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EFFECTS OF INCREMENT SIZE AND REINFORCER VOLUME ON PROGRESSIVE RATIO PERFORMANCE[1]

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The progressive ratio schedule requires the subject to emit an increasing number of responses for each successive reinforcement. Eventually, the response requirement becomes so large that the subject fails to respond for a period of 15 min and thereby terminates the session. This point is arbitrarily defined as the "breaking point" of the subject's performance. The measure is quantified in terms of the number of responses in the final completed (*i.e.*, reinforced) ratio run of the session. Previous work has shown that this measure varies as a function of several motivational variables and may thus be useful as an index of reinforcement strength. The present study is an extension of that work. The subjects were four rats. In the first experiment, the effects of the size of the increment by which each ratio run increased were studied. In two additional experiments, the volume of a liquid reinforcer was varied using both large and small ratio increments. The results indicate that the number of responses in the final completed ratio run increases as a function of the size of the ratio increment. However, the number of reinforcements obtained by the animals per session declines sharply. When large ratio increments are used, the number of responses in the final ratio increases as a function of the volume of the reinforcer, but when small increments are used, progressive satiation results in a decline in performance with the larger volumes of liquid.

In order to make precise comparisons between behaviors maintained by different reinforcers, an experimenter must be able to make some statement as to the relative strength of each reinforcer. This problem becomes particularly acute when one attempts to compare food-reinforced behavior with behavior reinforced by such events as electrical or chemical stimulation of the brain. A common technique for assessing the relative strengths of reinforcers has been to compare rates of responding (Guttman, 1954; Conrad and Sidman, 1956; Stebbins, 1959). However, in some instances, particularly in the case of behavior maintained by brain stimulation, responses per minute may be a very misleading index of reinforcement strength (Hodos and Valenstein, 1962).

Recently, the progressive ratio technique has been suggested (Hodos, 1961) as a means of evaluating the relative strength of a reinforcing event without reference to rate of responding. The technique is based on the rationale that the breaking point of an animal's behavior should be a good means of measuring reinforcement strength. An organism reinforced on a progressive ratio basis is required to emit a systematically increasing number of responses for each successive reinforcement; *i.e.*, the number of responses in each successive ratio run increases with a fixed increment. Thus, if the increment were five, the organism would be required to emit five responses for the first reinforcement, 10 for the second, 15 for the third, 20 for the fourth, *etc.* The criterion for the breaking point is reached when the organism fails to respond for a period of 15 min, at which time the session is terminated. The index of reinforcement strength is the number of responses in the final completed (*i.e.*, reinforced) ratio run.

Using this index, orderly relationships have been obtained (Hodos, 1961) between the breaking point of behavior and such variables as the concentration of a liquid reinforcer and the degree of food deprivation. The purpose of the present investigation is two-fold: (1) to study the effects of variation in the size of the ratio increment on progressive ratio performance, and, (2) to extend the earlier findings by determining whether the breaking

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point will vary systematically with changes in the volume of a liquid reinforcer.

METHOD

Subjects

Four adult, albino rats, three males (RS-70, RS-71 and RS-83) and one female (RS-80) from the colony of the Walter Reed Army Institute of Research were used. Two animals were subjects in each experiment. Prior to the start of the present series of experiments, each rat had been a subject in a previous progressive ratio experiment. During these experiments, the principles of laboratory animal care as promulgated by the National Society for Medical Research were observed.

Apparatus and Preliminary Training

The experimental space consisted of a metal compartment, 25 by 26 by 21 cm which was contained within an outer shell of sound-retarding material. Responses were made on a telegraph key lever which required an excursion of 2 mm and a force of 25 g to close the contact. Liquid reinforcement was delivered by a motor-operated dipper with interchangeable cups ranging in size from .025 ml to .40 ml. The operation of the dipper was programmed so that the cup would remain in the "up" position for 2.5 sec when the smaller dippers were used, 4 sec with the intermediate sizes and 7 sec with the largest. This allowed the rats sufficient time to consume the entire quantity of liquid. The reinforcer was sweetened condensed milk concentrate mixed with an equal volume of tap water. The progressive ratio schedule was programmed by a system of relay operated switching circuits and timers. Data were recorded on electromagnetic counters and cumulative recorders.

Each rat was trained to press the lever to receive .05 ml of milk. Following this initial training the rats were placed on the progressive ratio schedule. When the behavior showed no significant change for several successive sessions, collection of data was begun. Three experiments were carried out.

EXPERIMENT I

Procedure

The first experiment explored the effects of successive increases in the size of the ratio increment on the number of responses in the final completed ratio run. This function was obtained under conditions of free feeding in the home cage and also while the animals were at 80% of normal body weight. The ratio increments used were 2, 5, 10, 20, and 40, varied in ascending order. The volume of reinforcement was .05 ml. Six determinations were made at each increment, one per day, during free feeding on lab chow in the home cage. The procedure was repeated after the rats had been reduced to 80% of normal body weight. The schedule was then changed to the next higher increment.

Results and Discussion

Figure 1-A shows representative cumulative records for rat RS-70 at each of the ratio increments—2, 5, 10, 20, and 40—obtained under conditions of free feeding on lab chow in the home cage. The records in Fig. 1-B were obtained when the animal had been reduced to 80% of its free-feeding weight. In the first record of both Fig. 1-A and 1-B, each successive ratio run increased with an increment of two responses (PrR2). In the records labelled PrR5, each successive ratio run increased with an increment of five responses, *etc.*

In general, the number of responses in the final completed (*i.e.*, reinforced) ratio run increases as the size of the ratio increment increases. This is the case both under conditions of free feeding and under restricted food intake, although there are many more responses in the final completed ratio run during deprivation. Occasional bursts of responding are often observed after the final reinforcement of the session. While each response does postpone the termination of the session by 15 min these responses are not included in the analysis since the animal failed to satisfy the requirements of that particular ratio run. Moreover, while the number of responses in the final completed ratio run varies reliably with the size of the ratio increment, there is no systematic relationship between the total number of responses and increment size.

Another characteristic of progressive ratio performance is the appearance of frequent pauses during the ratio run at the higher ratios. These pauses result in the records of the larger ratio runs assuming a scalloped appearance. The extent of the curvature in-

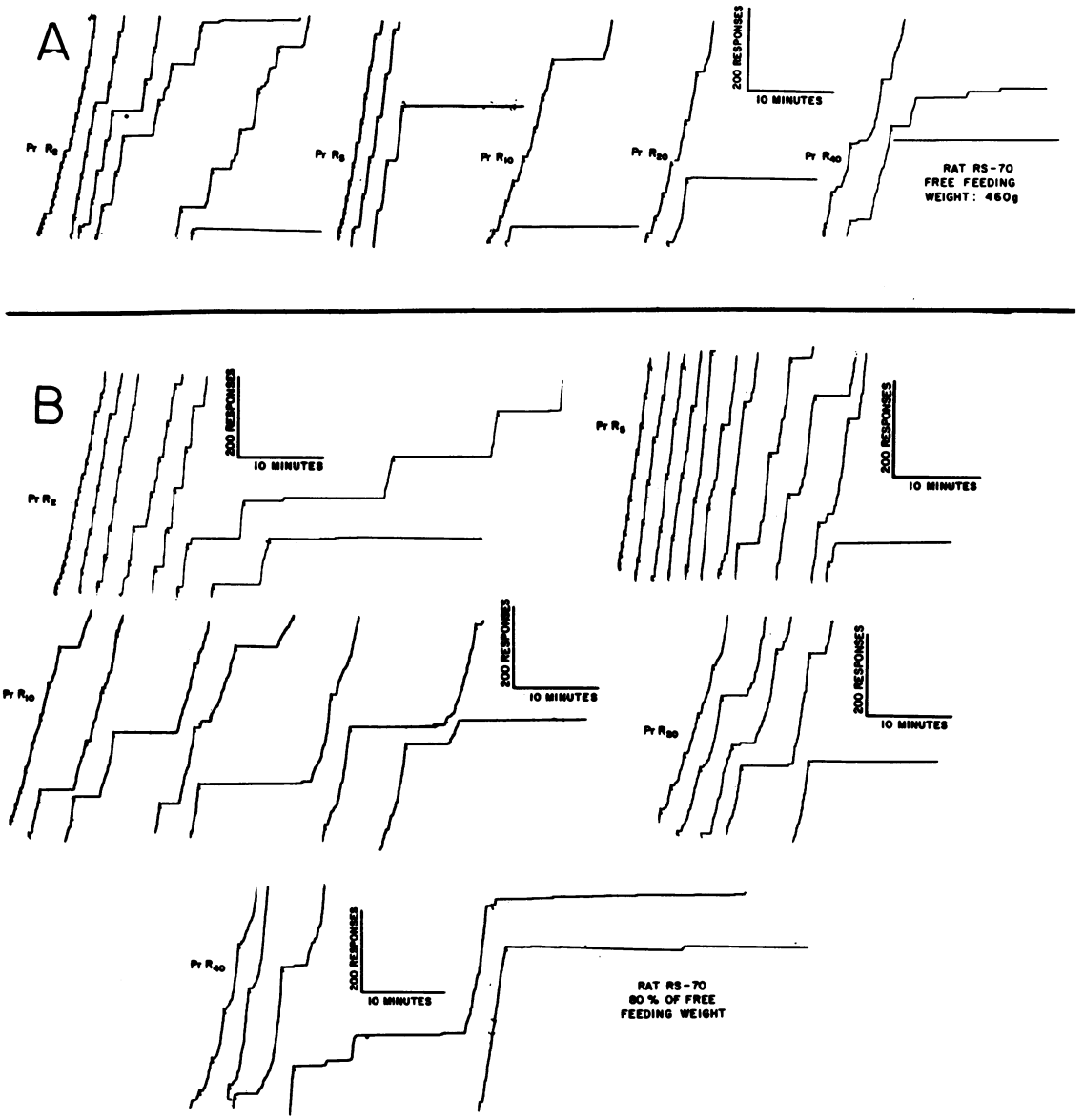

Fig. 1. Cumulative records illustrating typical performance of rat RS-70 on the progressive ratio schedule with ratio increments of 2, 5, 10, 20, and 40. The reinforcement was .05 ml of sweetened condensed milk. Pen deflections indicate reinforcements. A. Records obtained under conditions of free feeding on lab chow in the home cage. B. Records obtained under conditions of restricted food intake when the rat's body weight had been reduced to 80% of the free-feeding level.

creases when the animal's body weight is reduced, as may be seen in Fig. 1-B.

The upper half of Fig. 2 depicts the number of responses in the final completed ratio run as a function of the size of the ratio increment. Data are presented for two rats. Each point represents the median of six sessions. The solid lines represent performance under conditions of free feeding, while the broken lines represent performance at 80% of free-feeding weight. The lower half of the figure depicts the median number of reinforcements received at each ratio increment. Comparison of the upper and lower halves reveals that while the number of responses in the final completed ratio run continues to rise as a function of increasing the ratio increment, the number of reinforcements received rapidly declines to

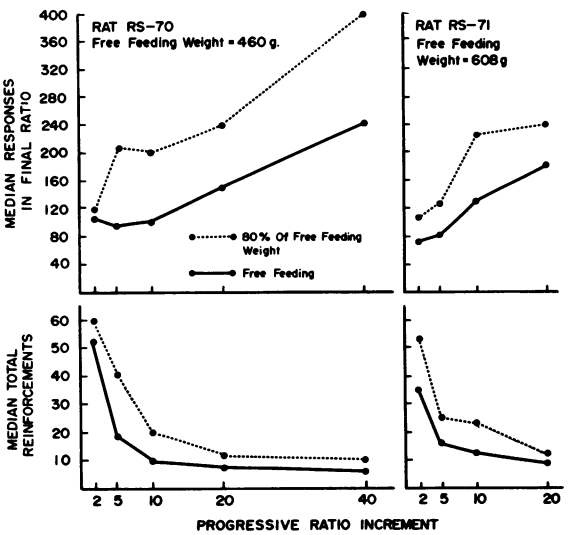

Fig. 2. Top: The median number of responses in the final completed ratio run is plotted as a function of the size of the ratio increment. Data are shown for rats RS-70 and RS-71. Bottom: The median number of reinforcements per session for each rat is plotted as a function of the size of the ratio increment. In both parts of the figure, the solid lines represent free-feeding data and the broken lines represent data collected at 80% of normal body weight. Rat RS-71 died before data could be collected on progressive ratio 40.

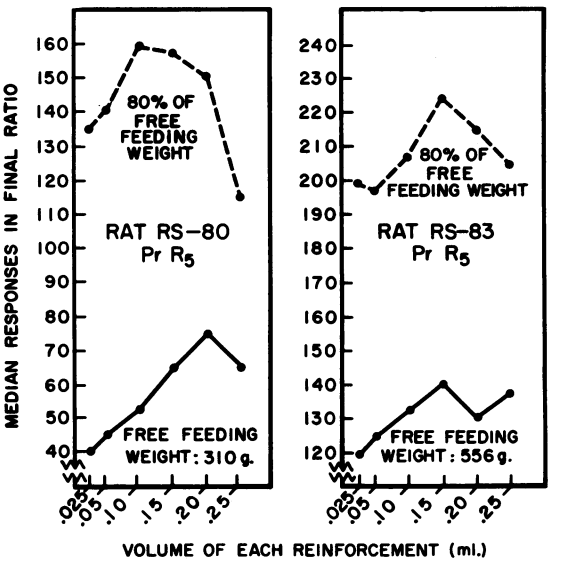

Fig. 3. The median number of responses in the final completed ratio run is plotted as a function of the volume of each reinforcement. Data are shown for rats RS-80 and RS-83. The schedule is progressive ratio 5. The solid lines represent free-feeding data and the broken lines represent data collected at 80% of normal body weight.

an asymptotic value. This finding holds for both free feeding and food-deprived performance, although in the case of food-deprived performance the values are higher. These data suggest that as the ratio increment becomes larger, the rat will emit only as many ratio runs as are necessary to obtain some minimum number of reinforcements.

EXPERIMENT II

Procedure

The effects of six different volumes of the reinforcer on the number of responses in the final completed ratio run were studied. The volumes used were .025, .05, .10, .15, .20, and .25 ml. Eight determinations were made with each volume, one per day, under conditions of free feeding in the home cage and again when the rats had been reduced to 80% of normal body weight. The various volumes of the reinforcer were presented in an irregular sequence and the schedule was PrR5.

Results and Discussion

Figure 3 summarizes the results. Each half of the figure contains data obtained from one rat. Each point represents the median of eight sessions. Solid lines indicate data obtained under conditions of free feeding and broken lines indicate data obtained when the animals had been reduced to 80% of free-feeding weight. Comparison of the solid and broken lines indicates that under conditions of deprivation, the rats will work through much higher ratios than they will under conditions of free feeding. In the case of rat RS-80 the number of responses in the final completed ratio run during deprivation is two to three times its value during free feeding. In the case of rat RS-83 the difference is nearly double.

A second finding is that both the free feeding and deprivation curves pass through a maximum at the intermediate volumes of reinforcement and then decline at the larger volumes. This is consistent with earlier findings (Conrad and Sidman, 1956; Guttman, 1954; Stebbins, 1959) which described response decrements with large amounts of reinforcement. One interpretation of this finding could be that beyond a certain point, larger volumes of milk are relatively weaker reinforcers than intermediate volumes. A more likely explanation would be in terms of an interaction between performance and progressive satiation.

In experiments in which the volume of each reinforcement is small, progressive satiation plays a minor role in determining the point at which the animal allows the session to terminate (Hodos, 1961). However, in the present experiment, the total volumes of the reinforcer ingested become rather large and begin to approach the animals' point of satiation. An analysis of the total volume of milk consumed per session indicates that when the volume of each reinforcement was .25 ml, rat RS-80 ingested a total of approximately 6.0 ml of milk under conditions of deprivation and rat RS-83 ingested approximately 10.0 ml under the same conditions. An examination of the records of these animals, which were made during initial lever-pressing training, revealed that while on continuous reinforcement, the rats would consume a maximum of 12.0 to 15.0 ml of milk per 2-hr session. Thus it would seem that the large volumes of milk consumed in Exp. II brought the rats close to satiation. This suggested that the decline in the number of responses in the final completed ratio run with large volumes of milk might not reflect a decline in the reinforcement strength of these larger volumes, but rather an interaction with progressive satiation. The third experiment was performed to support one or the other of these interpretations.

EXPERIMENT III

Procedure

In this study the rats were trained to press the lever on a schedule of PrR40 since the results of Exp. I show that on this schedule the animals' breaking point would be reached with fewer reinforcements and the effects of progressive satiation would thus be minimized. Four volumes of milk were studied: .025, .15, and .25 ml were selected from the volumes employed in the second experiment and, in addition, .40 ml was introduced to extend the upper range of reinforcement volumes. Eight determinations, in an irregular sequence, were made with each volume. The rats were maintained at 80% of normal body weight.

Results and Discussion

Figure 4 indicates that when the total volume of the reinforcer is kept relatively low by means of a high ratio requirement, the number of responses in the final ratio run has a monotonic relationship with reinforcer volume, even when the volume of each individual reinforcement is quite large. This suggests that the inflections seen in Fig. 3 represent the effects of progressive satiation rather than a decline in relative reinforcement strength.

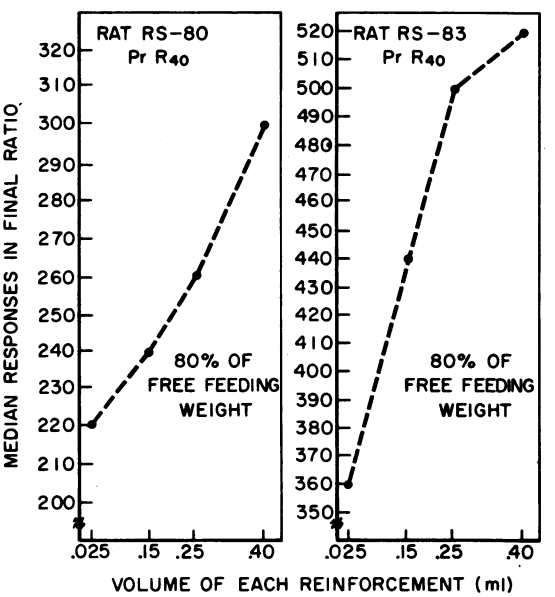

Fig. 4. The median number of responses in the final completed ratio run is plotted as a function of the volume of each reinforcement. The animals are at 80% of their normal body weight. The schedule is progressive ratio 40.

The data reported here and earlier (Hodos, 1961), have shown the number of responses in the final completed ratio run (*i.e.*, the breaking point of behavior) is sensitive to manipulation of a number of motivational variables. Increasing the degree of food deprivation, the concentration of the reinforcer or the volume of the reinforcer all result in increasing the number of responses in the final completed ratio run. But, in situations in which progressive satiation seems likely, as was the case in Exp. II, the data should be interpreted with caution. However, as demonstrated in Exp. III, satiation effects can be minimized by the use of large ratio increments.

In reporting the results of these progressive ratio experiments, the principle measure of performance was the number of responses in

the final completed ratio run. This measure correlated best with manipulations of the independent variables. Other measures, *i.e.*, overall rate, running rate, and total responses per session were also examined. Total number of responses failed to correlate systematically with manipulations of the independent variables. Overall rate and running rate, on the other hand, did differentiate between the conditions of free feeding and deprivation, but they were quite variable and were not sufficiently sensitive to differentiate between the different volumes of reinforcement in Exp. II and III and between the different ratio increments in Exp. I.

CONCLUSIONS

The results of the experiments reported here substantiate the use of the breaking point of progressive ratio performance as an index of the relative strength of a reinforcer without reference to the rate of responding. The technique should prove most useful as an index of relative reinforcement strength in those instances in which an organism's ability to respond at a high rate is somehow impaired. One case in point is that of an animal reinforced by stimulation of the brain. In this instance the rate of self-stimulation may be altered by forced movements or other motor side-effects of the stimulation. Another example would be that of brain-injured or drugged organisms which might show a decrement in rate which could reflect an impaired motor system rather than a motivational change.

REFERENCES

Conrad, D. and Sidman, M. Sucrose concentration as reinforcement for lever pressing by monkeys. *Psychol. Rep.*, 1956, **2**, 381-384.

Guttman, N. Equal reinforcement values for sucrose and glucose solutions compared with equal sweetness values. *J. comp. physiol. Psychol.*, 1954, **47**, 358-361.

Hodos, W. Progressive ratio as a measure of reward strength. *Science*, 1961, **134**, 943-944.

Hodos, W. and Valenstein, E. S. An evaluation of response rate as a measure of rewarding intracranial stimulation. *J. comp. physiol. Psychol.*, 1962, **55**, 80-84.

Stebbins, W. C. Relation of amount of reinforcement to discrimination and to secondary reinforcement strength. *J. comp. physiol. Psychol.*, 1959, **52**, 721-725.

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