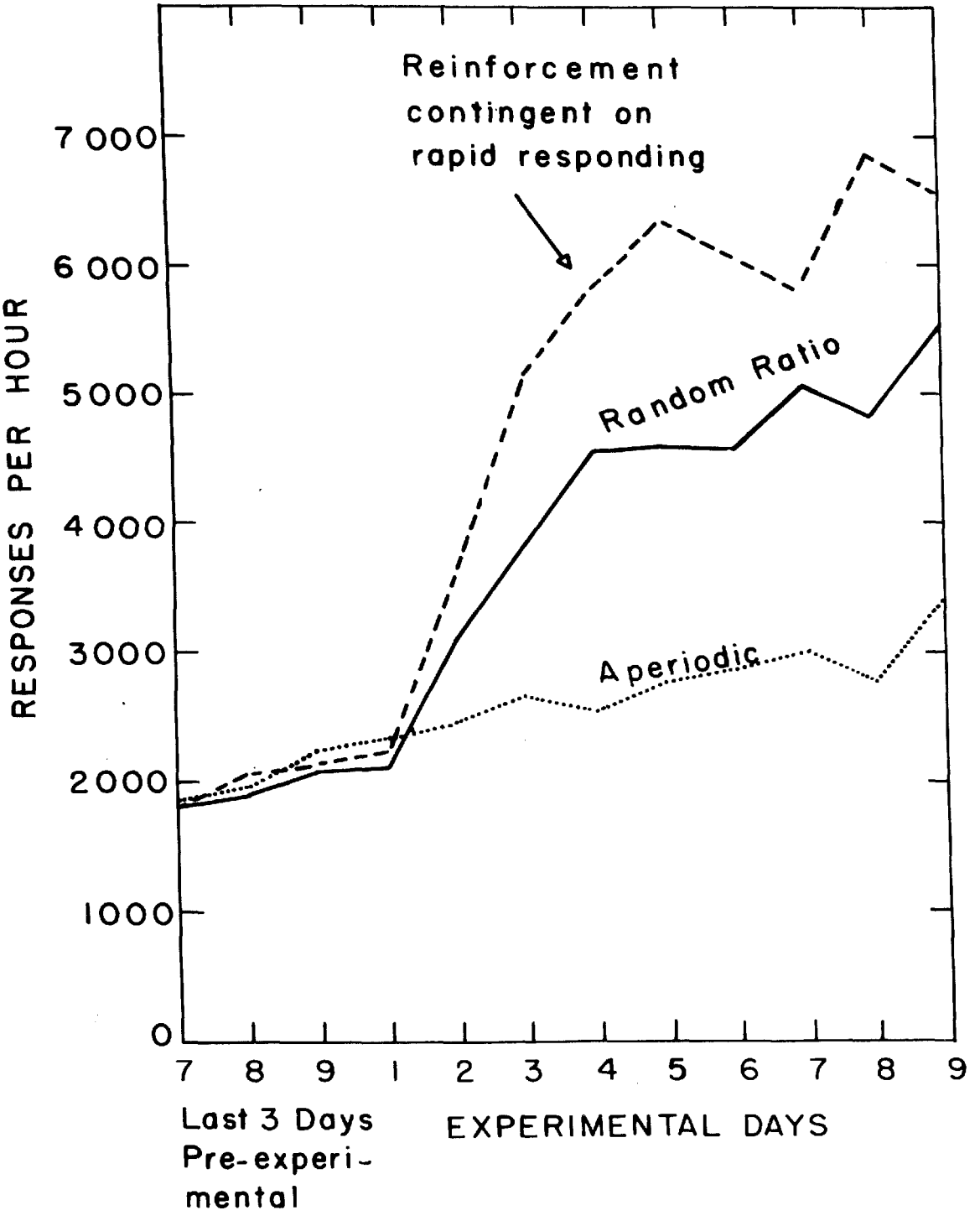


Figure 1. Rates of responding during training under three different patterns of partial reinforcement.

experimental hours, and by the end of the ninth hour of training under random ratio schedules the average rate of the eight birds involved was approximately three times as great as the rate prevailing under their pre-experimental aperiodic training. Table II shows the change in rates of birds in Group 1 and Group 3, from their average rates on the last three days under aperiodic reinforcement in the pre-experimental period, to their average rates for the last six days of training under their respective experimental conditions:

Table II: Changes in response rates,[2] individual birds in Groups 1 and 3.

Group 1 (random ratio)			Group 3 (aperiodic)		
Bird No.	Mean rate, last 3 days pre-experimental (aperiodic)	Mean rate, last 6 days random ratio	Bird No.	Mean rate, last 3 days pre-experimental (aperiodic)	Mean rate, last 6 days experimental (continued aperiodic)
75	1887	3053	57	1453	1658
66	1635	5439	60	1943	2212
68	1671	6396	70	2397	4787
72	1721	1820	64	2600	2806
58	2742	7336	62	1959	3558
79	1915	6652	61	1938	3292
77	2543	4645	73	2155	2344
76	1409	3480	74	1764	2563
Mean:	1940	4853		2026	2903

For purposes of testing the statistical significance of the increase in the rates among birds trained on random-ratio schedules, the first five of these birds have been treated as one experiment, and the three added birds as a replication. The difference between the rates

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2 In Table II and following tables "rate" refers to responses per hour.

of response under random ratio training and the same birds' rates under the preceding aperiodic schedule is significant at the 1% level, using one-tailed tests:

Table III: Significance test, change in response rates, Group 1.

Group 1:	Mean resp. per hour, last 3 days pre-experimental training (aperiodic)	Mean resp. per hour, last 6 days experimental training (random ratio)	Diff.	Sigma diff.	t	df	p
First 5 birds	1931	4809	2878	946	3.04	4	.028
3 added birds	1956	4925	2969	785	3.78	2	.032

Chi Square value, combined probabilities[3]: 14.06 (4 d.f.)

p: less than .01

In Table III the standard error of the mean difference has been computed from a distribution of the differences between each bird's performances under the two different conditions, so that each bird has in effect been used as his own control and any correlation between performances of the same birds under the two conditions is taken account of in computing the p values. The correlation is, however, minimal, largely because the variability among birds during the pre-experimental aperiodic training was experimentally reduced by the manipulation of drive levels.

It may be seen from Figure 1 that while birds clearly increased their rates of responding when shifted from aperiodic to random ratio

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3 This value has been computed by taking the logarithms (base 10) of the two probabilities, adding them, changing the sign, and multiplying by twice 2.3026 (the constant for converting to base e).

reinforcement, birds which remained on aperiodic reinforcement also speeded up somewhat. It is crucial, therefore, to determine how much of the observed increase under random ratio schedules may be attributed to the influence of this particular schedule. Comparison of the Group 1 birds with the Group 3 birds in Table IV shows that the difference in their rates of performance approaches very closely the 1% level of significance:

Table IV: Significance tests, response rates of Group 1 and Group 3 compared[4]

	Mean rate, last 6 days, aperiodic training (Group 3)	Mean rate, last 6 days, random ratio training (Group 1)	Diff.	Sigma diff.	t	d.f.	p
First 5 birds	3004	4809	1805	1214	1.49	8	.087
3 added birds	2733	4925	2192	972	2.26	4	.044

Chi square value, combined probabilities: 11.13

p: .025

	Mean rate, last 2 days, aperiodic training (Group 3)	Mean rate, last 2 days, random ratio training (Group 1)	Diff.	Sigma diff.	t	d.f.	p
First 5 birds	3208	5238	2030	1216	1.67	8	.068
3 added birds	2918	5069	2151	806	2.67	4	.028

Chi square value, combined probabilities: 12.51

p: .014

In the above table, the standard error of the differences have been

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4 The mean performance on the last six days has been the figure chosen for most of the statistical comparisons in this report because it covers the entire period of training after the random ratio birds were shifted to their second (and final) random ratio schedules. The mean of the last two days has been presented here to show how the rates compared after relatively prolonged training on the second schedule, excluding the initial period of adjustment to this schedule.

computed from the formula $\sigma_0 = \sqrt{\sigma_{m_1}^2 + \sigma_{m_2}^2}$ ignoring correlation. It would have been possible to include a correlational term, since Group 1 and Group 3 birds were matched with respect to their pre-experimental performance under aperiodic training (see Appendix table 2). It eventuated, however, that the correlation based on this factor was slightly negative (not significantly so), and the matching was therefore discarded.

Individual differences were very great in the reaction to random ratio schedules. One out of the original five birds failed to increase his rate during random ratio training -- in fact, on the eighth day of this training his rate dropped off to less than half what it had been under aperiodic training, although it picked up again on the ninth day. On the other hand, several birds had more than doubled their rates by the third day of random ratio training, and three had quadrupled their aperiodic rates by the end of their nine days of random ratio training (see individual bird records, Appendix table 3).

With the continuation of aperiodic training large individual differences also appeared among Group 3 birds. One bird increased his rate by more than 100%, and although this rate fell off during the last several days of the 9-day experimental period, another bird began a pronounced upward cycle on the fifth experimental day and by the ninth day had reached a rate 2.7 times as great as his pre-experimental aperiodic rate (Appendix table 5).

The magnitude of the individual differences is revealed in a study of the standard deviations:

Table V: Variability in response rate during training, Groups 1 and 3

	Group 1 (random ratio) (8 birds)	Group 3 (aperiodic) (8 birds)
Mean, last 3 days pre-experimental training (aperiodic)	1940	2026
Standard deviation, last 3 days pre-experimental	431	338
Mean, last 6 days experimental training	4853	2903
Standard deviation, last 6 days experimental	1818	906

On the basis of the hypothesis that random ratio training is effective in increasing the rate of responding because it tends to produce coincidence of reinforcement with rapid responding, we should expect large individual differences under this schedule, for the coincidence does not occur on every reinforcement. It is possible that by chance a given bird might receive most of its reinforcements while responding slowly, at least through one or two experimental sessions, and the increase in rate would be correspondingly delayed. Similarly, under aperiodic reinforcement, while the probabilities favor the reinforcement of slow responding, in some individual cases the reinforcements may by chance coincide more often with rapid responding. If this occurs, and an increase in rate results, the higher rate may be to some degree self-perpetuating, since the higher and more consistent the rate, the smaller the chances that a reinforcement will coincide with slow responding, even under aperiodic reinforcement. It is possible that with very prolonged training under aperiodic schedules, there would be long cycles in the rates of response -- long

periods of gradual increase followed by long periods of gradual decrease. Such cycles have in fact been observed by Jenkins (personal communication).

We might, then, expect fairly high variability among birds trained under aperiodic schedules, for there is no reason why the "cycles" should coincide from bird to bird. But why should there be an increase in variability as birds continued their training under aperiodic reinforcement? Why was the standard deviation of their response rate nearly three times as great during the last six days of their training on this schedule as during the last three days of the pre-experimental training? It will be recalled that during the pre-experimental training (prior to the last three days) drive levels were being manipulated in order to minimize variability. This was done on the assumption that the individual differences in response rate were due in large part to differences in how "hungry" different birds were at the same level of body weight. We now see that many of the differences may in fact have been due to the chance coincidences of reinforcements with different rates of responding; different birds may have been at different points in their long cycles of changing response rates, and the manipulation of drive levels may have set drive for each bird at a point which counterbalanced his momentary upward or downward trend. But after the manipulation of drive levels was discontinued, the response rates continued to change (due presumably to the changing coincidences of reinforcements with particular rates of response), and the drive levels established to counterbalance earlier deviations from the group mean would no longer serve to reduce variability. As a matter of fact, the difference in drive level might serve to increase variability in later stages of training.

The question remains as to why the individual differences should be greater under random ratio training than under continued aperiodic training. Table V shows that the variability of the random ratio birds is twice as great -- the F value of this difference is 4.0, barely significant at the 5% level. One can only speculate about the reason for the difference (if it is in fact not due to sampling error). One possibility is this: in random ratio reinforcement, bursts of several responses tend to be reinforced, and a "response unit" of several responses may be formed. Any measure of individual differences, then, if it is taken in terms of individual responses, will be magnified by the size of the response unit.

It will be recalled that one of the primary objectives of the study was to compare rates of responding under random ratio reinforcement with those under aperiodic reinforcement, with the ratio of responses to reinforcements held constant. Before the findings in Table IV can be fully evaluated, it is necessary to examine how successfully Group 1 was matched to the control group with respect to this ratio. Through the nine experimental days, the control group increased their rate of responding on the average. This meant that they were increasing their number of responses per reinforcement. The original ratios of the random ratio group were established at 10% above their ratios under the preceding aperiodic schedule, and after three days of training at these ratios, the ratios were increased again, by 20%, to keep their ratios roughly the same as those of the control group. Even this increase, however, was not quite enough to establish perfect matching. Over the last six days of training the average number of responses

per reinforcement among the random-ratio birds was 128; among the control birds (receiving continued aperiodic training), the number was 145.

The basic question is: could this difference in ratios have produced the difference in response rates shown in Table IV? There is little experimental evidence on which to draw for an answer to this question, but what evidence there is suggests that a difference in ratios of this magnitude would not produce a difference in response rates, in the direction observed. As may be seen from the sample curves Skinner presents (9, p. 288) there is no drop in response rates even when ratios are doubled and quadrupled under fixed ratio reinforcement; as a matter of fact, rates appear to increase somewhat with larger ratios, and other unpublished work with fixed ratios in Skinner's laboratory confirms this finding. Unfortunately, there is no work available on the relation between rates of responding and the size of the ratio under random ratio reinforcement, but if it is similar to the relationship under fixed ratio reinforcement, then the small difference in ratios described above would either make no difference in response rates or it would favor a difference in the opposite direction from the one observed. It appears likely, then, that the comparisons in Table IV are, if anything, conservative.

It seems fairly safe to conclude, then, that random ratio schedules do produce increased rates of responding, greater than the rates found under aperiodic schedules with the same ratio of responses to reinforcements (and with drive, total number of reinforcements, and total number of responses held constant.) It should be borne in mind, however, that

the entire increase under this schedule cannot be attributed to the coincidence of reinforcement with rapid responding, since once any increase in rate occurs due to this factor, the time period between reinforcements becomes smaller and this in itself would tend to produce further increases in rate. The effect of the coincidence of reinforcement with rapid responding without any concomitant changes in time intervals will be studied in the following section.

Change in rates when every reinforcement coindides with rapid responding

When birds are reinforced aperiodically (every three minutes on the average) but when the reinforcements always coincide with bursts of responses which occur at the rate of 2 1/2 responses per second or faster, the rates of response increase quickly to levels much above those prevailing under a simple three-minute aperiodic schedule. As may be seen from Figure 1, on the eighth day of training under their new schedule, Group 2 birds were responding at a rate nearly four times as great as their pre-experimental aperiodic rate, and their rate at this point was well over twice that of the control group. The increases in rates of the five birds which were put on this schedule were as follows:

Table VI: Changes in response rates, individual birds in Group 2

Bird No.	Mean rate, last 3 days pre-experimental training (aperiodic)	Mean rate, last 6 days training, reinforcements coincident with rapid responding
69	1686	4726
67	2473	6813
59	2412	6426
65	1892	7801
63	1607	5720
Mean:	2014	6240

This difference is significant beyond the 1% level of confidence when each bird's performance under experimental conditions is compared with his own performance under the pre-experimental 3-minute aperiodic schedule. A more fundamental question is: is this increase significantly greater than the increase which would have occurred had these birds remained on a simple aperiodic schedule? To test this question Group 2 birds must be compared with the five birds in Group 3 with which they were originally matched. Table VII shows that a significant difference is found between these two groups, using a one-tailed test:

Table VII: Significance test, response rates of Group 2 and Group 3 compared

Mean rate, last 6 days aperiodic training (Group 3)	Mean rate, last 6 days, reinforcement coincident with rapid responding (Group 2)	Diff.	Sigma diff.	t	df	p
3004	6240	3236	841	3.85	8	less than .01

The correlation between the performances of matched birds was negligible, and the correlation was ignored in computing the standard error of the difference.

It will be observed in Table VI that the individual differences in performance of Group 2 birds were small, relative to those reported for random ratio birds (see tables II and V). The standard deviation of the mean response rates of "rapid responding" birds during their last 6 days of experimental training was 1105 -- less than two-thirds the standard deviation of the random ratio birds -- and this lower standard deviation occurred despite a higher mean response rate.

The conditions of reinforcement prevailing for Group 2 during their experimental training should affect variability among birds in several ways: first, the conditions should favor the formation of an integrated response-unit, and this should increase variability, for any factors operating to produce variability would affect whole groups of responses rather than individual responses. The records accumulated during the experiment do not afford a basis for studying the nature of the response-unit which is developed, since the recorder would not show successive bursts of, say, 10 responses, as being very different from smooth responding at the same over-all rate, except for minute variations which make the recorder line look a little rough. In observing the Group 2 birds during their training, however, and in listening to the apparatus as it followed their pecking, it was evident that the birds did tend to emit bursts of six to fifteen responses, and to pause very briefly between these bursts. The conditions of training, of course, favored this kind of responding, since reinforcement always followed a run of responses of a certain minimum length and speed. Some individual birds gave runs of responses which were considerably faster and longer than would be necessary to deliver a reinforcement, but it is possible that if training had been continued beyond the ninth hour there would have been a tendency for these rates to adjust themselves to the minimum requirements of the reinforcement situation. In any case, assuming that the integration of a response unit would be more complete the more consistent the reinforcement of a particular kind of response-group, we should expect that in the present experiment the formation of an integrated unit would be most evident in Group 2.

It should also occur, but to a lesser extent, in Group 1, since reinforcement tends to coincide with runs of responses under random ratio reinforcement, but for this group the variation in the kinds of response-units which may by chance be reinforced is much greater than in Group 2 where the lower limit has been explicitly set. For Group 3 the integration of a group of responses into a unit would be minimal, since isolated individual responses are just as likely to be reinforced as runs of responses, and the occurrence of a reinforcement is independent of the pattern of responses preceding it.

If formation of a response-unit tends to increase variability of responding measured in individual responses, other things being equal, then we should expect Group 2 to be the most variable, Group 1 the next most variable, and Group 3 the least variable. As we have seen, however, Group 2 is in fact less variable than Group 1. A probable explanation is as follows: Under the Group 2 conditions of reinforcement a high degree of control over the conditions of reinforcement and therefore over the resultant response rates has been achieved. Individual differences are, therefore, greatly reduced under this schedule. Such differences as do appear, however, are magnified by a well developed response-unit, and the greater consistency among the performances of different birds under this schedule is therefore somewhat masked, but still great enough to produce a smaller standard deviation of their performances than is found among birds trained on random ratio schedules.

Some qualitative aspects of the cumulative response curves

Photographs of sample records from the three different conditions of reinforcement are shown in the Appendix (Figures 3, 4, and 5). These samples are not intended to represent "typical" performances in any sense, but they do give a qualitative picture of the nature of the data on which the preceding discussion has been based. It will be observed that there are occasional instances of pauses after reinforcement, and positive acceleration between reinforcements. Such "scallops" (at least, pronounced enough ones to be measurable from the rather gross records produced by the recorder pen) occurred in something over one-fourth of the inter-reinforcement intervals, and were approximately equally common in the three experimental groups. Pausing after reinforcement, and subsequent positive acceleration, has been the subject of much discussion by Skinner (9, p. 288 ff; also 10), who reported pronounced and consistent "scalloping" when he employed regular (periodic and fixed ratio) schedules of reinforcement. The fact that the phenomenon was not nearly so consistent nor so pronounced in the present study suggests that the regularity of Skinner's schedules was a major factor in producing response curves of the shape he reports.

Resistance to extinction

Figure 2 shows that the "Rapid Responding" birds (Group 2) gave about 50% more responses in the total extinction period than birds trained under aperiodic or random ratio schedules. While Groups 1 and 3 do not differ materially in the total number of

FIGURE 2

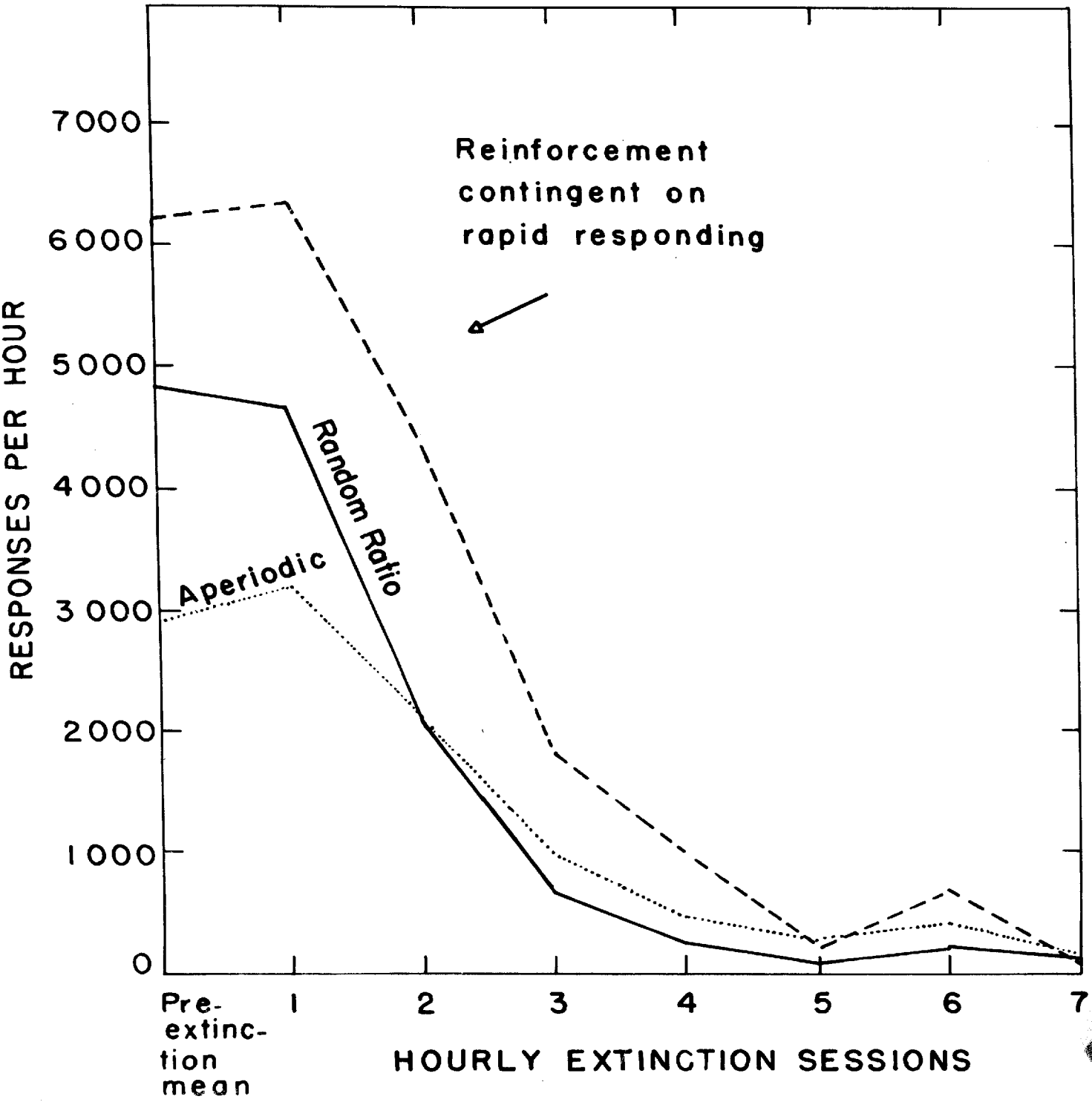


Figure 2. Number of responses in extinction, following three different patterns of partial reinforcement.

extinction responses, the shapes of their two extinction curves are somewhat different: the random ratio birds gave more extinction responses during the early part of extinction, and their curve fell off more rapidly.

Following are extinction records for the individual birds in each group:

Table VIII. Total number of responses in seven hours[5] of extinction, individual birds in each group

Random ratio (Group 1)		"Rapid responding" (Group 2)		Aperiodic (Group 3)	
Bird No.	Total extinction responses	Bird No.	Total extinction responses	Bird No.	Total extinction responses
75	5089	69	5610	57	6623
66	8334	67	14604	60	6459
68	9157	59	19424	70	10190
72	3165	65	20838	64	6103
58	7722	63	6339	62	8939
79	9110			61	10844
77	7645			73	4211
76	5157			74	2220

Complete extinction curves for the birds in each group are shown in the Appendix (Figures 6, 7, and 8).

Comparison of the records in Table VIII with those in Tables II (page 34) and VI (page 42) reveal that there is a relationship between the rate of responding during training and the number of responses in extinction: within each group, the birds which responded most rapidly during training tended to give the largest number of responses during extinction. The rank difference correlations are:

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5 Total responses in this table are actually the total number given in six hours and fifty minutes of extinction. Reinforcements were still being given during the first ten minutes of the first extinction hour, and responses made during this ten-minute period have therefore been excluded.

Group 1 (random ratio)	.86	± .09
Group 2 ("rapid responding")	.90	± .09
Group 3 (aperiodic)	.52	± .26

Significance tests of the differences in extinction performance between groups show, first of all, that the "rapid responding" birds were superior in their total number of responses in extinction, although the p values does not quite reach the 1% level of confidence (Table IX). For computation of the standard error of the differences in Table IX, birds have been paired on the basis of their rates of response during training (the fastest bird in Group 2 being paired with the fastest bird in Group 1, etc.) and correlation has been taken into account in computing the p values.

Table IX: Tests of the significance of the differences between the mean number of extinction responses, "rapid responding" birds compared to random ratio and aperiodic.[6]

	Mean, "rapid responding"	Means, random ratio, aperiodic	Difference	Diff.	t	d.f.	p.
"Rapid responding" vs. random ratio	13363	6693	6670	2345	2.84	4	.023
"Rapid responding vs. aperiodic	13363	7663	5700	2840	2.01	4	.058

It is evident from Table VIII that the performance of the "rapid responding" birds was considerably more variable than that of the first five birds in Groups 1 and 3. An F test of the variabilities shows that the "rapid responding" birds were significantly more variable in extinction than birds trained on simple aperiodic reinforcement (p. value is .01), and a greater variability among "rapid responding" birds

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6 In this table, the random ratio and aperiodic means are based on the five original cases in each group.

than among the random ratio birds is strongly indicated (p. value is less than .05).

This lack of homogeneity raises questions concerning the validity of the t tests appearing in Table IX, for the t's appearing there might be a function of the different variabilities rather than a function of the difference in means.

It is possible to reduce the variability in the scores and examine any remaining differences between means by transforming the scores to logarithms. When this is done and a new t-test is computed, the two p. values reported in Table IX above become .06 and .09 respectively.

A larger number of responses in extinction among birds whose reinforcements have coincided with rapid responding is, then, strongly indicated, although the null hypothesis cannot be rejected with as great confidence as would be necessary for clear demonstration of the point.

Comparing birds trained under aperiodic schedules with those trained under random ratio schedules, we find that there is virtually no difference between them in the total number of responses in extinction. The mean number of extinction responses for random ratio birds was 6922,[7] for aperiodic birds 6949,[7] and the difference between these means is of course minute compared to the standard error of the difference.

As mentioned earlier, however, there is a difference in the shape of the extinction curves under the two conditions. Initially,

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7 These means are based upon all 8 cases in each group.

the random ratio birds respond more rapidly during extinction, but their performance later falls below that of the aperiodic group, and the two groups approach the same asymptote on their cumulative response curves. Considering only the first 50 minutes of extinction (the first hour minus the first ten minutes, when reinforcements were still being given), the superiority of random ratio birds is significant at the 2% level of confidence:

Table X: Test of significance of the difference between the mean number of responses during the first extinction session, Group 1 compared to Group 3

	Group 1 mean	Group 3 mean	Difference	Sigma diff.	t.	d.f.	p
First five birds	3239	2613	626	401	1.56	4	.097
3 added birds	4052	2549	1503	388	3.92	2	.029

Chi square value of combined probabilities: 11.74, 4 d.f.

p: .02

Discussion of the extinction findings

Interpretation of the extinction findings raises some complex problems. It might be valuable as a first step to outline ways in which birds differed from each other in their situations during training, and then examine the relation of these variables to extinction performance.

It will be recalled that the random ratio birds were matched to the aperiodic birds with respect to their total number of responses during experimental training. They differed with respect to the time interval between reinforcements, for when random ratio birds increased their rate of responding, they received reinforcements sooner and were

taken out of the experimental chamber sooner. Groups 1 and 3, then, differed from each other in the following ways:

Time intervals between reinforcements (random ratio birds had the shorter intervals)
Rates of responding (random ratio birds responded more rapidly)
Nature of the reinforcement schedule (for random ratio birds, reinforcements more often coincided with rapid responding).

Comparison of the "rapid responding" birds with the aperiodic birds reveals quite a different situation. These two groups were identical with respect to the time interval between reinforcements -- for both groups, this interval averaged three minutes. They differed, however, in the following ways:

Total number of responses (and consequently ratio of responses to reinforcements)
Rates of responding (the "rapid responding" birds being faster)
Nature of the reinforcement schedule (for "rapid responding" birds, reinforcements always coincided with rapid responding).

Suppose we wished to know the answer to the following question: How does <u>rate of responding per se</u> affect resistance to extinction, other things being equal? This is a psychologically meaningful question, for a given number of responses might have quite different properties if they occur rapidly than if they occur slowly -- there should be differences in fatigue, in Hull's "inhibition of response," in the degree of integration of response units, etc. But by virtue of the fact that <u>rate</u> is a ratio:

$$\text{Rate} = \frac{\text{number of responses}}{\text{number of minutes}}$$

it is both logically and experimentally impossible to study the effects of variations in rate without at the same time varying one or both of its components -- number of responses and time intervals. It appears to the writer, therefore, that we cannot definitively answer questions

concerning the relationship of rate of responding to extinction performance. But we can hold constant one of its components and see what difference the other alone makes in extinction, and this is essentially what has been done in the group comparisons described above.

Comparison of the extinction performances of aperiodic and random ratio birds (p. 49) shows that when two groups are matched with respect to the total number of responses they give during training (and the ratio of responses to reinforcements), but differ with respect to rates of responding and the time interval between reinforcement, they do not differ in their total number of responses in extinction.

Comparison of "rapid responding" birds with aperiodic birds (Table IX) shows that when two groups are matched with respect to the time interval between reinforcements, but differ with respect to the number of responses per reinforcement, the group with the largest number of responses in training gives the largest number of responses in extinction.

These two findings suggest that it is the number of responses, rather than the temporal spacing of reinforcements, which is the significant factor. This conclusion would be consonant with Humphreys' conclusion and also with that of Mowrer and Jones. There are other findings on extinction in the study, however, which would not be explained on the basis of the number of responses during training.

First there is the fact that the <u>shape</u> of the extinction curve for the random ratio birds was different from that of the aperiodic birds, despite the similarity of the two groups in total number of extinction responses. Since the two groups were equated with respect to their number of responses during training, the difference in the shape of their

extinction curves must be related in some way to the difference in the time interval between reinforcements during training.

Next we must consider the relationship between performance in training and performance in extinction within the three groups. It will be recalled that for each group there is a positive correlation between the rate of responding in training and the total number of responses in extinction. In the aperiodic and "rapid responding" groups rate could vary only with variation in the number of responses, since the temporal pattern of reinforcement was held constant in each case. In these groups the positive correlation indicates that the individual birds which responded at the highest rates during training, and which therefore had the largest number of responses, also gave the largest number of responses during extinction. This finding is in conformity with the principle that the number of responses during training is the significant factor in extinction.

Among the random ratio birds, however, the high positive correlation has a different meaning. Since the number of responses was controlled, rate varied as a function of the interval between responses. In this case the correlation between rate of responding during random ratio training and the number of responses in extinction indicates that the shorter the time interval between reinforcements during training the larger the number of responses in extinction.

It will be recalled that while the number of responses was controlled during random ratio training, some birds had larger response "quotas" than others -- for each bird, the number of responses to be completed in each session was established on the basis of his

performance under pre-experimental aperiodic training. The birds which gave the largest number of responses during random ratio training did not give any more responses in extinction, on the average, than birds with small response "quotas;" the rank difference correlation between the number of responses during training and the number of responses in extinction was .02 for random ratio birds.

It appears, then, that for random ratio birds, the number of responses during training is not a significant factor in extinction, but that the time interval between reinforcements is. This conclusion is contrary to the conclusion reached on the basis of inter-group comparisons, where it was found that birds differing in their number of responses during training did differ in extinction, while birds differing in their inter-reinforcement interval did not.

Some of the apparent contradictions in the results may be resolved if one views extinction performance as a function of two major variables:

(1) the formation of integrated response units during training, and

(2) a generalization decrement -- a falling off of responding as the extinction situation becomes more and more different from the training situation.

The first variable has been discussed in some detail earlier. It should be emphasized that the term response-unit as here employed does not refer to the total number of responses per reinforcement, but rather to a smaller group of responses which are integrated behaviorally so that they operate in some respects as a single response.

The generalization decrement hypothesis has been the subject of full discussion and experimental test by Virginia F. Sheffield (8).

The hypothesis holds, briefly, that a reason why partial reinforcement exhibits superior resistance to extinction (as compared with 100% reinforcement) is that in partial reinforcement, the cues of non-reinforcement from preceding trials are present during subsequent reinforced trials, and therefore are part of the stimulus pattern to which the response is learned. When these cues are present during extinction, then, they do not produce a decrement in responding due to generalization as they do if they have never been present during training.

A similar principal was enunciated by Mowrer and Jones (7), who suggested that the more dissimilar the training and extinction situations, the easier it would be for the animal to form a discrimination between them, and the more likely it would be that responding in training would not carry over fully to extinction. Skinner has also recently promulgated the same point of view (10).

In the present experiment, considerable resistance to extinction may be expected in all three experimental groups, on the basis of the above hypothesis, since all groups have been only intermittently reinforced, and the extinction situation, at least at first, should be hardly distinguishable from the training situation. But the intervals between reinforcements have been shorter on the average (only about half as long) for the random ratio group as compared with the two groups which received reinforcements on the average every three minutes. Therefore the change in the situation from training to extinction should be greater for the random ratio birds than for birds in the aperiodic and "rapid responding" groups, and this should result in a decrement in the responding of the random ratio birds.

We have posited earlier that the formation of response-units would be most complete among the "fast responding" birds, where an explicit lower limit to the size of the response unit was set experimentally. The development of a response-unit should be next most complete, we argued, among the random ratio birds, and least complete among the aperiodic group. Let us now assume further that within the random ratio group, the faster the response rate achieved the more integrated the response unit. This is not unlikely, since the higher the response rate, the greater the probability that reinforcements will coincide with a burst of responses. It must also be assumed, of course, that a well-integrated response-unit will produce more individual responses in extinction, for each "response" in extinction will be composed of a group of perhaps five to ten responses.

We can now employ the two explanatory principles jointly to explain the findings of the experiment:

Finding:	Explanation:
"Rapid responding" birds gave more responses in extinction than random ratio birds.	"Rapid responding" birds have a somewhat better-developed response-unit, and the change from the training situation to the extinction situation is less for them, since their average time interval between reinforcements during training was approximately twice as great. Thus, both factors indicate more responses in extinction for the rapid responding group.
"Rapid responding" birds gave more responses in extinction than aperiodic birds	Aperiodic birds had a much less well-developed response unit. There was no difference between these groups, however, in the amount of change of the situation from training to extinction.

Random ratio birds gave the same number of responses in extinction as aperiodic birds	Random ratio birds had a more fully integrated response unit, which would tend to produce more responding in extinction, but they also underwent a greater change in the situation from training to extinction, which would tend to reduce responding in extinction. The two factors had opposite effects, and tended to balance one another.
The extinction curves for the random ratio and aperiodic birds differed in shape; the random ratio birds started their extinction at a higher rate, but dropped below the aperiodic birds later.	At the beginning of extinction, neither group had yet undergone much change in the stimulus situation, and the random ratio group, having larger response-units, responded at a higher level. However, the random-ratio group underwent a change in situation sooner, and its rate therefore declined sooner.
Among random ratio birds, those which responded at a higher rate in training gave more responses in extinction.	The birds which responded at a higher rate in training developed a better integrated response-unit, which produced more responses in extinction. At the same time, these birds had smaller intervals between reinforcements than the slow birds, and this factor should have reduced the responding of the faster birds in extinction. In this situation, however, the second factor was not strong enough to balance the first.

It will be evident that the last of the findings listed above is least well explained by the two hypotheses which have been employed. There is no evidence in the study that the faster random ratio birds underwent any greater generalization decrement than the slower members of their group; their extinction curves did not break any more sharply, as the hypotheses predict they should do (see Appendix, Figure 6.) There may be other factors involved which have not been considered here, and the above analysis can only be considered as suggestive and not in any sense conclusive.

Variability in extinction performance

It will be recalled that during training, the birds whose reinforcements always coincided with rapid responding showed considerably less variability in their performance than the random ratio birds, despite the fact that their mean rate was higher. In extinction the situation is reversed; the Group 2 birds are more variable than the random ratio birds (an F test shows a p value of less than .05), and are also more variable than the aperiodic birds (p. equals .01).

It has been assumed earlier that the Group 2 birds developed a more fully integrated response unit during their training. This would tend to increase variability, other things being equal, because as pointed out earlier any factor tending to produce a single extra response in extinction would produce a burst of responses in these birds, and any factor leading to the omission of a response would reduce the total number of responses by several instead of one. It was suggested earlier that the greater development of response-units in training did not produce greater variability in the Group 2 birds because the experimental conditions for these birds provided rather complete control over the conditions of reinforcement, and this produced enough uniformity to overcome the effects of the response-unit.

In extinction it is possible that new factors enter the picture to produce variability, and that there is no superiority for Group 2 in the experimental control of these factors. If this were the case, their larger response-unit would magnify whatever variability was produced, and their variability would be greater than that of the other groups.

SUMMARY

The major findings of the experiment are as follows:

1. When birds in a Skinner box are shifted from an aperiodic schedule of reinforcement to a random ratio schedule (with the number of reinforcements and the ratio of responses to reinforcements held constant) there is an increase in the speed of responding.

2. When birds are trained under a schedule of aperiodic reinforcement in which reinforcement coincides with a burst of responses of a certain minimum length and speed, there is a very marked increase in rate of responding, as compared with simple aperiodic reinforcement.

These results are interpreted to mean that, other things being equal, the rate of responding in a Skinner box will be an aspect of the topography of the response itself, and that whatever rate of responding is differentially reinforced will be learned.

3. Individual differences in rates of responding are greater for birds trained under random ratio reinforcement than for those trained under simple aperiodic reinforcement or under a schedule of aperiodic reinforcement in which reinforcements always coincide with rapid responding.

This finding is interpreted in terms of the formation of integrated response-units (which is believed to <u>increase</u> variability), and the consistency of the coincidence of reinforcement with a particular rate of responding. Such consistency, it is argued, will reduce variability.

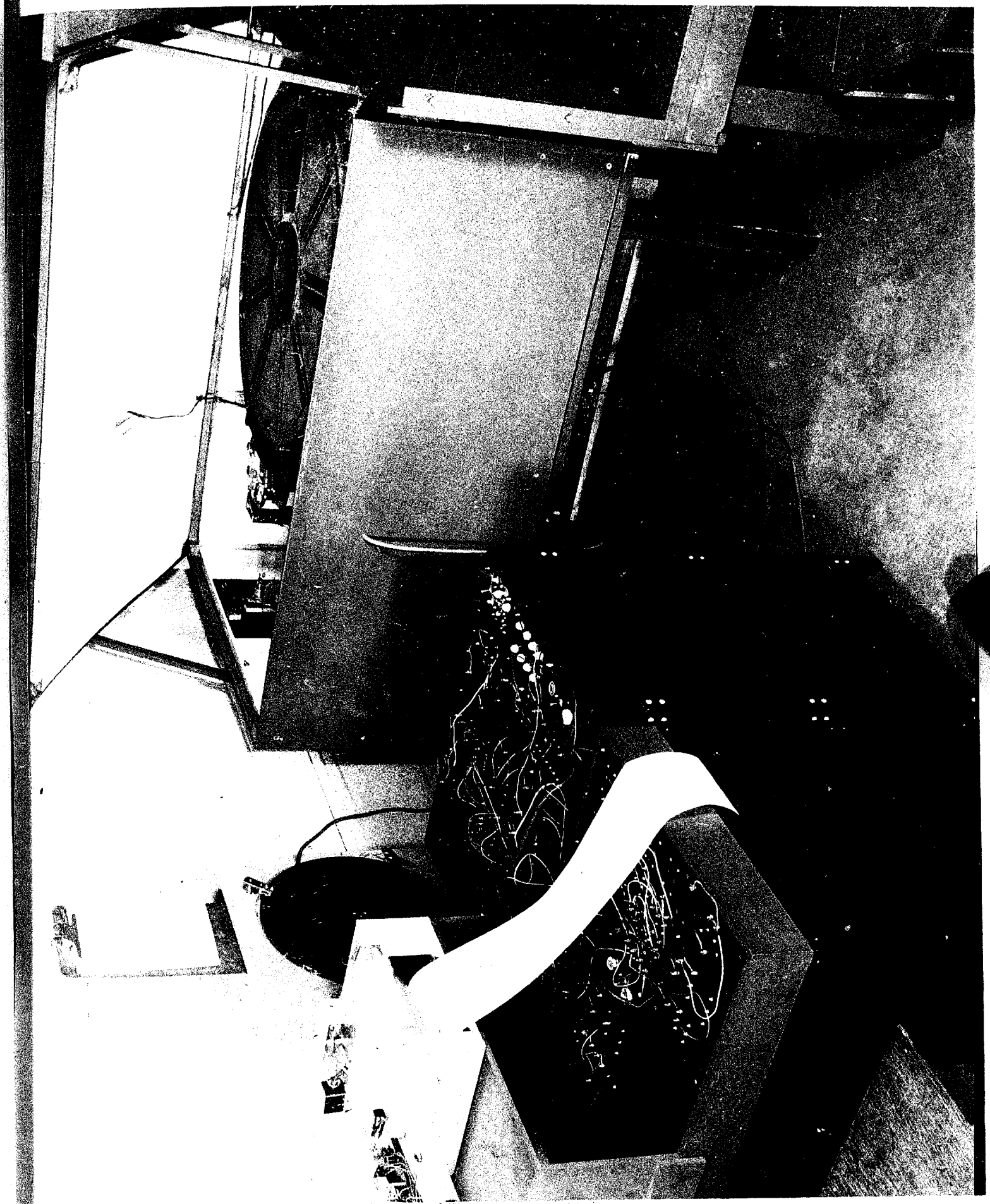
4. Birds trained on an aperiodic schedule in which reinforcements consistently coincide with rapid responding give more responses in extinction than birds given random ratio or simple aperiodic training.

This finding is interpreted in terms of the fuller development of the response-unit among the "rapid responding" birds.

5. Birds trained under a random ratio schedule give approximately the same number of responses in extinction as birds with simple aperiodic training, although the shapes of the extinction curves differ: the random ratio birds start extinction at a higher level of responding, and drop off to a level below that of the aperiodic birds.

This finding, it is argued, can be explained by virtue of the fact that the random ratio birds, although they have a more fully developed response-unit (which would increase their responding in extinction), also undergo a greater change from the training situation to the extinction situation than do the aperiodic birds, since the time interval between reinforcements during training is shorter for the random ratio birds, and that this factor through generalization decrement weakens their responding in extinction and balances the effects of their more fully integrated response-unit.

APPENDIX



Photograph of Apparatus

Appendix Table 1: Random ratio schedules[1]

Bird Number:	75	66	68	72	58	79	77	76
				A: First schedules				
	104	90	92	95	151	105	140	77
	300	260	265	273	436	304	404	224
	323	280	286	294	469	328	435	241
	404	350	357	368	586	410	544	301
	566	490	500	515	821	573	761	422
	567	491	501	516	822	574	762	423
	670	580	592	610	972	679	901	499
	878	760	776	799	1273	889	1181	654
	924	800	817	841	1340	936	1243	689
	993	860	878	904	1441	1006	1336	740
	1085	940	960	989	1575	1100	1461	809
	1212	1050	1072	1104	1759	1229	1632	904
	1362	1180	1205	1241	1977	1381	1834	1016
	1535	1330	1358	1399	2228	1556	2067	1145
	1650	1430	1460	1504	2396	1673	2222	1230
	1662	1440	1470	1514	2413	1685	2238	1240
	1697	1470	1501	1546	2463	1720	2284	1265
	1882	1630	1664	1714	2731	1907	2533	1403
	1940	1680	1715	1767	2815	1966	2611	1446
	2078	1800	1838	1893	3016	2106	2797	1550
				B: Second schedules				
	125	108	110	114	181	126	93	168
	360	312	319	328	523	364	269	485
	388	336	343	353	562	392	289	522
	485	420	429	442	704	490	362	652
	679	588	590	618	985	686	506	913
	680	589	591	619	986	687	507	914
	803	696	711	732	1166	812	599	1081
	1053	912	931	959	1528	1064	785	1417
	1108	960	980	1009	1608	1120	826	1491
	191	1032	1054	1085	1729	1204	888	1603
	301	1128	1152	1186	1890	1316	971	1752
	453	1261	1287	1325	2111	1470	1085	1957
	634	1416	1446	1489	2372	1652	1218	2200
	842	1596	1630	1678	2674	1862	1374	2479
	980	1716	1752	1804	2875	2002	1477	2666
	994	1728	1765	1817	2895	2016	1488	2684
	2036	1764	1801	1855	2955	2058	1519	2740
	257	1956	1998	2056	3277	2282	1684	3038
	326	2016	2059	2119	3378	2352	1735	3132
	2493	2160	2206	2271	3619	2520	1859	3355

1 Numbers in this table represent the serial numbers of responses which were reinforced. Thus, for bird 75 under his first schedule, reinforcements occurred on the 104th response, the 300th, etc.

Appendix Table 2: Matching of birds[1]

Group 1 (random ratio)			Group 2 (rapid responding)			Group 3 (aperiodic)		
Bird No.	Base rate[1]	Base Weight	Bird No.	Base rate[1]	Base Weight	Bird No.	Base rate[1]	Base Weight
68	1671	77%	63	1607	77%	57	1453	78%
75	1887	77	65	1892	78	60	1943	79
72	1721	80	59	2412	78	70	2397	80
58	2742	84	67	2473	83	64	2600	83
66	1635	82	69	1686	80	62	1959	81
79	1915	80				61	1938	78
77	2543	82				73	2155	82
76	1409	77				74	1764	79

1 Birds on the same horizontal line are matched with one another; thus, birds 68, 63 and 57 are matched. The matching was done primarily on the basis of the response rates shown above. These rates are the average number of responses per hour during the last three days of pre-experimental training. Base weights were also taken into account in the matching.

Appendix Table 3: Rates of responding,[1] individual birds in Group 1 (random ratio)

Last three days, pre-experimental (aperiodic):	Bird No. 75	66	68	72	58	79	77	76	Mean, eight birds
Day 7	1660	1531	1816	1544	2490	1525	2718	1280	1820
8	1910	1777	1810	1700	2285	1910	2400	1372	1895
9	2090	1596	1387	1920	3452	2310	2510	1575	2105
Random ratio training:									
Day 1	1971	807	972	2224	2961	3610	2347	2010	2113
2	1958	2623	2728	2595	4500	5542	2500	2221	3084
3	2633	4022	4540	2519	5436	5495	3048	2636	3791
4 (2)	2070	3312	5439	2074	7754	8621	4154	2979	4550
5	3112	4610	7429	2019	7000	6091	3536	2966	4595
6	2534	5508	6303	1078	6880	6248	4583	3362	4562
7	3439	5760	6957	1947	6660	6436	5378	3878	5057
8	3773	5866	6136	778	7044	5976	5341	3750	4837
9	3392	7576	6111	3025	8680	6540	4880	3947	5520
Extinction:									
Day 1 (3)	2900	5100	6174	2333	5500	6488	5162	3855	4689
2	1370	2770	2420	1150	2562	2510	2140	1541	2058
3	933	993	622	26	600	812	1113	220	665
4	323	538	493	25	123	150	285	103	255
5	143	40	91	26	160	40	90	168	95
6	10	103	787	80	160	370	85	65	207
7	330	50	10	125	207	140	20	5	111

1 Figures in this table are number of responses per hour. The figures for the nine days of random ratio training have been converted to an hourly basis from raw data which gave numbers of responses for variable periods of time. These response rates have been corrected for differences in eating time between these and the Group 2 and 3 birds.

2 On the fourth day of random ratio training, birds were shifted to new reinforcement schedules (See Appendix table 1-B) under which the number of responses between reinforcements averaged 20% higher than under the schedules employed for days 1 to 3.

3 During the first extinction session birds were given two reinforcements according the their regular random ratio schedule and then reinforcements were discontinued.

Appendix Table 4: Rates of responding[1] individual birds in Group 2 (reinforcement coincident with rapid responding).

Last three days, pre-experimental (aperiodic):	Bird No. 69	67	59	65	63	Mean, five birds
Day 7	1712	2284	1970	(2)	1260	1806
8	1712	2570	2662	1777	1681	2080
9	1635	2565	2605	2007	1881	2139
Training under 3-minute aperiodic reinforcement, with reinforcement contingent on rapid responding:						
Day 1	2000	2495	2282	2459	1945	2236
2	2543	3322	3944	4516	3757	3616
3	4048	5650	4905	6340	4660	5121
4	4747	6650	5490	6373	5837	5820
5	5210	7292	6495	7240	5470	6341
6	4660	7010	6353	7700	4510	6047
7	4400	6522	6192	7118	4772	5801
8	4938	6900	7541	9754	5190	6865
9	4400	6506	7490	8616	5836	6570
Extinction:						
Day 1[3]	4293	5800	7800	9000	4800	6339
2	1541	4400	6038	8258	1570	4361
3	330	2278	2744	3585	150	1817
4	259	2028	1384	1065	259	999
5	20	88	838	62	25	207
6	52	1190	1670	385	90	677
7	5	40	200	53	5	61

1 Figures in this table represent numbers of responses per hour.

2 No record was obtained for bird 65 on this day -- the recorder pen ran out of ink.

3 During the first extinction session birds were given two reinforcements according to their regular schedule and then reinforcements were discontinued.

Appendix Table 5: Rates of responding,[1] individual birds in Group 3 (aperiodic reinforcement)

Last three days, pre-experimental (aperiodic):	Bird No. 57	60	70	64	62	61	73	74	Mean, eight birds
Day 7	1250	2076	2115	2390	1868	1700	2003	1541	1868
8	1370	1764	2700	2440	1712	1938	2106	1774	1976
9	1738	1990	2375	2971	2297	2175	2355	1978	2235
3-minute aperiodic training: (cont'd)									
Day 1	2011	2114	3348	1207[2]	3204	2355	2200	2303	2341
2	1490	2540	3434	2920	2466	2433	1960	2567	2476
3	1297	2491	3735	3204	2465	2874	2342	2900	2663
4	1233	2335	4270	2296	2283	2882	2407	2640	2543
5	1477	2313	5683	2842	2890	3260	1555	2278	2787
6	1400	2050	5850	3154	3258	3178	2210	1897	2875
7	1825	1926	4845	2822	3310	3120	3355	2900	3013
8	1670	1855	3715	2744	4216	3378	2350	2360	2786
9	2342	2796	4360	2977	5393	3935	2185	3300	3411
Extinction:									
Day 1[3]	2130	2420	4750	2800	3770	4762	2665	2280	3197
2	1750	1450	4012	2660	2220	3014	1541	233	2110
3	1120	864	1203	415	1342	2303	400	95	968
4	920	710	282	55	998	558	130	60	464
5	610	259	168	55	544	325	140	45	268
6	168	916	570	518	400	622	15	30	405
7	160	280	105	0	495	110	0	10	145

1 Figures in this table represent numbers of responses per hour.

2 On this day bird 64 appeared to be sick and was given a tablet of a sulpha compound.

3 During the first extinction session birds were given two reinforcements according to their regular schedule and then reinforcements were discontinued.

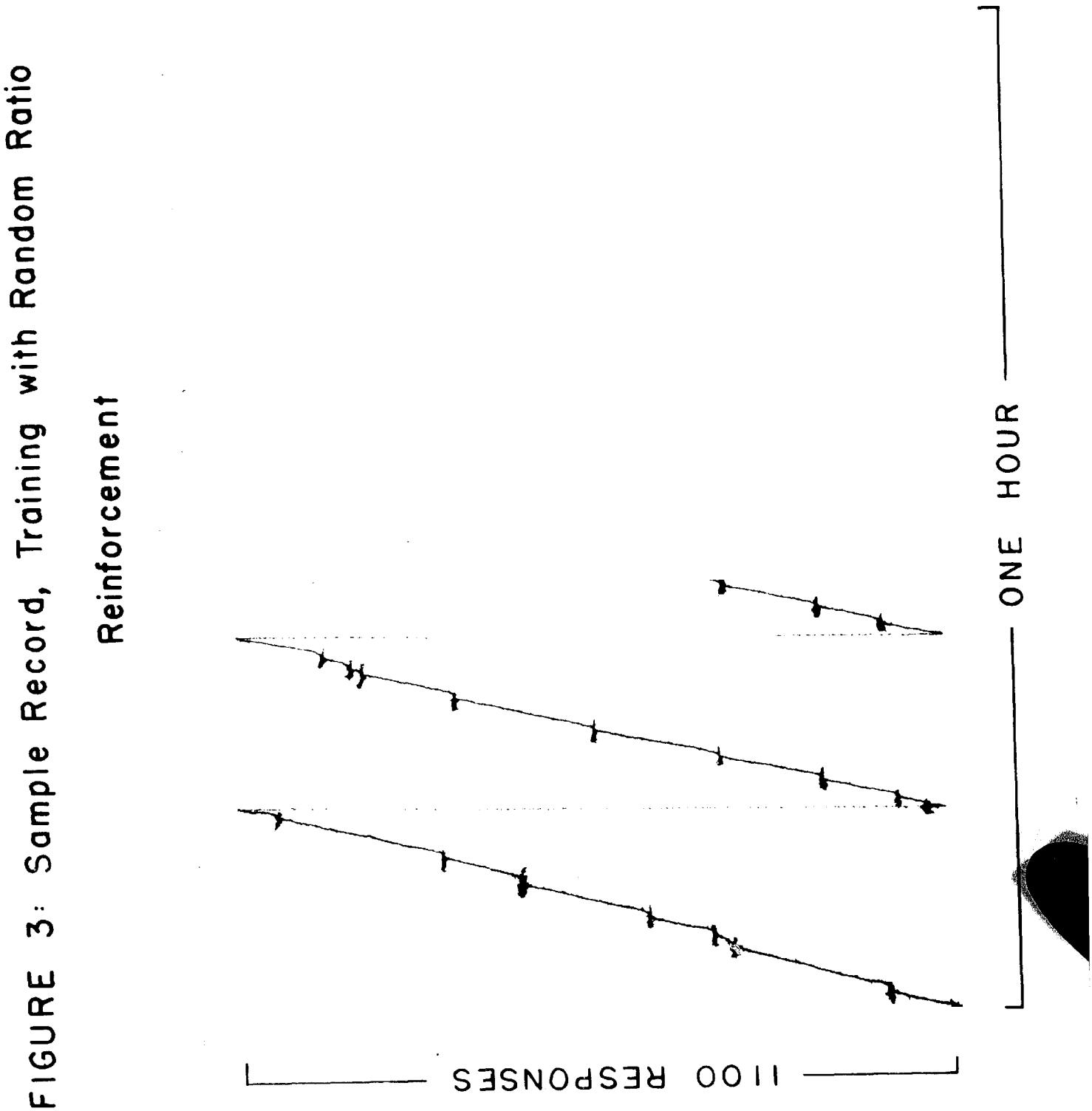


Figure 3. Sample record, one pigeon, one session of training with random ratio reinforcement. The record shows responses per unit time. The marks across the line show reinforcements.

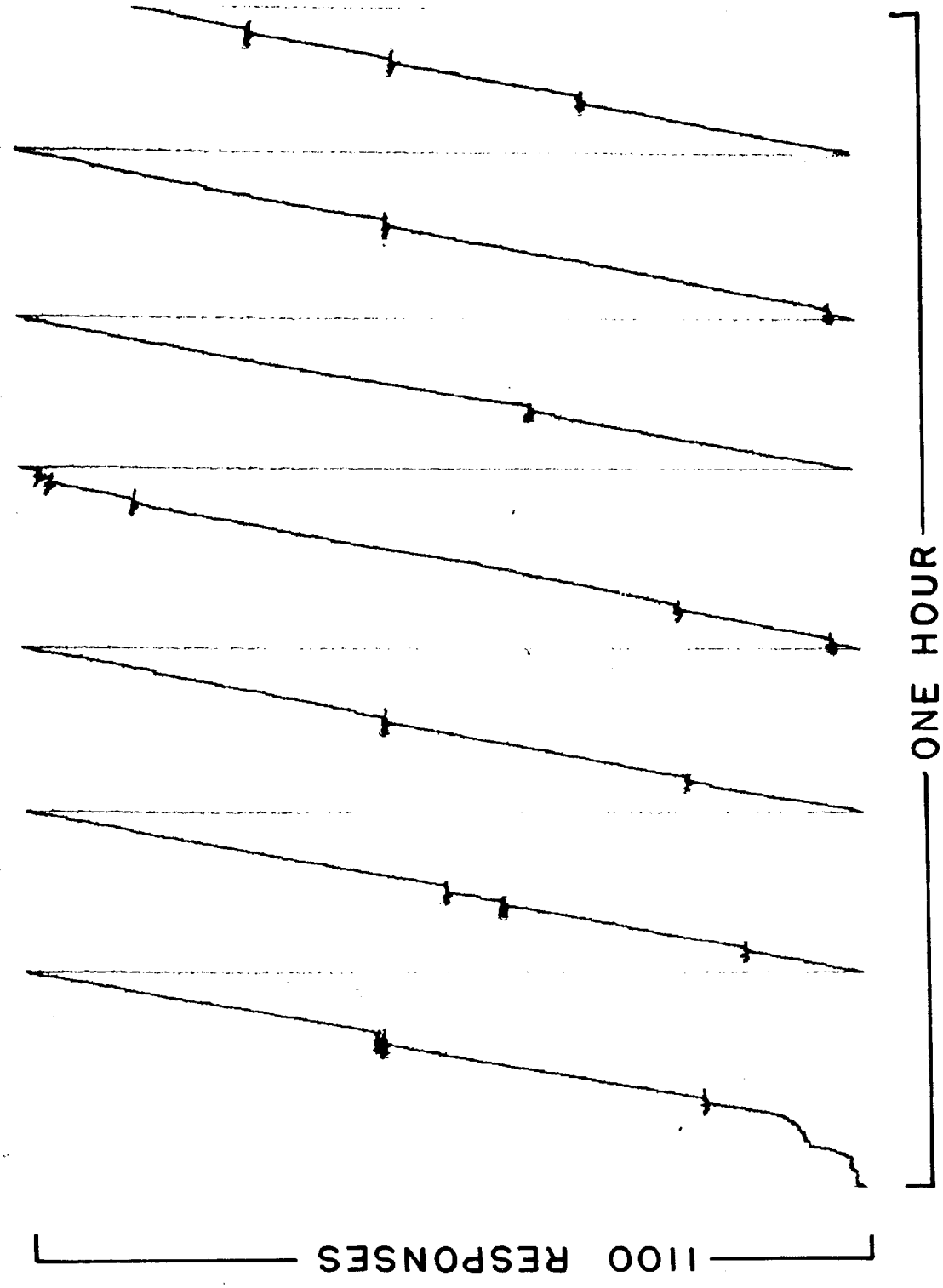


FIGURE 4: Sample Record, Training with reinforcement Contingent on Rapid Responding

Figure 4. Sample record, one pigeon, one session of training with three-minute aperiodic reinforcement, in which reinforcement is coincident with rapid responding. The record shows responses per unit time. The marks across the line show reinforcements.

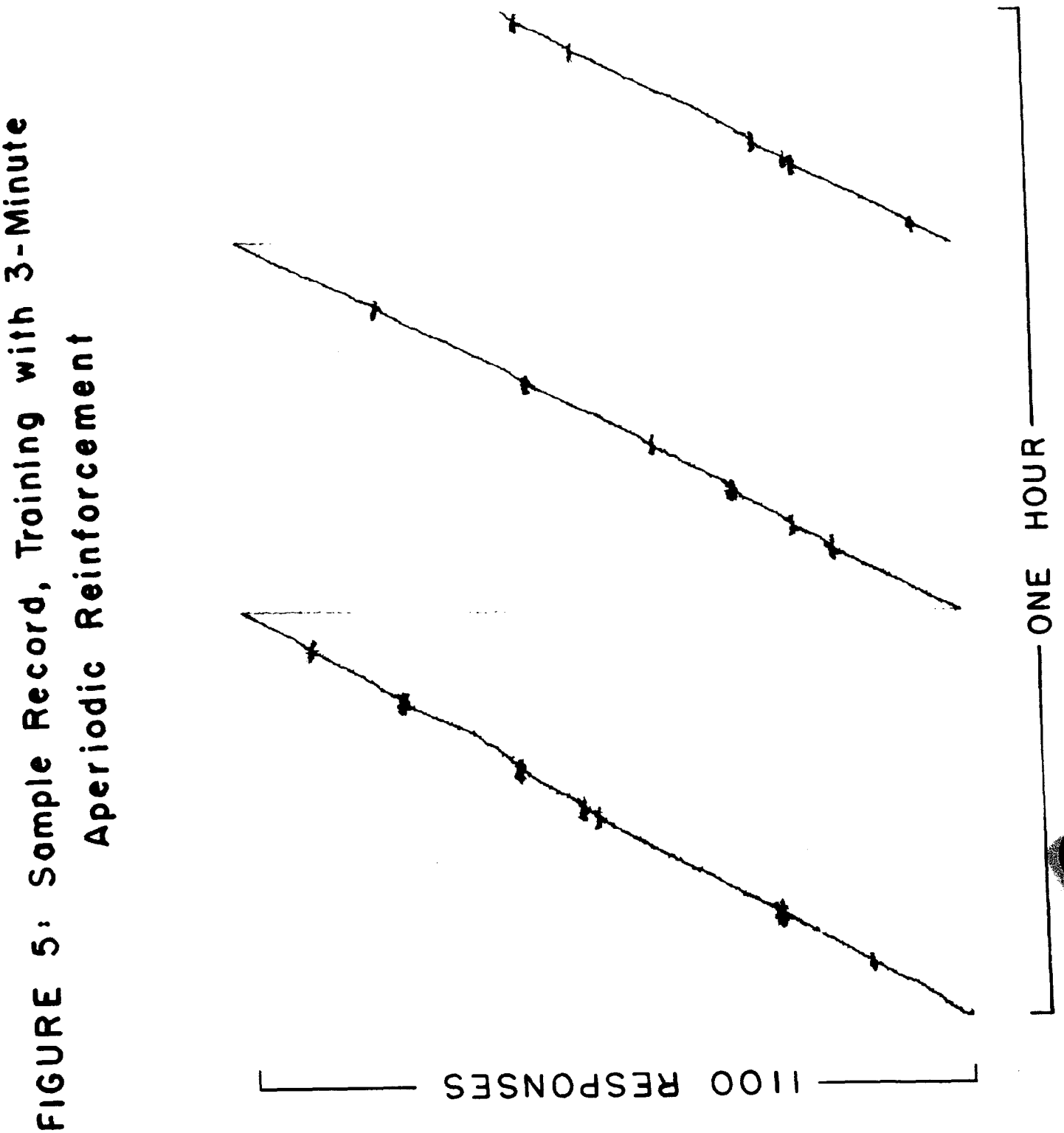


Figure 5. Sample record, one pigeon, one session of training with simple three-minute aperiodic reinforcement. The record shows responses per unit time. The marks across the line show reinforcements.

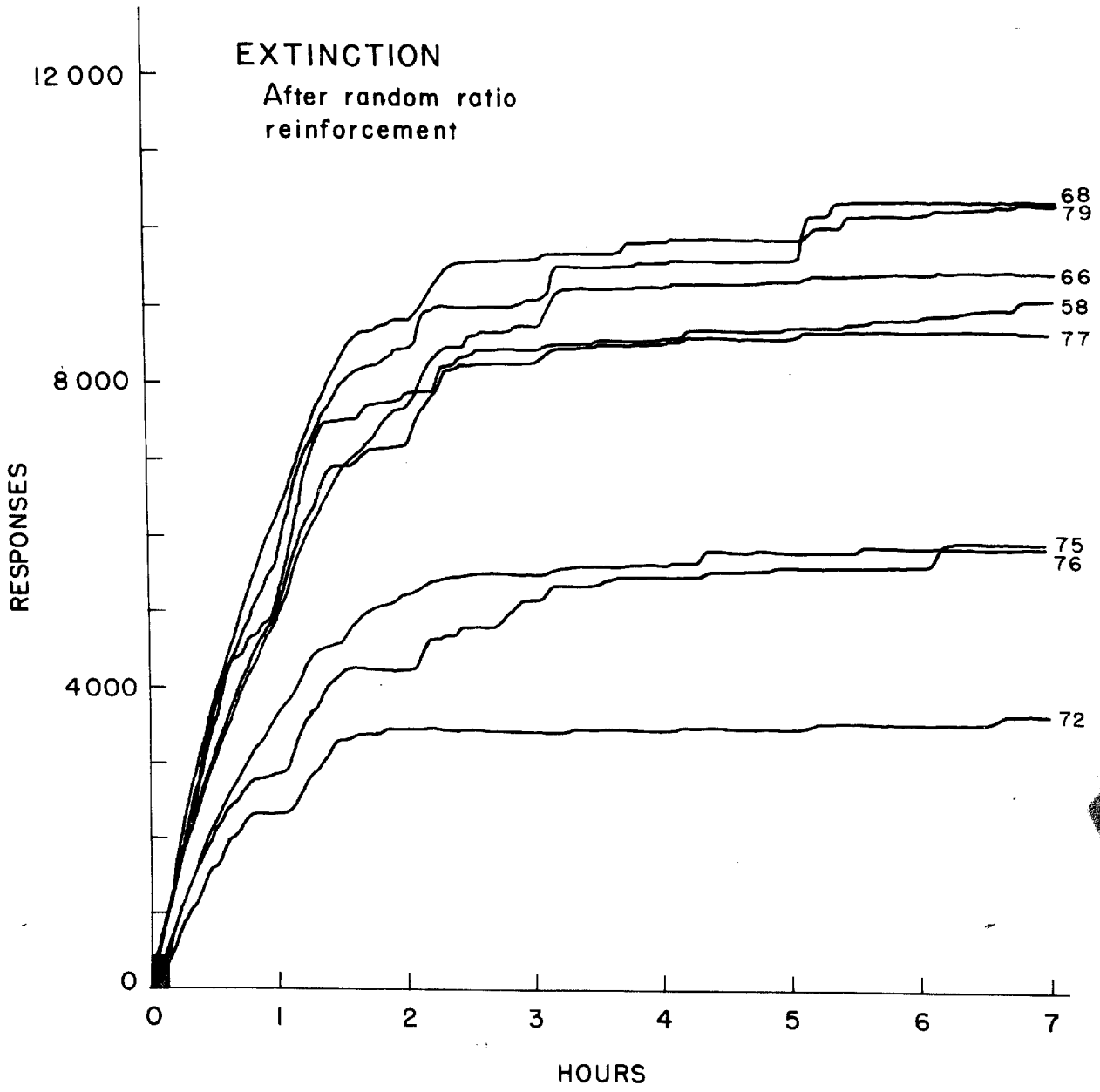


Figure 6. Extinction records of individual birds after random ratio reinforcement. The shaded area in the left corner represents a period in which reinforcements were still being given. The number of the bird is shown at the end of each record.

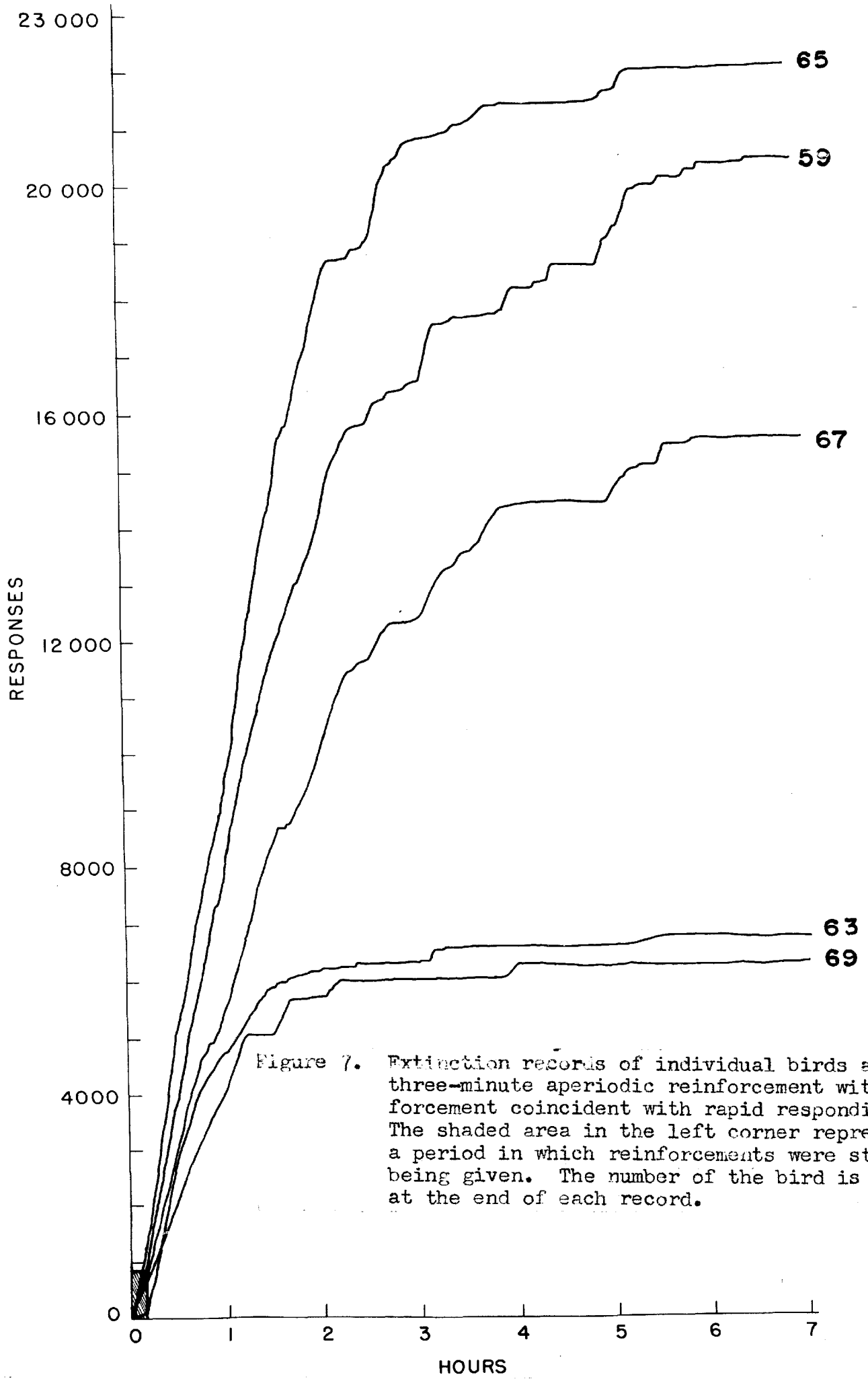


Figure 7. Extinction records of individual birds after three-minute aperiodic reinforcement with reinforcement coincident with rapid responding. The shaded area in the left corner represents a period in which reinforcements were still being given. The number of the bird is shown at the end of each record.

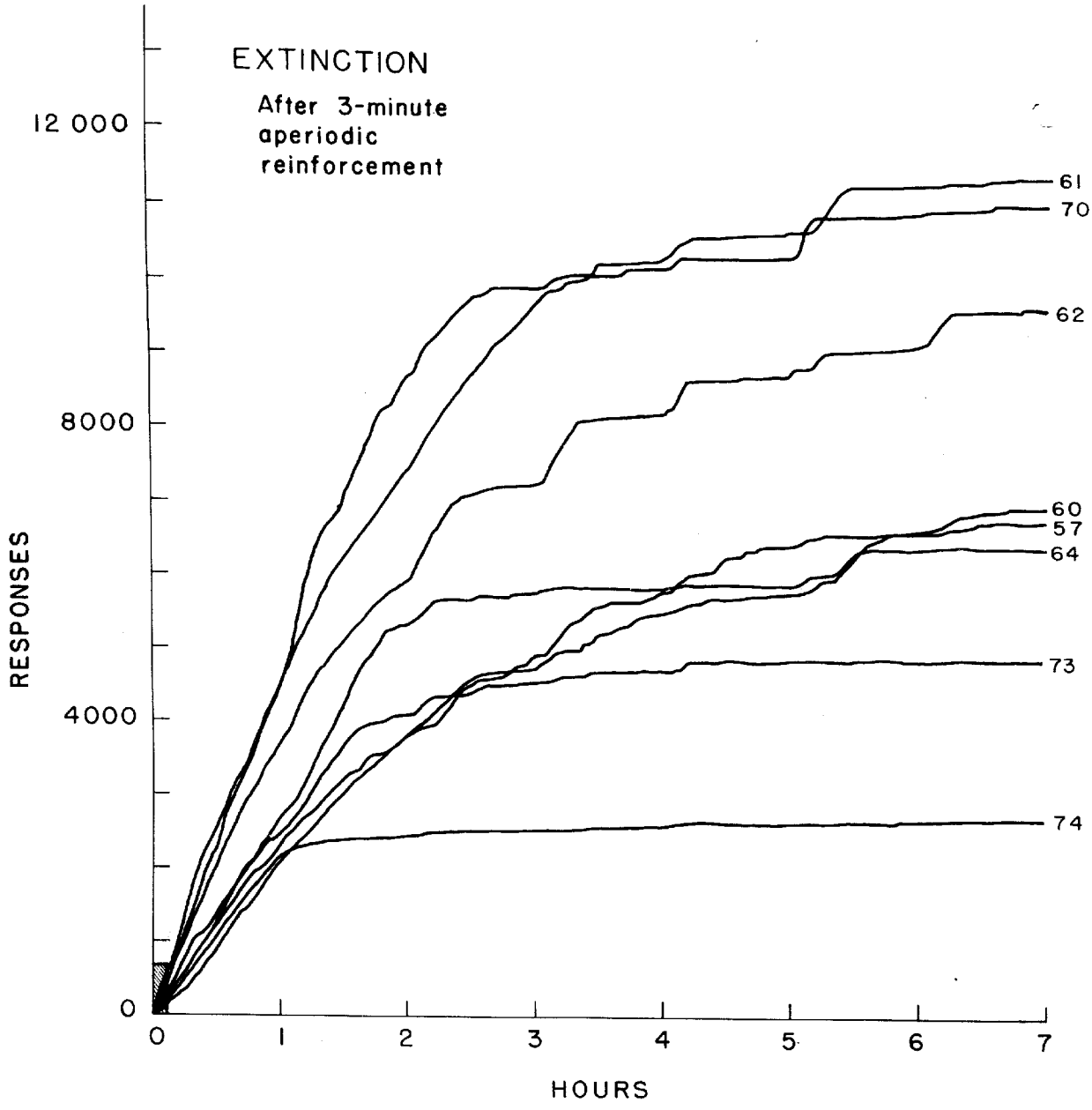


Figure 8. Extinction records of individual birds after aperiodic reinforcement. The shaded area in the left corner represents a period in which reinforcements were still being given. The number of the bird is shown at the end of each record.

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