Trans. Nat. Acad. Science & Technol. 1983.5:191-207

EXPERIMENTS ON PACING UNDER FIXED-RATIO AND VARIABLE-INTERVAL SCHEDULES OF REINFORCEMENT

Alfredo V. Lagmay
Department of Psychology, University of the Philippines
Diliman, Quezon City, Philippines

ABSTRACT

A strict version of differential reinforcement of low rates, called *pacing*, is added to a fixed-ratio schedule for the white Carneaux in a Skinner box. The experiment answers in the affirmative the question as to whether the bird can estimate the size of a ratio independently of the rate at which its pecking behavior is reinforced. The time course of its fixed-ratio behavior with pacing tends to develop longer pauses after reinforcement until the bird finally gives up responding altogether. Under a variable-interval schedule with pacing, the responding shows "breakthroughs" from pacing, signifying that the paced behavior generates an aversive condition.

Introduction

In a previous paper,[8] a technique for the control of the free operant was described. By not reinforcing high rates, nor low rates, of responding, one has an experimental condition which we may calling *pacing,* which is a very strict condition for reinforcement because, in effect, too "enthusiastic" responding as well as "sluggish" behavior will not be reinforced even if the animal is very highly motivated. It was suggested in that paper that perhaps, a pacing requirement such as was used in these experiments may generate an aversive condition in the behavior of the organism itself, so that when the pacing condition is removed, the rate of responding temporarily recovers to an "overshoot" level, a phenomenon suggestive of an "exhilarating" release from an aversive contingency imposed by an effortful task.

Since then many experiments[4, 5, 9, 14, 15] have been reported that show the effects of an effortful or aversive task on behavior. All of these researches, including those published before 1964,[1, 2, 3, 6, 7, 10, 11, 12, 13, 16] have shown the depressing or weakening of effortful or aversive contigencies on responding.

This paper reports on some experiments, which, while they were performed to resolve certain problems related to contingencies of reinforcement, are now dealt within the context of behavior under aversive conditions.

It should be noted that no investigator has so far ever reported on a pacing contingency such as the one used in these experiments, which is not a simple differential reinforcement of low rates nor of high rates.

In order to make this paper self-contained, the following descriptions as to basic experimental arrangements are taken from the previous report.

Apparatus

Although most of the features of the experimental box, the recorder, and the programming apparatus are discussed in more detail elsewhere,[6] these will be briefly described here in order to make this account complete in itself. The pacing apparatus, however, is not described anywhere else.

Experimental box. This was a standard Skinner box for pigeons of the type being used in the Harvard Psychological Laboratories for the study of operant behavior. It was made from a picnic ice-box about 11" x 13" x 20". The insulation and thickness of its double walls afforded a considerable amount of sound-proofing from outside extraneous sounds. In order to further secure adequate masking of unwanted sounds, white noise was constantly delivered inside the experimental chamber.

The box was divided into two compartments by a panel. On one side was the pigeon chamber and on the other, the food magazine. The bird pecked at a plate of translucent plexiglas, which was mounted behind a circular opening in the panel about one inch in diameter at about the level of the bird's head when it was standing normally. When the bird pecked at this plate, a pair of metal contacts were separated from each other and a corresponding electrical circuit was broken. A relay operated by this circuit was used for programming the experiment and for recording. The plexiglas key was always lighted from the magazine side of the panel. When a response was reinforced, the key light went off almost simultaneously with that response and a light over the food-magazine, which was below the key, went on. For the duration of the reinforcement, which was about 3.5 secs., food was available and the magazine light was on. After 3.5 secs., food was no longer available, and the magazine light went off; at the same time, the light through the response key was turned on again.

A light of moderately low intensity was furnished by a 6-watt bulb in the bird compartment during the experiment. At the end of the experiment, this light as well as all other lights in the box were turned off, thus leaving the bird in complete darkness.

In one corner of the box was a cup where fresh water was always available.

In order to minimize grain-hunting behavior during the experiment, the cross-wire grid floor of the pigeon chamber was raised by about 1 inch from the metal bottom of the box. Any grain that might be thrown into this compartment from the food magazine was therefore completely out of reach of the bird.

Fresh air was constantly kept in circulation inside the experimental chamber by means of a motor ventilator.

The programming apparatus and cumulative recorder. The experiments were run through a system of switching circuits which arranged for the automatic delivery of critical stimuli and which, with timers and counters, made the programming of reinforcements possible. From the time the bird was put into the box up to the end of the experiment, there was no direct contact of any form between the experimenter and the subject. Responses as well as reinforcements were recorded through a cumulative recorder, which gave continuous records throughout the experiment.

The pacing apparatus. The requirement of control of rate of responding at the moment of reinforcement, for which the experimental apparatus must provide, may be satisfied by the following conditions:

(1) Too *long* an inter-response time is not reinforced: a lower limit for rate of responding is imposed;

(2) Too *short* an inter-response time is not to be reinforced: an upper limit for rate of responding is required; and

(3) The animal must have emitted just before and at the moment of reinforcement an arbitrary *number* of successive responses at a rate the limits of which are set by (1) and (2) above.

The instrumentation of conditions (1) and (2) was achieved by means of two vacuum-tube timers each of which set the limits for inter-response times.

Condition (3) was met by making every pacing response step a counter which in turn determines the number of successive pacing responses that must be made before a reinforcement is delivered. If a non-pacing response is made before the full count is reached, the counter resets back to zero count and the bird has to start all over again.

Isolation of pacing apparatus. Since the pacing response also required that there was to be no differential external stimulus control with respect to the reinforced and non-reinforced regions of the inter-response time spectrum, it was necessary to mask all critical sounds from the timers and the counter that had to do with marking those regions off. Clicks from the timer and relays connected to it were handled by the masking noise inside the experimental chamber.The pacing counter which made an unusually loud buzz when it reset for a non-pacing response or which clicked with some intensity when a successful pacing response was made, was set up in another room some distance away from the experimental box.

Subjects

The subjects for this studies were male White Carneaux pigeons which were about one and a half years old at the start of the experiments, and, since the life span of these birds is at least 15 years, variation in behavior due to age is ruled out.

The weights of the birds were brought down to a little below 80% of their *ad lib* weights by almost completely depriving them of food for about a week. About 2 or 3 grams of grain per day were given during this deprivation period, which was sufficient to prevent digestive disturbances that usually attend complete deprivation. After this, the daily feeding schedule was merely a matter of giving them the balance of the ration that would bring their weights up to the 80% level, as described below.

The birds were tamed before the start of the experiments in order to minimize handling effects.

All birds were trained to eat from the magazine hopper of the experimental box and to peck at the key by reinforcing progressive approximations to contact of the beak with the response key.

Control of Other Factors

The birds were given a daily ration of a grain mixture consisting of about 40% vetch, 10% hemp seed, and 50% kaffir corn either in the experimental box or in their cages in the lofts. Their weight at the start of every experiment was always about 80% of the *ad lib* minus the ration for the day, part or all of which they worked for in the experimental chamber. Any unfed portion at the end of the experiment which was necessary to bring the weight up to the 80% level was given outside in the cages fifteen minutes after the bird was taken out of the box. This fifteen-minute delay for non-experimental feeding after the bird was taken out of the box was followed just to make sure that a relatively long period of non-responding in the experimental box was never correlated with the termination of the experiment and with a reinforcement immediately thereafter.

The room where the bird was located was lighted and darkened by an automatic switching timer which kept the light-dark cycle constant from day to day.

There were no provisions for the control of humidity, but the temperature, though variable, was kept within limits of indoor comfort for the people working in the laboratory. The performance of the White Carneaux, however, has been shown to be relatively insensitive to wide variations in humidity and temperature of the range obtaining at the laboratory.

Some Other General Problems

Measurements and replicates. Data were obtained through a cumulative recorder which kept continuous records of responding as a function of time for the entire experimental session. Derivative data that were of any special interest could be obtained from this cumulative graph. Whenever a figure is given with respect to a day's performance by a single subject, it will be assumed to be typically replicated otherwise, it will be accordingly qualified.

Every experiment was run with at least two subjects, with repeated measurements taken of the performance over a period of time, usually covering both transitional developmental phases and steady states. Occasionally, an experiment was repeated on the same subject at some other value of the experimental variable, provided that the process under consideration was known to be reversible.

The results of some part of an experiment were sometimes also replicated in the study of other subjects which underwent a similar history for other purposes. Consequently, some observations that are reported for any particular experiment may apply to more than two subjects.

Controls. The experiments were designed so that each subject was its own control. Before any experimental variable was introduced, baselines were usually first established by stabilizing the response of the bird over some schedules the properties of which were relatively better known. The time required to get such a baseline was arbitrarily determined by the nature of the experiment and the time course of the performance. The length of the experiment could usually not be specified in advance because the deciding criterion was the appearance of certain significant changes in the responding which could not be predicted ahead of time. Different birds took different times to stabilize or to arrive at important changes in their behavior. The choice was to allow each experiment to run its course, as against the alternative experimental design in which individual difference with respect to time might be emphasized.

Experiment A

FIXED-RATIO SCHEDULE OF REINFORCEMENT WITH SLOW PACING

Problem. A bird that is placed under a fixed-ratio schedule of reinforcement invariably shows a development course of responding which progressively increases towards faster rates until a terminal value is reached. From there on, the rate is stable at that value. Studies of pigeons placed on a mixed schedule of two fixed ratios with widely disparate values, e.g. 50 and 250, indicate that they respond *as though* they were able to estimate or count approximately 50 pecks. Records under this schedule show short runs and breaks appropriate to a ratio 250. The rates of responding, however, are identical for both schedules and are taken to be at the upper limiting value for such ratio performances.

Of the various factors that may be dealt with in the investigation of this apparent ability of the bird to approximate a specified number of ratio responses is the prevailing rate of responding at the moment of reinforcement. In the above-mentioned studies, the initial rate of the bird, when it starts the ratio run, is the same as the terminal rate. If we were interested in finding out whether or not the

rate at which the bird is reinforced is the crucial factor, or the only factor, that could possibly influence its performance in other portions of the ratio curve, then a means must be found to control for the terminal rate – to prevent the so-called ratio "end effect" from developing. This can be conveniently provided for by the slow pacing of responses at the region of the curve where a reinforcement occurs. If the bird still runs at a faster rate than the reinforced rate, then the determining factor for this run cannot be the rate at which it is reinforced.

Procedure. Two of the subjects for this experiment were shaped up to pace at limits of 1.5 and 2.0 secs for three pacing responses. Then the birds were put on a tandem schedule consisting of a 1-min. variable-interval schedule with added pacing set at the above limiting values. For all practical purposes, these two birds may be considered to have had no history of reinforcement of inter-response times beyond the above-mentioned limits. After being stabilized on this tandem schedule, they were switched to a fixed-ratio schedule with added pacing at the same limits, but with the exception that if a bird did not perform very evenly in respect to the total ratio requirement, the number of pacing responses was reduced from three to two. This reduction was made in order to control for the size of the ratio from run to run, since the requirement of two pacing responses could be met within much less variable limits in some birds than in others. Fortunately, we had to do this with only one out of the three subjects reported in this experiment.

The ratio that was used with the added pacing requirement was calculated in the following way: The number of responses for the 1-min. variable-interval schedule with added pacing was divided by the number of reinforcements occurring for the entire experimental period. The resulting figure minus the three paced responses was then set as the fixed ratio.

Another bird which had had an extensive history of variable-interval responding was added to this experiment. It underwent a shaping up process similar to that of the above birds, the only difference being that the latter were controlled for their entire experimental history at pacing limits of 1.5 and 2.0 secs.

Results. Figure 1 at (A) shows the initial responding of S-106 on a fixed ratio of 35 with added pacing. The record is read as a cumulative graph where the line resets back to the zero point of the ordinate after every reinforcement. The ratio counts are relatively constant at this time. This bird never had any history of reinforcement above or below the specified pacing limits of 1.5 and 2.0 secs.

Figure 1 at (B) shows the responding of the same bird under identical experimental conditions two months later. From a relatively slow rate of about 0.6 responses per sec. in Record A, "runs" of about 2 or 3 responses per sec. have developed just before reinforcement, as indicated in Record C. These runs are well above and beyond that for which the pacing apparatus had ever reinforced the bird. The fast runs are variable in length, but the specified ratio count is pretty well approximated by many of these runs, such as in segment *x* and elsewhere. After each run, there is a tapering off to the pacing rate at which the responding is reinforced. The results for this bird are therefore positive: high rates develop which are

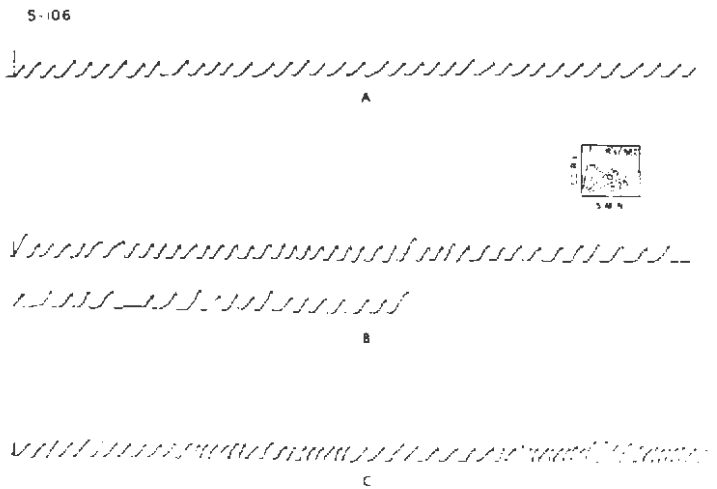

Figure 1. Showing various stages in the development of rapid "estimation runs under fixed ratio of 35 with added slow pacing for a bird without any experimental history of reinforcement at fast rates. (A) Initial fixed-ratio performance with pacing at limits 1.5" and 2.0". (B) An intermediate stage under the same condition 18 days after (A). (C) Under the same conditions 2 months after (A).

different from any that had prevailed at the moment of reinforcement during practically the entire history of the bird with respect to the response key of the experimental chamber.

Compare Records A and C in Figure 1 and note that pauses are shorter or have disappeared where the fast runs have developed. Record B is an intermediate record and was taken 18 days after A. It shows an earlier stage of the development of rapid runs.

The results for another bird, S-66, which had been previously exposed to a variable-interval schedule of reinforcement, are represented in Figure 1-X. Record A reports an entire experimental session under a fixed-ratio schedule of 40 responses with added pacing at limits 1.3 and 1.6 secs. The schedule had just been shifted from a 1-min. variable interval with added pacing. Four days afterwards, runs of approximately the size of the required ratio are already in evidence, as shown in *b* and *c* of Record B of Figure 1-X. It should be noted in this record that instead of an initial run at a fast rate followed by paced responding, the pigeon starts with a pacing rate and then bursts into a fast run at about the completion of the ratio count required by the schedule. This is shown in *a* and *d* of this same Record B (Figure 1-X). As a result, the bird's performance at this point becomes incompatible with the pacing condition. The bird executes another run approxi-

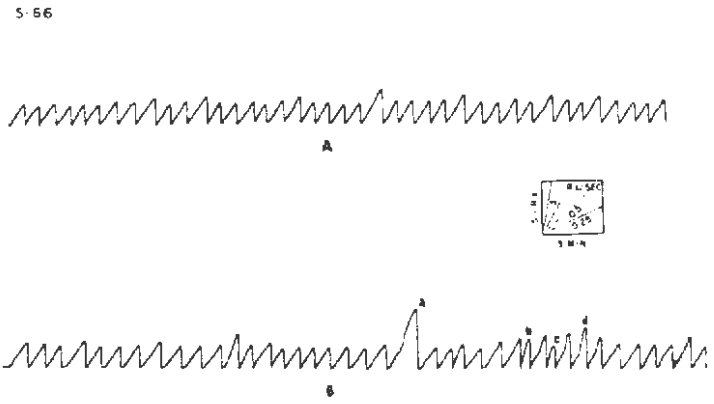

FIGURE 1-X

Figure 1-X. Showing the development of fixed-ratio "estimation" runs under moderately slow pacing conditions for a bird with an extensive history of variable-interval reinforcement. (A) Initial responding at fixed-ratio schedule of 40 with pacing at limits 1.3" and 1.6". (B) 4 days after (A). Note: how the ratio is 'measured" either by a rapid run, *b* and *c*, or in terms of pacing run, *a* and *d*.

mately equal in magnitude to the required ratio value before it settles down to a pacing rate for which it gets reinforced. The absence of pauses after reinforcement in Figure 1-X at A should be noted. It is characteristic of birds that have had a prolonged history of variable-interval responding that this pause should be absent when the pacing condition which is introduced is at moderately slow rate limits.

S-105 was an exact duplicate of S-106 as to history and control conditions. Records of a typical performance are shown in Figure 2: Record A indicates a relatively even responding at about 0.6 response per sec. under a fixed ratio of 47 with added pacing. The bird had just been shifted from a 1-min. variable-interval schedule with added pacing. Then in succeeding experimental sessions, progressively longer pauses after reinforcement developed. Part of the record for the 12th day after that of Record A is shown in Figure 2 in B record. *Two days after this the bird simply ceased to respond to the key:* a very important finding!

The foregoing procedure was repeated for a fixed ratio value of 35 with added pacing and the results were similar: on the 17th day *the bird was reinforced only 8 times within a period of 5 hours.*

The procedure was again repeated at a much lower ratio of 20 with added pacing. As indicated in Figure 2 in record C, the bird was able to sustain its responding. This is a typical record of the sessions on the 7th day and thereafter.

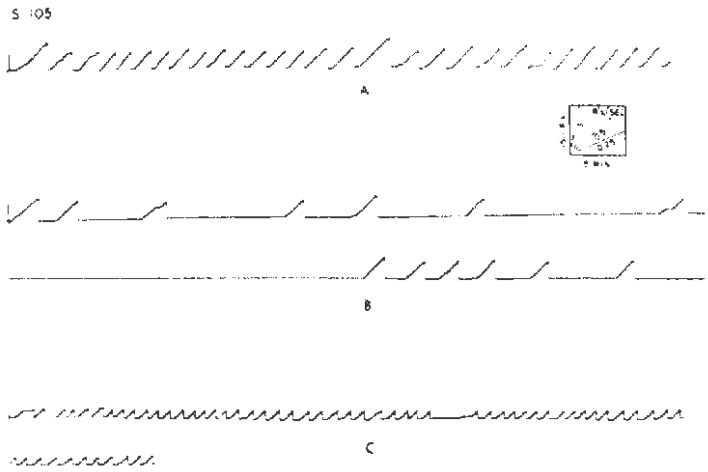

FIGURE 2

Figure 2. The development of very long pauses under a fixed-ratio schedule with slow pacing in a bird without any experimental history of reinforcement for rapid responding.
(A) Initial responding at fixed ratio of 47 with pacing at limits 1.5 ' and 2.0"
(B) 12 days afterwards under the same conditions. In 2 days more after this record, the bird ceased to respond completely.
(C) Recovery at fixed ratio of 20. Typical performance for 7th day and afterwards.

Discussion. Pacing at slow rates was used as a method for assessing the role of what is happening at the time of reinforcement in relation to rapid runs in ratio responding. This method required a controlled history of reinforcement at a specified pacing rate before exposure to a ratio schedule with added pacing. Whatever may be the factors that account for the rapid runs which develop in ratio performance, this experiment demonstrates that they do not, or need not, include the rate at which the bird is reinforced. As indicated in *a* and *d*, Figure 1-X at B, however, progress towards the fixed-ratio value is itself reinforcing.

As will be seen in Experiment B, rapid runs may also occur on a variable-interval schedule with pacing whether or not a bird has had a history of reinforcement at rapid rates. Figure 5 and Figure 6 at C illustrate these rapid rates under pacing. The size of these fast runs are highly variable and may occur after a short pause or after a pacing run. The fast runs in the curves under fixed ratio, however, are distinctly of about the ratio count. The bird "estimates" the ratio under pacing and the variability of the estimate may be of responses occurring at a pacing rate rather than in rapid runs.

Since pacing behavior involves a rather well-defined topography of mediating response, a given number of pacing responses means a well-defined amount of such behavior. As mentioned earlier, the behavior we are speaking of may be regarded as a chain the only reinforced portion of which is the peck at the key. A given pacing

response which gets recorded represents a much greater amount of behavior under pacing than under fixed-ratio reinforcement without pacing. This chain, therefore, is such as to make the ratio a strenuous requirement, possibly equivalent to a large ratio without pacing. The relatively longer pauses at the end of the ratio curves in this experiment are consistent with this view. However, the restraining factor of pacing at the moment of reinforcement may even be the most formidable element responsible for these longer pauses, since it prevents the organism from entering into a natural gradient in strengthened behavior at the moment of reinforcement, i.e. heightened rates of responding. There would in effect be two sources of the indisposition to respond after completing the ratio: an augmented effortfulness in the performance of what amounts to large ratio requirement and the aversiveness of the task in being prevented from performing at high rates at the moment of reinforcement.

The preceding paragraph applies with special force to the subjects of this experiment that had never been reinforced at rapid rates. One of these birds eventually ceased to respond at a fixed ratio of 47 with added pacing, though the topography of the pacing response was intact up to the last reinforced run.

Experiment B

VARIABLE-INTERVAL SCHEDULE OF REINFORCEMENT WITH PACING

Problem. The variable-interval schedule, with or without the added pacing condition, was used in the previous experiments as a baseline against which the effects of another variable may be assessed. Variable-interval responding could, however, be treated separately in its own right. The object of the following experiments was to investigate some of the properties of variable-interval performance under pacing conditions at slow rates.

Procedure. A direct comparison of variable-interval curves, with and without pacing, where the performance under both conditions develop approximately concurrently, was made by using multiple-schedule techniques. Each of the two schedules was placed under stimulus control: when the bird was on a variable-interval without pacing, the response key was illuminated white; when it was on a variable-interval schedule with pacing, the key was red. One-half of the experimental hour was under one schedule and the second half, under the other. In order to avoid any possible sequence bias in the allocation of the halves of the experimental session, the first half of the hour was assigned to a particular schedule in alternate sessions. In the intervening session it was assigned to the other schedule.

It was necessary to equate the number of reinforcements on the two schedules. This is especially important in a multiple schedule where the *change* from

one condition to the other may give an important difference simply because the density of reinforcements had changed. When there is not such a relatively rapid shift from one schedule to another as in the single-schedule technique which was used in the previous experiments, this question may not be of any significance.

Observations of the prior performance of the birds indicated that by using a 2-min. variable-interval schedule without the pacing condition for comparison against a 1-min. variable-interval schedule with pacing, we could achieve approximately the same number of reinforcements per unit time. We therefore simply ran the motor for the 1-min. variable-interval half as fast as usual in order to get a 2-min. variable-interval schedule. This procedure had the added advantage that no reinforcements in the 2-min. variable-interval schedule without pacing would come closer together than twice the shortest interval on the 1-min. variable-interval schedule. This made some provision, therefore, for the comparison and interpretation of pauses after reinforcement, because in the pacing condition no reinforcement could possibly occur unless the bird had made at least four responses, which necessarily required time.

Preceding this experiment, two birds had undergone an extensive history of variable-interval responding, under pacing conditions and without pacing. The performance of these two birds on the multiple schedule were observed for 18 hours and 11 hours respectively, until a clear-cut difference between the two schedules could be seen. Then the pacing condition was removed and the birds were allowed to run under a 2-min. variable-interval schedule for both red and white keys.

In a second part of the experiment, no use was made of a 2-min. variable-interval schedule in order to equate for number of reinforcements. The subjects were two birds reported in earlier experiments and three others that were used for some other experiments. In these cases, the birds were simply put on a 1-min. variable-interval schedule, allowed to stabilize, then put on a 1-min. variable interval with added pacing, and allowed to stabilize again.

Results. Record A in Figure 3 shows a typical record for one of the subjects after 18 hours of exposure to the multiple schedule described above. The first half of this graph shows responding under a 1-min. variable-interval schedule with pacing, the schedule being under control of a red response key. The bird ran at approximately 0.4 response per second with relatively long pauses after reinforcement. The second half of this record is for a 2-min. variable-interval under the control of a white key. A rapid rate of about 2.0 responses per second, which is appropriate to the straight variable-interval schedule, comes out as soon as the color of the key is changed to white. The rate then subsides to a lower rate of about 1.3 responses per second with occasional short runs at approximately the pacing rate, as at p and q. The pauses after reinforcement in this half of the record have almost disappeared or, at least, are much shorter than in the earlier pacing condition. Figure 3 at B shows the loss of stimulus control with respect to the colors of the key eight hours after the pacing condition was removed. The loss was progressive over this interval of time.

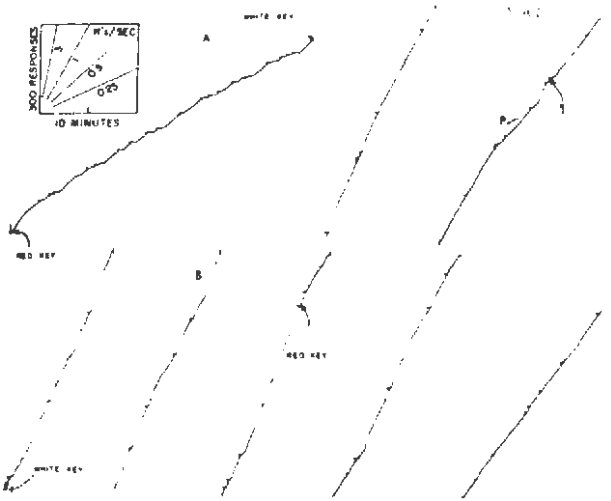

FIGURE 3

Figure 3. (A) Comparison curves for the 18th hour of a multiple schedule where the two parts of the schedule are under stimulus control: *red key* – 1-min. variable interval with pacing (limits at 2.0" and 2.5"); *white key* – 2-min. variable interval only. (B) Showing loss of stimulus control with respect to the key-colors in the multiple schedule on the 8th hour after the bird was put on a straight variable-interval schedule on both red and white.

The other bird's performance is indicated in Figure 4. Record A was taken 11 hours after the multiple schedule was started, and Record B was made 5 hours after the pacing was removed. All observations pertinent to the previous subject with respect to pauses after reinforcement, rate differences, and the occasional appearance of pacing rates under the non-pacing stimulus may also be made here. Note the runs at the pacing rate in the variable-interval schedule, as in *m* in Figure 4, Record A. and *n* in Figure 4, Record B. Before the state of the multiple-schedule in Figures 3 and 4, Record A, is reached, however, there is a relatively brief and occasional appearance of fast runs immediately after a reinforcement while under the pacing condition. This is indicated in Figure 5 in A. After these fast runs, the bird paces at a rate of about 0.5 response per second, which is somewhat higher than that at the stage where the longer pauses have made their appearance – about 0.4 response per second. A somewhat weaker version of this same phenomenon is seen in the curve for the other bird, as shown in Figure 5 in A. After a relatively short pause of about 1 or 2 seconds, there is a brief run of about 5 to 8 responses at a fast rate, after which the bird settles down to a pacing rate. This pacing rate is about 0.5 response per second and is again higher than that in Figure 3, record A, where, after a long pause, the rate is of the order of 0.4 response per second. It is left an open question at this point whether, where the pauses are short under

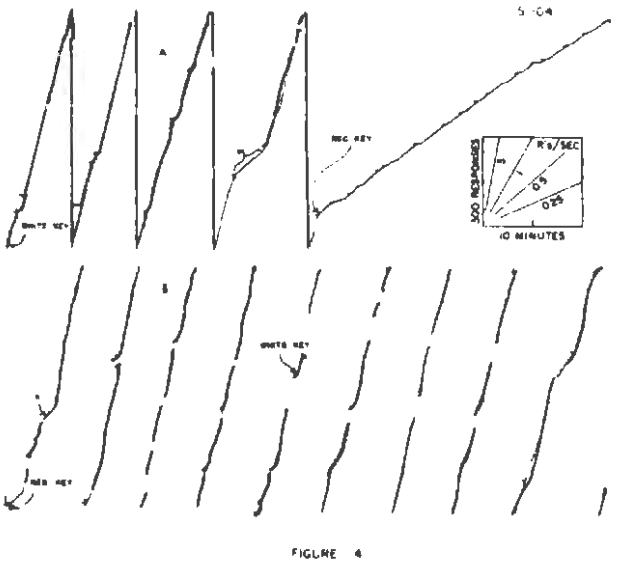

FIGURE 4

Figure 4. A set of curves for another bird, S-104, under the same experimental treatment as that of S-102 in Figure 3.

the pacing condition, the runs are inductive effects from the variable-interval part of the multiple schedule.

We may now examine the results of the single-schedule technique, where the birds were allowed to stabilize on a 1-min. variable-interval schedule with added pacing. Five subjects used earlier in this study were subjected to this procedure for some purpose or other and all gave uniform results at stable states. A typical curve is shown in Figure 6, Record B. The responding is even, the pauses after reinforcement are quite marked, and the rate is the reinforced pacing rate. S-102 and S-104, which had been exposed previously to variable-interval contingencies, where there was opportunity to develop high rates of responding, show fast runs immediately after reinforcement under an added pacing condition. Figure 6, Record A, and 6, Record C show examples of this kind of run about 5 days after the birds were first subjected to the variable-interval reinforcement schedule with added pacing.

These fast runs under a pacing condition are not confined to occasions where a short pause follows a reinforcement. They may occur while the bird has begun slow pacing – "breaking through" the paced responding, as it were. This is shown in *a* and *b* of Figure 6, Record D, for two different birds. Curiously enough S-149 for the curve in Figure 6, Record D, had never had any history of reinforcement at high rates prior to this "breaking through".

Discussion. Pauses after reinforcement under a variable-interval schedule with added pacing are markedly longer than those of the control situation where the

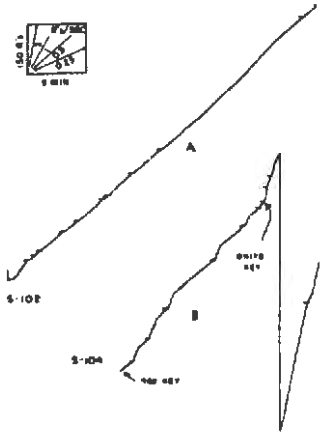

FIGURE 5

Figure 5. Showing rapid runs after a short pause following reinforcement before going down to a pacing rate, for birds under multiple-schedule procedure. (A) shows this effect only occasionally and in weak form. The stronger version is in (B) for that part of the curve on the red key.

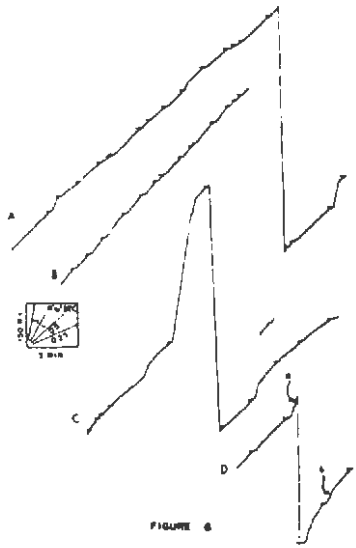

FIGURE 6

Figure 6. Variable-interval curves under slow pacing conditions obtained from different birds with the single-schedule technique. (A) and (C) show rapid runs after a short pause following reinforcement for S-102 and S-104, respectively. (B) shows a stable performance curve under 1-min. varible-interval schedule with slow pacing. Note the longer pauses. (S-149. (D) shows an example of "breaking through" at a fast rate from a pacing run (S-149).

pacing is absent. Steps were taken to rule out the possibility that such a difference might depend on the number of responses that have to be emitted before reinforcement. If, by making only one or two responses since the last reinforcement, another reinforcement occurs, as in the usual variable-interval schedule, then the bird is necessarily in a different situation in terms of this number from that in the pacing condition where the bird has to emit at least four responses before reinforcement. Since the only difference in the two parts of the multiple schedule was the pacing condition, the longer pauses in the variable interval with pacing must be due solely to this difference. The possibility of color preference is excluded by the fact that the birds on a straight variable-interval schedule alternately on red and white keys gave the same rates of responding on both colors, with identical characteristics of the curves immediately after reinforcement.

The above findings have its analogues in the preceding experiments on a fixed-ratio schedule with pacing, where the pauses are very much longer than those which hold for an equivalent straight ratio performance. The result also recalls the case of paced fixed-ratio responding at a ratio value of 47, where the bird progressively developed longer and longer breaks until it ceased to respond. These converging lines of evidence point to the possible aversive character of slow paced-behavior. Since there were no aversive stimuli in the external environment of the subject under the pacing condition, the aversive stimulus must have been the organism's own behavior.

The fact that a bird which has had no history of reinforcement at fast rates still shows rapid runs, i.e. "breaking through" the pacing, may similarly indicate that running at a preferred rate removes the organism from an aversive condition. These fast runs under a variable-interval schedule with slow pacing could not have been due to what had happened just before and at the moment of reinforcement because the rate at the moment of reinforcement was controlled at slow rates. Neither could it have been the immediate effect of a reinforcement since the run come only either after a short pause or after pacing had been started. Another possibility, of course, might lie in the pre-experimental history of the organism. But even if this were true, the argument is not in any way diminished under the circumstances.

It is significant that the presence of fast runs in fixed ratio with pacing is correlated with relatively shorter pauses or absence of pausing. In the variable-interval with pacing, fast runs are also accompanied by shorter pauses after reinforcement. Where there are no rapid runs the pauses are longer.

Summary and Conclusions

(1) The slow pacing technique applied to the study of fixed-ratio schedules shows that rapid rates may occur in fixed-ratio responding although the bird has never had any experimental history of reinforcement at such high rates. It is in-

ferred that progress towards the fixed ratio value may be reinforcing and leads to such rapid rates as are not accounted for in terms of the usual ratio "end effect".

Furthermore, a relatively accurate estimation of the value of the ratio is found to be possible either in executing a slow pacing run or a rapid run. This "estimation" behavior of the pigeon in fixed-ratio responding, therefore, does not depend upon the rate at which it is running.

(2) The performance under a variable-interval schedule with slow pacing shows: (a) Relatively longer pauses after reinforcement than a control performance with no pacing. It was shown that these longer pauses were not due to the absence of a quick reinforcement since the last reinforced response. They are, it is suggested, due to the possible aversive character of slow-pacing behavior. (b) "Breaking through" at a rapid rate after a pacing run or, at some brief transitional stage, a rapid run after short pause, which are not explained in terms of progress towards a count as in the case of the fixed ratio with pacing.

(3) In both variable-interval and fixed-ratio schedules with pacing, fast runs are correlated with shorter pauses after reinforcement or with the absence of pauses. When there are no rapid runs after reinforcement, the pauses are relatively longer. Again, the possibility that pacing behavior has aversive properties may explain this. This also confirms (2) above.

A BRIEF RETROSPECTIVE ON A FEATURE OF THE EXPERIMENTAL RESULTS

The foregoing experiments, while difficult of execution and instrumentation, were rather simple and straightforward in design and in answering some questions in the laboratory investigation of contingencies of reinforcement, with special reference to what is happening to the organism at the moment of reinforcement. The experiments tried to tease out the concept of "ratio end effect" and to throw some light on the capacity of the organism to estimate counts without actually counting, as part of the general problem of the organism effort at all times to maximize the results of its behavior.

However, there were results that were quite unexpected during the experiments, which were not really part of the original project. The most fundamental of these was that a slow-pacing contingency, as here defined, had repeatedly demonstrated its aversive character: when an animal is prevented running at optimum rates under the very strict conditions of pacing, even if the task be as simple as executing a ratio of less than 50 responses, the organism will develop a strong indisposition to respond. Almost like a profound extinction process seem to be set in motion, or that some aversive condition is generated in behavior of the animal itself such that the organism would rather starve than engage in paced behavior.

There are suitable analogues to this type of situation in human behavior, such

as that of an aspiring writer who has all the elementary skills for turning out a good paper but who is kept from achieving a satisfactory output because of a self-imposed criteria of excellence that makes his task extremely difficult.

There are all manner of procedures for suppressing, depressing or, in general, weakening any given behavior such as electric shock, verbal punishment, making tasks more physically effortful, and so forth, but a method that merely requires a much higher degree of precision in responding could be just as effective in knocking out the behavior. A pacing requirement is something of this method, with the added feature that a reinforcement is automatically more and more delayed if the individual manifests any behavior that denotes enthusiasm. The gradually lengthening pauses after such small ratios with the pacing requirement reminds us of profound extinction effects that go with extremely large ratios that are required for reinforcement.

References

1. Applesweig, M. H. 1950. *The role of effort in learning and extinction.* Ann Arbor, Michigan: University Microfilms. Pub. No. 1501.
2. _____. 1951. Response potential as a function of effort. *J. Comparative and Physiological Psychol.*, 44: 225-235.
3. Azrin, N. H. 1960. Effects of punishment intensity during variable-interval reinforcement. *Journal of the Experimental Analysis of Behavior.* 3; 123-142.
4. Chung, S. H. 1965. Effects of effort on response rate. *J. of the Experimental Analysis of behavior.* 8: 1-7.
5. Elsmore, T. F. and Brownstein, A. J. 1965. Effort and response rate. *Psychonomic Science.* 10: 313-314.
6. Ferster, C. B. and Skinner, B. F. 1957. *Schedules of Reinforcement.* New York: Appleton-Century-Crofts.
7. Holland, J. G. 1958. Human vigilance. *Science.* 128: 61-67.
8. Lagmay, A. V. 1964. The pacing of behavior: a technique for the control of the free operant. *Natural and Applied Science Bulletin.* XVIII, 3-4: 233-248.
9. Miller, L. K. 1968. Escape from an effortful situation. *J. of the Experimental Analysis of Behavior.* 11: 619-627.
10. Mowrer, O. H. and Jones, H. 1943. Extinction and behavior variability as a function of effortfulness of task. *J. of Experimental Psychology.* 33: 369-386.
11. Skinner, B. F. 1938. *The Behavior of Organisms: an Experimental Analysis.* New York: Appleton-Century Crofts.
12. Solomon, R. L. 1948. The influence of work on behavior. *Psychological Bulletin.* 45: 1-40.
13. _____, _____. 1948. Effort and extinction rate: a confirmation. *J. of Comparative and Physiological Psychology.* 41: 93-101.
14. Weiner, H. 1964. Response cost and fixed-ratio performance. *J. of the Experimental Analysis of Behavior.* 7: 79-81.
15. _____. 1964. Response cost during extinction following fixed-interval reinforcement in humans. *J. of the Experimental Analysis of Behavior.* 7: 333-335.
16. Weiss, R. R. 1961. Response speed, amplitude, and resistance to extinction as joint functions of work and length of behavior chain. *J. of Experimental Psychology.* 61: 245-256.

F.G. David, Discussant

On the whole, the empirical finding in the two experiments, reported by Dr. Lagmay, included the following: A) Added to a stable, fixed ratio (FR) or reinforcement, wherein the ratio was about 35 responses per one instance of reinforcement, a pacing schedule of 1.5-2.0 responses per second induced (a) the disappearance of the ratio "end-effect", which is characterized by a rapid increase in the rate of responding just immediately before reinforcement, (b) the decrease or disappearance of the characteristic pauses just immediately after reinforcement, and (c) induced the appearance of "fast runs" or rapid rate of responding, especially at intervals where pauses would have occurred or immediately after the periods of pacing. B) Added to a high ratio of FR-47, the pacing schedule induced the disappearance of responding altogether. (Responding was restored only when the ratio was reduced to FR-20.) And C) In a tandem of two concurrent variable interval schedules of reinforcement (VI), for which the average interval per instance of reinforcement was 1.0 minute for one schedule, and 2.0 minutes for the other schedule, and in which each of the schedules was under a distinct stimulus control – red response-key for the VI-1.0 minute and white for the VI-2.0 minutes –, the pacing added to the VI-1.0 minute induced the appearance of pauses immediately after reinforcement and the over-all decrease in the response rate. Complementarily, under the VI-2.0 minutes, to which pacing was not added, there appeared a compensatory appearance to "fast runs" of responding and an over-all increase in response rate.

In consideration of the empirical finding, Dr. Lagmay raised the thought and explication that A) the addition of a pacing schedule provided a test, which showed, more obviously, that the experimental animals, or pigeons in the study, could "estimate" or "count" ratios or the passage of time; and B) the addition of the pacing schedule increased the work-demand on the animals, so much that the response-characteristic, that was required, was by itself aversive. One particular basis for this explication was the cessation of responding of the bird which was put under a demanding schedule of a high FR-47, which was coupled with a pacing schedule.

While the two experiments in the study only dealt with a small sample of five pigeons, the empirical finding appeared to be firm enough. Despite all this, one can raise certain obvious weakness of an "own-control" experimental design, especially pertaining only to a very limited sample. An "own-control" design can not account for the variance due to individual differences; more so, if the experimental subjects are not looked at as a block and nuisance factor. This objection is not a mere matter of one's being bothered about a lack of experimental-design or statistical elegance. It is pretty substantive, particularly in respect to contemporary pieces of evidence, obtained even in fairly radical "Skinnerian" laboratories, predisposed to hold a mechanistic, reductionistic view of reality, physical or behavioral and biological, that individual difference is significant even among common, experimental

animals. In this light, the singular case of the pigeon subject to the FR-47 plus a pacing schedule, the case for the explication of effortfulness or aversiveness, might just be unique to the bird in question. Of course, this objection is a matter of empirical debate, and it can be dealt with, without difficulty, by means of a replication of the case with many more pigeons, under similar regiment of experimental conditions.

And concerning the facts of "fast runs", which appeared to be tied up to the compensatory release from the pauses and pacing effects, one wonders whether or not these kinds of effects can be obtained with any type of responses. May it be that this so-called pacing effects are unique to the response of pecking in the bird? May it be that the whole matter is a case for so-called species-specific behavior? May it be that pecking follows a "tempo", such as that attributed to the effects of the related studies of Gilbert. Works by Robert Bolles and by Gilbert on species-specific responses and on "tempo" in pigeons' pecking are crucial for consideration, therefore, of the case for the effects of pacing.

Finally, one must note, especially in connection with the second experiment by Dr. Lagmay, that response-rate under a tandem of two or more concurrent schedules of variable interval has been shown quantitatively to be proportional to the rate of reinforcement. Herrnstein, a contemporary of Dr. Lagmay at the Harvard Laboratory, has worked on an elegant and well-confirmed quantitative analysis of the law of effects. The said law is expressed in a non-formidable equation. The point, in connection with the paper now under discussion anyhow, is that the effects, obtained in the experiments, need not be looked at as an admirable case for the ability of pigeons to "estimate" schedules, as they may be mere mechanical matching of probabilities. For, indeed, if the pigeons can "estimate" response requirements relative to reinforcement rate, why do they have to emit many responses at a steady rate, under the VI schedule, when all that is required is either a single response at the lapse of the average interval or a few responses in accordance with the pacing limitation? Maybe the principle of parsimony must be invoked here, that the more complex explication of "estimation" is unnecessary, inasmuch as the matter can be accounted for in terms of a simpler concept of matching probabilities, as well as of "tempo."