

NON-SPATIAL DELAYED ALTERNATION BY THE PIGEON¹

BEN A. WILLIAMS

HARVARD UNIVERSITY

Pigeons were trained on a non-spatial delayed alternation task in which the color not pecked on the previous trial was correct. When varying delays were interposed between trials, alternation accuracy decreased as a function of delay, but remained greater than chance with a 45-sec delay. Successful alternation on the longer delays was accomplished without behavioral mediation of the delay intervals. Also, during initial testing when a position cue was available in addition to the color cue after incorrect trials, alternation accuracy was greater after a preceding incorrect trial than after a correct trial. When the position cue was removed, no differences occurred as a function of the outcome of the preceding trial.

An established finding of delayed response experiments is the difference in accuracy obtained from the usage of spatial *versus* non-spatial cues. A variety of experiments, usually with primate subjects (Yerkes and Yerkes, 1928; Nissen, Riesen, and Nowlis, 1938; Nissen and Harrison, 1941; Riesen and Nissen, 1942), but also with the raccoon (Michels and Brown, 1959) have shown that delayed response performance using spatial cues is more accurate than that using non-spatial cues. These differences between the spatial and non-spatial results are of significance, both for cross-species comparisons and for a theoretical interpretation of the delayed response. Unlike the spatial situation, the longest delay successfully mediated by any species in the non-spatial procedure has been only 1 to 2 min, and also unlike the spatial situation, an interpretation of the mediation of the delay intervals in terms of a chain of behavior is usually inapplicable. A possible implication is that spatial delayed response and non-spatial delayed response are fundamentally different learning problems.

Crucial to any interpretation of non-spatial

¹This experiment was conducted when the author was a NSF Predoctoral Fellow, and was supported by research grants NIMH 15494 and NIH-GM-15258 to Harvard University, R. J. Herrnstein, principal investigator. The author wishes to thank R. J. Herrnstein, C. G. Gross, and D. V. Cross for their criticisms of an earlier version of this manuscript. Reprints may be obtained from Ben A. Williams, Department of Psychology, The Colorado College, Colorado Springs, Colorado 80903.

delayed response is whether nonprimate subjects can perform proficiently on this procedure when relatively long delays are employed. Of the few studies pertinent to this question, raccoons have been found to perform with an accuracy of 65 to 55% over the range of 15 to 30 sec (Michels and Brown, 1959), whereas pigeons have been found to perform accurately with delays up to only 5 seconds (Berryman, Cumming, and Nevin, 1963; Blough, 1959; Smith, 1967). Thus proficient non-spatial delayed response performance with nonprimate subjects is apparently very difficult to accomplish.

The present study sought to demonstrate proficient delayed response performance for pigeons when non-spatial cues are used. To do this, a variant of delayed response was used (non-spatial delayed alternation) that has been found to be learned only with great difficulty even when primate subjects and short delay intervals are employed (*cf.* Nissen and Taylor, 1939). An earlier study (Williams, 1971) has shown that pigeons can learn non-spatial delayed alternation, but only when fixed-ratio response requirements are imposed. The present experiment imposed the fixed-ratio requirements in the alternation procedure with varied delay intervals between trials.

METHOD

Subjects

Four White Carneaux pigeons were maintained at approximately 80% of their free-

feeding body weights. Subjects 5 and 6 were naive with respect to color discrimination but had been previously trained on an auditory discrimination. Subjects 273 and 295 had previous training on a number of simple color discriminations and schedules of reinforcement.

Apparatus

An operant conditioning chamber was constructed from an aluminum picnic cooler. The bird's chamber was a 12 in. (30.5-cm) cube, and was equipped with an overhead houselight and constant white noise input to mask outside noise. On the front panel, two Gerbrands pigeon keys, 0.75 in. (1.9 cm) in diameter, were mounted 4 in. (10 cm) apart, center to center, and 9 in. (23 cm) off the floor, with each key requiring the application of at least 15 g (0.15 N) force for operation. Behind each pigeon key were two 7.5-w Christmas tree light bulbs, one of which was illuminated behind each key each trial. Each peck on either of the keys produced a feedback click resulting from the activation of a relay located just behind the front panel. Directly between and 5 in. (13 cm) below the keys was a 2 in. by 1.75 in. (5.0 by 4.5 cm) aperture through which the birds were fed when a food magazine was activated. The electrical control equipment for the conditioning chamber was located in the next room.

Procedure

Alternation acquisition. Before the tests for the effects of varying delays, the subjects were first extensively trained on the color alternation problem with the minimal delay possible. The stimuli used throughout training were red and green lights, each of which appeared behind only one of the keys on a given trial. The color behind a given key changed randomly after every correct trial, but the positions did not change after an incorrect trial. Consequently, after an incorrect trial the position last pecked could also serve as a cue.

The color designated correct on the first trial of a session was randomly varied. Afterwards, the correct color on a given trial was always the one not responded to on the preceding trial, regardless of whether the preceding trial was correct or incorrect.

The four subjects were divided into two groups of two subjects each, with each group

arbitrarily assigned to different fixed-ratio (FR) reinforcement schedules. For a given value of FR, that number of correct or incorrect pecks would produce a completed trial. Correct and incorrect pecks were counted separately so that whichever reached the FR requirement first determined whether the trial was designated correct or incorrect. The FR values used were FR 15 for Subjects 273 and 295, and FR 30 for Subjects 5 and 6. All subjects were given one session on each of the smaller values of FR 1, FR 5, and FR 15 before training was begun with the schedule used for the duration of the experiment.

Each subject was run daily with the sessions terminating after a fixed number of reinforcements. For Sessions 1 to 6, this number was 50, for Sessions 7 to 8, 60, and thereafter 70. Responses comprising a correct trial were reinforced by a 2.8-sec access to the food magazine, with 0.2 sec of blackout following reinforcement before the keylights were illuminated for the beginning of the next trial. An incorrect trial resulted in a 3-sec blackout of all lights, so that the time between the end of one trial and the beginning of another was always 3 sec, regardless of whether the trial was correct or incorrect. Training continued on this schedule for 30 days after the first day with 80% correct trials, at which time tests were begun for the effects of the variation of the delay interval between trials.

Delay variation, Phase I. The procedure for delay testing was the same as that during acquisition, except that different intertrial intervals were used. The intertrial intervals presented in this phase were 3, 5, 7, 10, 13, 16, 20, 25, 35, and 45 sec. The schedule of their presentation consisted of five consecutive days of training on each delay, with the order of testing being from the briefest to the longest. After the five days of training under each delay not the original training delay (3 sec), five days of training with a 3-sec delay were given before proceeding to the next higher delay. Interspersed between the testing of the 20- and 25-sec intervals for Subjects 295 and 273, and between the 13- and 16-sec intervals for Subjects 5 and 6, was a 45-day period of testing for color alternation transfer using different sets of colors and a 3-sec delay. Before testing was resumed for the red-green delayed alternation, 10 days of retraining were given using the 3-sec training delay. Also, for Sub-

jects 5 and 6, because the 30 additional training days beyond the 80% accuracy criterion did not ensure asymptotic performance for the first delays tested, retesting of the 3-, 5-, and 7-sec intervals was given after the 45-sec interval was completed.

Delay variation, Phase II. After the above training with successively higher intervals, a second phase was begun using only four of the above intervals, with each presented for only one session at a time, and with the order of their presentation randomly arranged in four blocks of four delay presentations each. The intervals tested were 3, 7, 13, and 25 sec. Except for the change in delay presentation, the procedure for these 16 sessions was the same as described above.

Delay variation, Phase III. In Phases I and II, the positions of the two colors remained unchanged after an incorrect trial. Consequently, the possible use of position cues is confounded with the outcome of the previous trial. Phase III was designed to separate the two variables. The only change of procedure from Phase II was that the positions of the two colors no longer remained the same after an incorrect trial, but changed randomly as they did after a correct trial. The discrimination problem remained to peck the color on which the fixed ratio was not terminated on the previous trial. Before the presentation of the different delay intervals, 10 sessions of training were given using the training delay of 3 sec. After these 10 sessions, the same delay intervals as in Phase II were presented (3, 7, 13, and 25 sec) as were the same random orders of presentation. To examine whether responding changed as the result of more training under this new procedure, the 16 days of testing were repeated, producing a total of 32 days of testing.

RESULTS

Acquisition

The average number of sessions required to reach the criterion of 80% correct trials was 21.25, with the range being 17 to 26. The details of the acquisition performance are presented elsewhere as part of a larger report (Williams, 1971).

Delay Variation, Phase I

Accuracy of phase alternation as a function of the delay intervals is shown in Fig. 1 for

each of the four subjects. Two functions are shown for each bird: accuracy of trials after a preceding correct trial, and accuracy of trials after a preceding incorrect trial. For all subjects, accuracy for both functions decreased with increasing delay. Especially noteworthy is the maximum delay for which accurate responding (greater than 50%) was maintained. This maximum has not been attained for any of the subjects, even though a delay of 45 sec was the longest interval used. A second feature of Fig. 1 is the relation between accuracy after correct trials and that after incorrect trials. For all subjects, accuracy after an incorrect trial is generally greater, with the difference between the two functions increasing as a function of the length of delay.

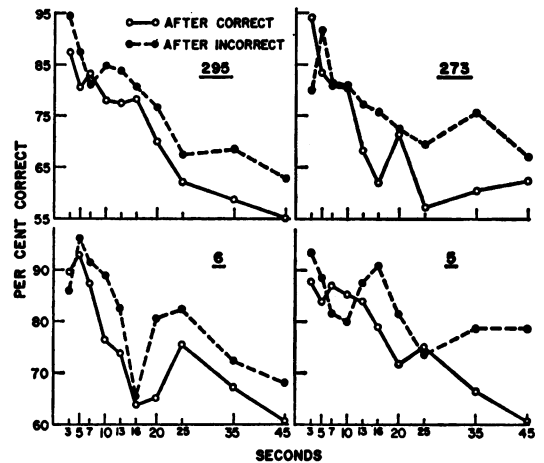


Fig. 1. Phase I alternation accuracy (proportion of trials that were correct) for individual subjects as a function of delay. Total accuracy is subdivided into that after correct trials and that after incorrect trials.

Delay Variation, Phase II

The results of Phase II are shown in Fig. 2. In general, the results from Phase I were replicated. Accuracy was again a decreasing function of delay, and for all subjects accuracy after incorrect trials was generally greater (the functions for trials after incorrect trials are more erratic because of the smaller number of observations per point, especially for the 3- and 7-sec delay intervals where the number of observations is quite small). The one departure from the results of Phase I is the performance of Subject 5. Figure 2 reveals that whereas its accuracy after a correct trial decreased much as it did during Phase I, its

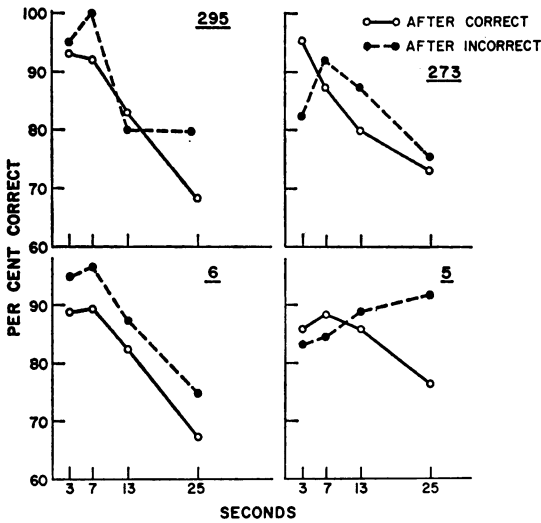


Fig. 2. Phase II alternation for individual subjects. Total accuracy is divided into that after correct trials and that after incorrect trials.

function for accuracy after an incorrect trial has changed. This function no longer decreased with increasing delays, but actually increased.

A final observation from Phases I and II concerns the effect of the FR schedules on the overall accuracy of responding. Since the present procedure required several pecks per trial instead of only one peck per trial, an important question is how the accuracy of all pecks—not just those terminating a trial—changed with increasing delays. Table 1 shows these data for Subject 295, which are representative of the results from all subjects tested. Accuracy for both trials and total pecks for all delay values in Phase II are presented. Both functions decreased with increasing delay, but accuracy for trials was always higher than accuracy for pecks. Although this difference between the two measures is quite small, its cause is of some significance. Pecks were less accurate than trials because the pigeons often responded one to five times at the beginning of a trial to the incorrect color, and then corrected this tendency before the FR requirement was completed. The percentage of trials on which such changeovers between colors occurred varied with the individual subject, occurring on 5 to 10% of the trials for Subject 5, on 20 to 30% of the trials for 295 and 6, and on 40 to 50% of the trials for Subject 273.

Table 1

Accuracy of alternation for different delay values expressed as both percentage of correct trials and as percentage of correct pecks. The data shown are those of Subject 295 in Phase II.

Delay (sec)	Percentage of Trials Correct	Percentage of Pecks Correct
3	93.3	91.2
7	92.7	89.6
13	82.3	80.9
25	71.9	71.0

Delay Variation, Phase III

To ensure that no change was occurring as a result of continued testing with the change in procedure to Phase III, the presentation of the four delay intervals four times each was replicated, producing a total of 32 days of testing with this new procedure. Because the results of the two repetitions were virtually identical when averaged across subjects, the results for the two tests were combined and are shown in Fig. 3. The accuracy after a correct trial is almost unchanged from that found in Phase II. The accuracy after an incorrect trial, however, was no longer greater than after a correct trial. To provide a statistical test of this change in the relation between mean accuracy after correct and after incorrect trials, a sign test was conducted for Phases II

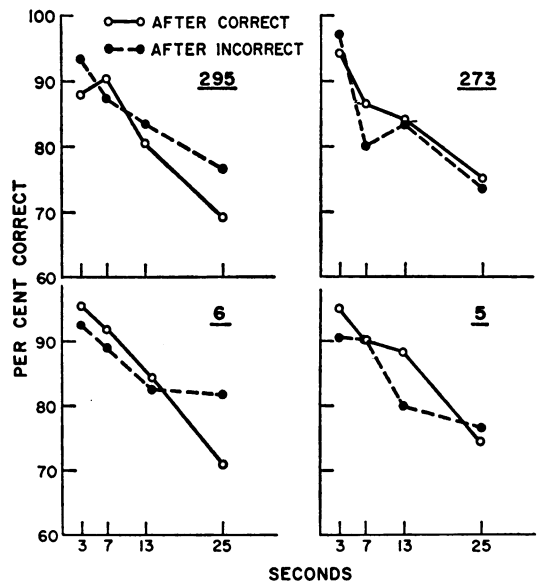


Fig. 3. Alternation accuracy for individual subjects in Phase III as a function of delay, with accuracy divided into that after correct and after incorrect trials.

and III, respectively, by assigning either plus or minus to the relation between mean accuracy after correct and incorrect trials for each delay interval for each subject. Whereas this test showed a significant difference for Phase II ($z = 1.75$, p less than 0.05), the difference for Phase III was not significant ($z = 0.25$, p greater than 0.05).

Mediational Behavior

In view of the consistently high accuracy maintained at the long delays for all three phases of testing, a final question to be asked of the above data is how the delay intervals were mediated. It has been noted previously that even when non-spatial cues are used, subjects sometimes display overt stereotyped mediational behavior during the delay interval (Blough, 1959). In view of this observation, the present experiment was continued to observe whether such behavioral mediation occurred here. After completion of Phase III, training was continued, the only change being that the houselight in the bird's chamber was on throughout the delay interval so that the bird's behavior could be observed. For none of the birds was there any discernible behavior correlated with any of the contingencies of delayed response testing. It is noteworthy that this observation occurred after the position cue after incorrect trials had been removed. When this position cue was present in Phases I and II, some data indicated that behavioral mediation did occur, *i.e.*, Subject 5 in Fig. 2. This inference is based only on the data, however, not on the observation of the subject.

DISCUSSION

The most noteworthy feature of the present results is the marked proficiency of the pigeon under a delayed response procedure, in comparison both to results obtained with other species, and to previous results obtained with pigeons using different procedures. As regards the limit of delay under which accurate responding could be maintained, the maximal delay of the present experiment far surpasses that reported previously for pigeons using different delayed response tasks. Smith (1967), Berryman, Cumming, and Nevin (1963), and Blough (1959) all reported that accuracy of responding under a delayed matching to sample procedure declined sharply from 0 to 5

sec, being approximately 60% at the 5-sec interval. Blough did report that two of his pigeons maintained a 90% accuracy at a 10-sec delay, but these subjects displayed overt mediating behavior during the delay intervals. The maximal delay found in this experiment also surpasses that found with the raccoon using a WGTA baiting procedure (Michels and Brown, 1959), and is comparable to that found for the rhesus monkey using a delayed color matching-to-sample procedure (Scheckel, 1965).

Several significant differences are apparent between the present procedure and previous delayed response tasks using non-spatial cues. First is the use of the alternation procedure instead of either a baiting procedure or matching-to-sample. Perhaps accurate responding can be maintained over longer delays with delayed alternation than with other delayed response procedures. This conjecture is not supported, however, by previous experiments on non-spatial delayed alternation, in which the task was learned only with great difficulty, even with short intertrial intervals (*cf.* Pribram and Mishkin, 1956; Mishkin, Vest, Waxler, and Rosvold, 1969). Similarly, using a spatial alternation problem, Hearst (1962) found that pigeons could perform accurately only with delays up to 10 sec. Thus, the alternation procedure itself does not seem to enhance delayed response performance.

A more promising explanation for the present results is the use of the fixed-ratio schedule of reinforcement. The present author has found previously (Williams, 1971) that the use of the FR schedule was necessary for successful acquisition of color alternation, and hence whatever facilitated acquisition may have facilitated delayed response performance as well. Previous experiments (Smith, 1967; Berryman *et al.*, 1963), using pigeons and delayed matching to sample, have used FR schedules, but only with responding to the sample stimuli, not to the choice stimuli. In contrast, previous data (Williams, 1971) have indicated that it is during the choice between stimuli that the FR variable is important.

The present results emphasize a fundamental question concerning the delayed response that too often has been neglected. Whereas previous experiments have usually examined such performance from the standpoint of comparative psychology, a more fundamental

question is how successful delayed response performance, such as that seen in the present experiment, is to be explained. The fact that non-primate subjects can be controlled by environmental stimuli absent for substantial periods of time when the response is made, independently of whether the cues were reinforcement associated or not, raises the questions of the basis of such control, and how it is related to learning of a more permanent nature.

The most widely held interpretation of proficient delayed response performance is that such performance depends upon the maintenance of some kind of response chain throughout the delay interval (e.g., Fletcher, 1965). The declining accuracy with increasing delay is then attributed to the greater probability that the chain will be disrupted. Discounting the problems involved in ever proving such response chains are not present, such an interpretation seems inadequate for the present experiment for two reasons. First, no overt chaining was observed to occur. Second, there is substantial reason to believe that if any chain were present, it would often have been disrupted; *i.e.*, the animals often changed between the two colors within a trial. Even though the terminal link of any response chain would presumably have been pecking red or pecking green, the animals' behavior varied after this terminal link had been reached. Any response chain present would presumably control only which of the two colors the animal pecked at the beginning of a trial. It would not explain variable changes between the colors during the trials.

An alternative to a response chaining explanation of delayed response performance derives from considering the performance as simply one form of discrimination learning. By this view (e.g., Cowles, 1941; Harlow, 1951), the delayed response problem consists of two phases: the learning phase when the cue to be retained is presented, and the retention test when the delayed response choice is made. The reason that response accuracy decreases as a function of delay, then is that the learning during the presentation of the cue is incomplete due to its being presented for only one trial and to the great interference from previous learning. The problem with such an interpretation is that it postulates a relation between retention and amount of delay that

is not supported by the results of ordinary discrimination learning. When the intertrial interval has been varied in studies of discrimination learning, either no effect of this variable is seen (Biederman, 1967; Clayton, 1966; D'Amato, 1960) or longer intertrial intervals have facilitated learning (Thompson and Thompson, 1949; Walker and Motoyoshi, 1962). Thus, the effect of intertrial interval on discrimination learning differs from that on the delayed response. On the other hand, two other learning situations, successive discrimination reversal learning and learning set acquisition, have been found to yield an inverse relation between learning proficiency and intertrial interval (*cf.* Stretch, McGonigle, and Morton, 1964; Johnson, 1968; Harlow and Warren, 1952; Hayes and Thomson, 1953). It is noteworthy that these two tasks also involve the greatest learning proficiency of any discrimination problem. Why the effects of intertrial interval on them should be similar to those on the delayed response, however, and dissimilar to those on simple discrimination learning, can now be only conjectured.

REFERENCES

- Berryman, R., Cumming, W. W., and Nevin, J. A. Acquisition of delayed matching in the pigeon. *Journal of the Experimental Analysis of Behavior*, 1963, 6, 101-107.
- Biederman, G. Simultaneous discrimination: parameters of reinforcement and ITI. *Psychonomic Science*, 1967, 8, 215-216.
- Blough, D. S. Delayed matching in the pigeon. *Journal of the Experimental Analysis of Behavior*, 1959, 2, 151-160.
- Clayton, K. N. T-maze acquisition and reversal as a function of intertrial interval. *Journal of Comparative and Physiological Psychology*, 1966, 62, 409-414.
- Cowles, J. T. Discrimination learning and pre-delay reinforcement in "delayed response". *Psychological Review*, 1941, 48, 225-234.
- D'Amato, M. R. Distribution variable in simple discrimination learning in rats. *Canadian Journal of Psychology*, 1960, 14, 216-219.
- Fletcher, H. J. The delayed-response problem. In A. Schrier, H. Harlow, and F. Stollnitz (Eds.), *Behavior of nonhuman primates*, Vol. 1. New York: Academic Press, 1965. Pp. 129-165.
- Harlow, H. F. Primate learning. In C. P. Stone (Ed.), *Comparative psychology*. New York: Prentice-Hall, 1951. Pp. 183-238.
- Harlow, H. F. and Warren, J. M. Formation and transfer of discrimination learning sets. *Journal of Comparative and Physiological Psychology*, 1952, 45, 482-489.
- Hayes, K. J. and Thomson, R. Nonspatial delayed response to trial unique stimuli in sophisticated chim-

- panzees. *Journal of Comparative and Physiological Psychology*, 1953, **46**, 498-501.
- Hearst, E. Delayed alternation in the pigeon. *Journal of the Experimental Analysis of Behavior*, 1962, **5**, 225-228.
- Johnson, R. N. Effects of intercranial reinforcement intensity and distributional variables on brightness reversal learning in rats. *Journal of Comparative and Physiological Psychology*, 1968, **66**, 422-426.
- Michels, K. M. and Brown, D. R. The delayed response performance of racoons. *Journal of Comparative and Physiological Psychology*, 1959, **52**, 737-740.
- Mishkin, M., Vest, B., Waxler, M., and Rosvold, H. E. A reexamination of the effects of frontal lesions on object alternation. *Neuropsychologia*, 1969, **7**, 357-363.
- Nissen, H. W. and Harrison, R. Visual and positional cue in the delayed responses of chimpanzees. *Journal of Comparative Psychology*, 1941, **31**, 437-445.
- Nissen, H. W., Riesen, A. H., and Nowlis, V. Delayed response and discrimination learning by chimpanzees. *Journal of Comparative Psychology*, 1938, **26**, 361-386.
- Nissen, H. W. and Taylor, F. V. Delayed alternation to non-positional cues in chimpanzees. *Journal of Psychology*, 1939, **7**, 323-332.
- Pribram, K. H. and Mishkin, M. Analysis of the effects of frontal lesions in monkey: object alternation. *Journal of Comparative and Physiological Psychology*, 1956, **49**, 41-47.
- Riesen, A. H. and Nissen, H. W. Non-spatial delayed response by the matching technique. *Journal of Comparative Psychology*, 1942, **34**, 307-313.
- Scheckel, C. L. Self-adjustment of the interval in delayed matching: limit of delay for the rhesus monkey. *Journal of Comparative and Physiological Psychology*, 1965, **59**, 415-418.
- Stretch, R. G., McGonigle, B., and Morton, A. Serial position reversal learning in the rat: trials/problem and the intertrial interval. *Journal of Comparative and Physiological Psychology*, 1965, **57**, 461-463.
- Smith, L. Delayed discrimination and delayed matching in pigeons. *Journal of the Experimental Analysis of Behavior*, 1967, **10**, 529-533.
- Thompson, M. E. and Thompson, J. P. Reactive inhibition as a factor in maze learning: II. The role of reactive inhibition in studies of place learning versus response learning. *Journal of Experimental Psychology*, 1949, **39**, 883-891.
- Walker, E. L. and Motoyoshi, R. The effects of amount of reward and distribution of practice on active and inactive memory traces. *Journal of Comparative and Physiological Psychology*, 1962, **55**, 32-36.
- Williams, B. A. Color alternation learning in the pigeon as a function of fixed-ratio schedule of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1971, **15**, 129-140.
- Yerkes, R. M. and Yerkes, D. N. Concerning memory in the chimpanzee. *Journal of Comparative Psychology*, 1928, **8**, 237-271.

Received 8 May 1970.