Use of a Changeover Key to Train Serial Learning in the Pigeon

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USE OF A CHANGEOVER KEY TO TRAIN SERIAL LEARNING IN THE PIGEON

by

Rhoda Kay Yutzy-Ryan

A Thesis Submitted to the Faculty of The Graduate College in partial fulfillment of the requirements for the Degree of Master of Arts Department of Psychology

Western Michigan University
Kalamazoo, Michigan
December 1986
USE OF A CHANGEOVER KEY TO TRAIN SERIAL LEARNING IN THE PIGEON

Rhoda Kay Yutz-Ryan, M.A.
Western Michigan University, 1986

Three pigeons were presented with a serial learning task involving a sequence of three colors: yellow, green and red. The colors appeared on a lit key one at a time in random order. The pigeons were required to peck the colors in the correct order and to use a second lit key (the changeover key) to change the color when it was incorrect. The data show that the pigeons were able to learn the task and generalize to novel arrays at a high level of accuracy. This extends the findings on serial learning with pigeons to a type of sequence where the correct stimuli are not all present at the same time, showing that the birds are capable of learning an even more complex task than previously studied, and providing an opportunity for further nonhuman research on an important type of human behavior.
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# TABLE OF CONTENTS

LIST OF TABLES .......................................................... iii
LIST OF FIGURES ............................................................ iv
INTRODUCTION ............................................................... 1
  Serial Learning .......................................................... 1
  The Changeover Procedure ............................................. 13
METHOD ..................................................................... 15
  Subjects ........................................................................ 15
  Apparatus ..................................................................... 15
  Procedure ..................................................................... 17
    Terminal Experimental Task ............................................ 17
    Training Condition ....................................................... 19
    Condition I (First Generalization Condition) ................. 24
    Condition II (Final Generalization Condition) ............... 25
RESULTS ......................................................................... 26
  Color Errors .................................................................. 27
  Latencies ....................................................................... 30
DISCUSSION ..................................................................... 33
BIBLIOGRAPHY ............................................................... 37
LIST OF TABLES

1. Sequences of Colors During Each Experimental Condition ........................................... 20
2. Average Percent of Correct Color Choices for Each Sequence .................................................. 31
3. Average, High and Low Latencies to Correct and Incorrect Choices .................................................. 32
LIST OF FIGURES

1. Schematic Drawing of the Experimental Panel
   as Viewed by the Subjects..............................16

2. Percentage of Correct Choices and Correct
   Trials for Each Subject During Sequences
   1, 2 and 3 of the Training Condition..................28

3. Percentage of Correct Choices and Correct
   Trials for Each Subject During Conditions
   I and II..................................................29
INTRODUCTION

Serial Learning

Much complex human behavior consists of sequences of responses where the arrangement of the sequence (which type of response occurs first, which next, etc.) depends to some extent on the spatial or temporal arrangement of a sequence of stimuli. The importance of some learning of this sort is that the sequence of behaviors can continue to occur under appropriate circumstances even in the absence of any environmental sequences of stimuli except those resulting from the organism's own behavior. Thus a child learns to emit a sequence of verbal responses called numbers. Whatever the stimulus conditions occurring during learning, the value of this behavior for the child and for other members of the community inheres in the later occurrence of the proper sequence where there are no external controls for the different responses of the sequence.

The analysis of serial (or sequential) learning in terms of basic behavioral concepts and functional relations has long been of interest to behaviorally oriented psychologists. Keller and Schoenfeld (1950) included treatment of this topic in their highly influential textbook, Principles of Psychology, where they dealt with such
sequential behavior in terms of chaining (pp. 197-230).
In a simple chain of responses the first response occurs
under the control of the ambient stimulus situation. This
response then produces a stimulus change which evokes the
next response, which produces another and different
stimulus change, which evokes the next response, and so on
until the last response in the sequence produces the ter-
"inal reinforcement considered responsible for the main-
tenance of the sequence. The stimulus changes occurring
during the sequence are considered to function as condi-
tioned reinforcement for the response that produces them
and as discriminative stimuli for the next response in the
sequence.

An analysis of sequential behavior in terms of chain-
ing is clearly appropriate to many examples of such beha-
vior, but when the responses do not produce any environ-
mental changes, as in Hunter's (1920) temporal maze (de-
scribed later), or as with many kinds of human verbal
sequences, the analysis becomes more difficult. To main-
tain the chaining model it has seemed necessary to infer
the occurrence and function of stimuli that are not read-
ily observable, such as distinctive kinaesthetic stimuli
resulting from the responses themselves, or even less
substantial (mental) representations of the composition of
the proper sequence.

Human research on this type of learning is somewhat
difficult to interpret in terms of basic behavior processes both because it is difficult to find tasks that do not involve extensive prior learning, and because the human's extensive verbal repertoire seems often to play a major role in the learning. Nonhuman research with simpler organisms has been beneficial in the preliminary study of other phenomena that are confounded by the ordinary human repertoire, and would seem useful in the experimental analysis of the type of sequential behavior discussed above.

At present a great deal of basic research data is available on the pigeon as an experimental subject. Such subjects are inexpensive, easily maintained, and standard research equipment is available for pigeon research in many operant conditioning laboratories. These animals also have excellent vision which makes it possible to use high quality stimulus control units in developing the sequence of responses. Primates would be more like humans, whose behavior is of main interest, but pigeons are presumably simpler organisms in addition to being less expensive and easier to work with.

In what is probably the first work with pigeons on sequential responding that, in its final phases, is not easily interpreted as a form of chaining, Straub, Seidenberg, Bever, and Terrace (1979) trained their subjects (using a forward chaining procedure) to peck the
colors green, white, red and blue in that order. All colors were presented simultaneously and the pigeon was required to correctly peck the entire sequence before receiving reinforcement. Incorrect pecks were punished with a 20 second time out. Repeat pecks to a color were not treated as errors as long as they did not violate the correct sequence. Training sequences consisted of random presentations of 15 linear combinations of the four colors. Generalization trials introduced four novel arrangements of the colors.

All the pigeons learned to respond correctly to the sequence. The average proportion of trials correctly completed during the last 18 sessions of training was 0.57 across all three subjects with a low of 0.36 and a high of 0.77. Straub et al. (1979) determined a chance performance to be less than 0.01 thus placing their performance at much greater than chance. Generalization to new arrays occurred at 0.32 probability with a range from 0.05 to 0.67 which was still a greater than chance performance.

Errors were analyzed in terms of latencies of responses at each position of the sequence, backward errors (pecks to a color already selected) and forward errors (pecks to a color that came later in the sequence). They found that forward errors occurred at a much higher percentage than backward errors (90% as opposed to 10%). They also found latencies of forward errors increased with
sequential distance from the correct response. Average latencies of a correct peck was 1.00 second while the average latency of forward errors one removed was 1.9 seconds.

The research of Straub et al. (1979) was primarily directed at the work of Rumbaugh and his colleagues (1977) which seemed to show that chimpanzees could compose and react to sequences of verbal stimuli that were analogs of the human sentence. Critics of the ape language research maintained that the apparent sentences were simply behavioral sequences that had none of the linguistic significance of human verbal sequences. Some of the chimpanzees' behavior, however, was like the typical human verbal sequence in being emitted as a sequence without each response producing external stimuli for the next response. By showing that even pigeons could learn to emit such sequences, which could not reasonably be called "sentences," Straub et al. (1979) provided evidence against interpretation of the chimpanzees' behavior as truly linguistic.

In addition to its possible relevance to the ape language research, Straub et al. (1979) interpreted their findings as support for the necessity of the cognitive "representation" construct. They concluded that the pigeons abstracted the correct sequence of colors or "learned a representation" of the sequence. This was
based on the fact that there were no external cues available to guide the pigeons through the sequence. They felt that the latency data also supported this based on both the existence of "air pecks" and the rapidity of successive responses. "Air pecks" are those responses emitted by the pigeon where a peck would be initiated in the direction of the correct key but would not be of a high enough intensity to close the switch and activate that key. The pigeon would then continue to emit the next correct response which would be counted as an error since the previous response had not been registered. These responses accounted for the majority of the forward errors. The latency of these errors would then be longer because the pigeon was making an intermediary response before making the forward error. They felt that this type of response showed that the pigeon had learned a representation of the sequence as the pigeon was attempting to peck through the correct chain. The rapidity of the pigeons' responses also supported their theory based on the statement by Lashley (1951) that certain responses in sequential chaining occur too rapidly for each response in the sequence to be controlled by self-generated feedback, thus further proving the existence of a representation.

An interpretation can be made of the pigeons' sequential behavior without the "benefit" of the inferred representation, as follows. The trial begins with an inter-
trial interval where the house light is on but the keys are unlit. After a variable period with an average duration of 20 seconds, all four keys are illuminated, one green, one white, one red and one blue. The order of the keys across the panel varies randomly from one trial to the next, but irrespective of its location, a peck on the green key immediately after the intertrial interval ends will be followed by all keys remaining lighted (which is important to the pigeon since only if the keys remain lighted is the bird getting closer in time to food) whereas pecks on any of the other three colors will result in all keys and the house light going dark for 20 seconds followed by another intertrial interval. In other words, pecks to any color but green are clearly punished at this point in the sequence. That the key and house lights stay on after pecks to green is not exactly an event that could be considered a form of reinforcement for such pecks, but pecking is the only way that food is obtained and is therefore strong behavior in this situation. Given that pecking, in general, is strong, and that pecking white, red, and blue are weakened by the time-out punishment, the control over pecking by the green key, irrespective of its location, can be assumed to be stronger than any other form of control at this point in the sequence. But the green key cannot be pecked until it is seen. Therefore, the sight of the
green key is a form of reinforcement and behavior such as visual scanning which has resulted in such reinforcement is momentarily strong. Thus if the bird is looking at the white key, pecking is momentarily weaker than scanning, and this condition will continue until the bird is looking at the green key.

The initial stimulus condition consisting of the termination of the intertrial interval and the onset of all four colors plays a double behavioral role: it is a discriminative stimulus in the presence of which pecking white, red and blue has been punished and pecking green has not, with the result that pecking green is at least relatively strong, and it is also a conditioned establishing operation (a moti vative variable like food deprivation which increases the reinforcing value of food, only in this case it is a learned moti vative variable) (Michael, 1985) which increases the reinforcing value of seeing green and thus increases the momentary strength of any behavior that has resulted in seeing green--namely visual scanning.

After having pecked the green key one or more times, (that is, "finding oneself in front of and pecking the green key," ) with all four keys remaining lit is a stimulus condition where pecking white has been followed by the keys remaining lit whereas pecking red or blue has been punished by the time-out. Thus, the control over pecking
by the white key, irrespective of its location (as one stands in front of and pecks the green key), can be assumed to be stronger than any other form of control except perhaps continuing to peck the green key, which does not harm, but has not resulted in moving closer in time to food and would thus be expected to weaken with repetition. Again however, pecking white cannot occur until white is seen, so visual scanning behavior is strong until it is displaced by pecking white. In other words, the stimulus conditions consisting of having just pecked green with the key and house lights remaining on constitutes an SD change (a change in what behavior is momentarily strong due to reinforcement and what behavior is momentarily weak due to punishment) and a conditioned establishing operation change (a change in what key color is momentarily reinforcing to see).

Now, finding oneself standing in front of and pecking the white key with all the key lights still on represents a new SD in the presence of which pecking green or blue has been punished, but pecking red has not and would thus be expected to be strong at this point in the sequence; and as before, this stimulus condition also represents a new conditioned establishing operation in the presence of which seeing red would be strong as a form of reinforcement and thus scanning would be strong when looking at the other colors; and so on until the food is deli-
vered and the intertrial interval begins again.

What is necessary for a behavioral interpretation of such sequential responding is to bring in the weakening effect of the time-out punishment as a basis for a type of discriminative stimulus control, the unique stimulus situation (some of which arises from the pigeon's position and overt behavior) that exists at each phase of the sequence, and the scanning behavior that is generated by that stimulus condition functioning as a motivative variable. Such an interpretation is, of course, speculative, but in many respects, less so than the one favored by Straub et al. (1979) since the processes proposed are, at least in principle, observable, and they are quite analogous to processes that have been well studied in other behavioral research.

Representations and ape language research aside, the work of Straub et al. (1979) constitutes a valuable contribution to the general effort to extend behavioral research and behavioral interpretation to increasingly complex, and thus increasingly human like behavior. In this spirit Richardson and Warzak (1981) developed another arrangement for the study of sequential behavior. Seven pigeons were trained (again using a forward chaining procedure) to peck a series of four colored lights in a specific order. This study also used a fifth dark key to increase the number of possible arrays. The procedure
used by Richardson and Warzak included an increase in the amount of feedback and stimulus cues available to the pigeon. In this procedure, the five keys with four colors were simultaneously presented. Also in the chamber was a row of five dark keys located directly above the response keys. A peck to a correct response key resulted in an increase in the brightness of the pecked key and presentation of a matching color in the leftmost unoccupied key in the row of dark keys. Therefore, as the pigeons correctly pecked through the sequence, they also "built" a correct sequence on the upper keys. (This procedure is similar to the one used by Rumbaugh (1977) in which "Lana Chimpanzee" learned to select a string of symbols, depending on the conditional cues present in the environment, and to "build a sentence" with those symbols to obtain a desired object.)

The pigeons were required to correctly complete the entire sequence before receiving reinforcement. Incorrect pecks were followed by an offset of all displays and a 0.5 second buzzer. Training sequences consisted of the presentation of 10 linear combinations of the correct sequence plus the dark key. Generalization trials involved the presentation of 10 novel combinations.

All the pigeons in this study learned to respond correctly under the serial learning paradigm at a high level of accuracy. Richardson and Warzak (1981) deter-
mined a chance performance to be approximately once in 24 trials or 0.04. Changes in accuracy when presented with the novel arrays averaged a 21.3% decrease in accuracy with a range from 14.7% to 25.5%.

Errors were analyzed in terms of forward errors, backward errors, repeat errors, and dark-key errors (selection of a dark key). They found, as did Straub et al. (1979), that forward errors predominated, there were more one-step forward errors than two- and three-step forward errors, and that forward errors had longer latencies than correct pecks, repeat errors and backward errors.

Richardson and Warzak (1981) used a chaining model to explain the performance of correct strings, with trial onset being the discriminative stimulus for pecking dim-A: bright-A being the discriminative stimulus for pecking dim-B: etc. They felt that the bright-dim discrimination could account for the higher probability of forward errors. Repeat errors (also considered backward errors) could be due to the nature of pecking in pigeons (pigeons will frequently peck a stimulus several times in succession even when repetitive responses are never reinforced) (Richardson and Clark, 1976). Richardson and Warzak attributed the longer latencies of forward errors to the existence of the "air-peck" response by the pigeons as did Straub et al. (1979).
The Changeover Procedure

The experiments of Richardson and Warzak (1981), although interesting in their own right, are not really relevant to the type of human behavior mentioned above where no distinctive external stimulus changes follow each response in the sequence. Although inspired by the work of Straub et al. (1979), but unlike theirs, Richardson and Warzak's results are easily interpretable as simple chaining. Their procedure is, in a sense, a throwback to an easier understood form of behavior.

The purpose of the present experiment was also to study the acquisition and stable state behaviors of pigeons under a serial learning paradigm. The procedure used in this study, however, afforded even less stimulus support than either the Richardson and Warzak (1981) or Straub et al. (1979) procedures. This serial learning task presented the stimuli one at a time and required that the pigeon make a decision at each stimulus presentation as to whether that stimulus was the correct or incorrect stimulus to continue the chain and, if incorrect, to search for the correct stimulus until found. This decision-making occurred through the use of a changeover key which, when pecked, would change the stimulus presented.

This procedure more closely follows the example of
stimulus stringing provided by the temporal maze (Hunter, 1920, 1929). The temporal maze consisted of two adjacent
loops sharing a central path which led away from a starting point. Correct performance on this apparatus re-
quired that subjects make a predetermined number of turns
in one direction and then in the other direction. A
significant feature of this apparatus is that no specific
stimuli in the external environment changed during the
sequence so that the only stimuli controlling the sub-
ject's response at any point were those surrounding the
response made previously.

The similarity to the present experiment is shown in
the constancy of cues present at any given point. Al-
though the color stimulus presented changed, there were
no other stimuli present to cue the next response and the
only stimuli controlling a response were those associated
with the response to the previous stimulus.

The format of the present study also makes the actu-
al decision-making behaviors of the subjects more expli-
cit. The presentation of one stimulus at a time and the
use of a changeover key to change the available stimulus
allowed the observation of the subject's response to each
stimulus in the chain and also the response of
"switching" to obtain the next stimulus in the chain.
METHOD

Subjects

Three experimentally naive White Carneaux pigeons were the subjects for this study. All subjects were maintained in a state of food deprivation at approximately 80% of body weight throughout the experiment.

Apparatus

The experiment was conducted in two operant conditioning chambers containing three response keys, a grain feeder, and a house light. A white noise was continuously present and a fan provided ventilation. The response keys, feeder and house light were all centered on one wall of the chamber. The response keys were 8 cm apart and were aligned in a horizontal row above the grain hopper. The grain hopper was situated in the lower right hand corner of the chamber wall and was illuminated when food was delivered (See Figure 1). A PDP/8A computer by Digital Equipment Corporation controlled the experimental program and data collection.
Figure 1. Schematic Drawing of the Experimental Panel as Viewed by the Subjects.
Procedure

Terminal Experimental Task

For this experiment, the row of three keys functioned as follows: the left key was the changeover key (CO) and was used to change the color which was present on the center key or color key (CLR). The right key was the intertrial interval key (ITI) which the pigeon pecked to begin each trial. The experimental task was to peck the colors presented on the CLR key in the sequential order: YELLOW-GREEN-RED using the CO key to change the color presented on the CLR key until the correct color in the sequence was presented. The CO key was also used to change the correct color once it was pecked.

At the beginning of each session, the lighted ITI key was presented while the other keys remained dark. A peck to the ITI key initiated the trial. The ITI key remained lit until pecked by the pigeon at which time this key became dark and both the CO key and the CLR key were simultaneously activated. The CO key remained an amber color during the entire experiment while the color on the CLR key was randomly varied between the colors yellow, red and green. A correct sequence was to peck the CLR key first in the presence of yellow, then in the presence of green and finally in the presence of red using the CO key to change the color present on the CLR key and obtain
the next correct color in the chain. A correct response to the color key resulted in a 0.3" darkening of the CLR key concurrent with the presentation of the correct color on the adjacent key (or ITI key) for 0.3". A correct response to the CO key resulted in a change in the color presented on the CLR key. Incorrect responses to the CLR key resulted in a stimulus-free time-out condition where the chamber was completely darkened for 15 seconds after which the ITI light again came on and the pigeon could start another trial. Correctly completing the entire sequence with no incorrect responses to the CLR key earned access to grain for 4 seconds.

The subjects were presented with three conditions of increasing complexity. During the Training Condition all responses were strictly programmed and any incorrect responses to either CO or CLR key resulted in punishment. Also, a correction trial consisting of the sequence in which the error occurred was presented until the pigeon had correctly completed that specific sequence. Following this, the sequences were again randomized. During Condition I or the First Generalization Condition, the pigeons continued to be punished for any incorrect responses to CO or CLR keys but the correction trials were not presented following an error. For Condition II, or the Final Generalization Condition, multiple responses to the CO key were not considered errors but simply resulted
in another change of the color on the CLR key.

Nine different random arrangements of the three colors were used during the experiment with three different arrangements per condition. The arrangements presented during the training condition and the final generalization condition (Condition II) were based on the six possible variations of the colors. The arrangements presented during the first generalization condition (Condition I) also used the CO key response as an extra variable. (See Table 1).

Training Condition

The training condition was divided into three phases. During Phase I in the training condition, all subjects were initially conditioned to eat from the hopper. Auto-shaping was then used to condition responses to a lit key; in this case, the ITI key. Once the subjects were consistently responding to the ITI key when lit, training was begun on completion of the correct sequence. A backwards chaining method was used to teach the correct chain of responses beginning with correctly responding to the CLR key when the color red was present. Training on the CO key was also included as part of the chain. Following this order, the pigeons were first trained to correctly peck the color key when it was red to obtain food. They then were required to peck the CO key to turn on the red
Table 1

Sequences of Colors During Each Experimental Condition

<table>
<thead>
<tr>
<th>Condition</th>
<th>Sequence Number</th>
<th>Sequence Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training</td>
<td>1</td>
<td>Y-G-R</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>R-G-Y-R-G-Y-R</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>G-R-Y-G-R</td>
</tr>
<tr>
<td>Condition I</td>
<td>4</td>
<td>Y-R-G-R</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>R-Y-G-Y-R</td>
</tr>
<tr>
<td>Condition II</td>
<td>7</td>
<td>R-Y-G-R</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>G-Y-R-G-Y-R</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>Y-R-G-Y-R</td>
</tr>
</tbody>
</table>

color on the CLR key, then peck that key to obtain food. Following this, the first color presented on the CLR key was green and the pigeons needed to peck the CLR key when it was green to turn on the CO key and then peck the CO key to change the color on the CLR key to red which they could then peck to obtain food. The pigeons were then trained to peck the CO key to turn on the CLR key which was green and then continue through the sequence. The same backward chaining steps were used to train responding to the CLR key when it was yellow and also to train using the CO key to change the yellow color on the CLR
it was necessary to train the pigeons to respond to the CLR key both in the absence of the other key and in its presence so as to teach the chain of colors and also the function of the CO key in obtaining the next correct color in the chain. At the completion of this training phase, the subjects were able to respond correctly to the entire sequence of stimuli. A correct chain of responses to this sequence consisted of first pecking the CLR key when it was yellow, then pecking the CO key to change the yellow color to green, then pecking the CLR key when it was green, then pecking the CO key to change the green color to red and finally pecking the CLR key when it was red to receive reinforcement.

During Phase II in the training condition, the pigeons were presented with a sequence in which the colors did not appear in the correct order. This sequence required that they "peck past" one or more incorrect colors using the CO key to change the color on the CLR key until the correct color in the sequence appeared on the CLR key. A correct response at this point consisted of pecking the CLR key and then pecking the CO key to obtain the next color in the chain. The sequence presented in Phase II consisted of the three colors which appeared on the CLR key in the following order: G-R-Y-G-R. Therefore, to correctly complete this chain the pigeon must peck first the CO key to change the green color on the CLR key, then
peck the CO key again to change the red color on the CLR key. At this point the yellow color appeared on the CLR key and the pigeon needed to peck that color and then again peck the CO key to change the yellow color on the CLR key. The next color up was green, so the pigeon needed to peck the CLR key and the peck the CO key to change the green color on the CLR key to red. The pigeon could now peck the CLR key when it was red and receive reinforcement. Any incorrect pecks to either the CO key or the CLR key resulted in a 15 second time-out and then a re-presentation of the sequence. Once the pigeons were responding at a high rate of accuracy on this version of the sequence, this sequence was presented in conjunction with the first sequence on a random schedule.

Phase III in the training condition consisted of a third sequence where the three colors were presented in a varied order. The pigeons were still required to only respond to the correct order of colors (yellow first, then green and finally red). The sequence of colors which appeared on the CLR key for this variation was: R-G-Y-G-R. This sequence was not trained separately but was presented first on a random basis with the sequence in Phase II. Following that, all three sequences were presented together on a random schedule.

For the purposes of data collection, each response was considered a "choice" and each CO/CLR key configura-
tion was considered a "choice point." The computer tallied the number of correct and incorrect responses at each choice point. Correct or incorrect responses included not only responses to CLR keys but also responses to CO keys. For instance, pecking the CLR key when it was green at the beginning of a trial constituted an error as did pecking the CO key before pecking yellow when the CLR key was yellow at the beginning of a trial. Pecking the CLR key when yellow and then the CO key to change to the next color constituted two correct responses ("choices") to the same configuration. More than one peck to either the CO key or the CLR key were also considered errors.

Data were also collected on number of incorrect trials and latency to choice responses. Data were analyzed in terms of percentage of correct responses at each "choice point."

**Condition I (First Generalization Condition)**

During this condition three entirely novel sequences of the same three colors were presented in a random order. These sequences consisted of color presentations on the CLR key in the orders: Y-R-G-R, R-Y-G-Y-R, and G-Y-R-Y-G-R. Incorrect responses to both the CO key and the CLR key again resulted in a 15 second darkening of the chamber, however, correction trials were no longer presented after an incorrect response and conclusion of the time
out. The additional feedback for correct responses to the CLR key was continued. The sequences presented in this condition all required the subject to "peck past" incorrect colors to find the correct color and also included the additional task of requiring the subject to "peck past" a color that had already been correctly responded to earlier in the sequence.

This condition was an intermediary step between the training condition with its many experimental controls and the final condition with minimal experimental controls. This condition also functioned as an additional training condition as the pigeons were for the first time exposed to sequences where they had to peck past only one incorrect color before being presented with a correct color.

**Condition II (Final Generalization Condition)**

The final condition consisted of again presenting three novel sequences of the same three colors. The sequences presented in this condition were: R-Y-G-R, G-Y-R-G-Y-R, AND Y-R-G-Y-R. During this condition incorrect responses to the CO key did not result in punishment and were not counted as errors. Continuing to peck the CO key simply resulted in a change in the color on the CLR key. Therefore, it became possible for a subject to "miss" a correct color and then "peck around" the se-
quence until that color again became available, respond correctly to that color and continue in the sequence. Incorrect responses to the CLR key (i.e., responding to a color out of sequence) continued to be treated as errors and were consequated with a 15 second darkening of the chamber. Correction trials were not presented following completion of the punishment contingency, but the feedback for correct color pecks was continued.
RESULTS

All three subjects learned the experimental task and generalized to novel presentations at a high level of accuracy. Accuracy was computed both according to the number of correct choices made per sequence and according to the number of trials correctly completed per session. Probability of correct responding was computed at 0.5 for choice responding and from 0.002 to 0.03 for completion of a correct sequence depending on how many responses were required for correct completion of the sequence.

Acquisition data on percentage of correct "choice" responding are shown in Figure 2 for Phases I, II and III during the Training Condition. All three subjects showed the most disruption when Phase II was introduced. None of the subjects successfully completed 30 sequences (number of sequences required for a complete session) in the allotted amount of time (approximately 1 hour) on this sequence during the first session. Subject 1 had one session with less than 30 sequences, Subject 3 had two sessions and Subject 4 had six. Subject 4 also required special experimenter intervention (the lit keys were manually changed from the computer panel to shape correct responding) before it was able to successfully complete 30 sequences on Phase II.

There was again a disruption when the sequence for
Phase III was introduced though not as severe as with the sequence for Phase II. Subjects 1 and 4 each had one session with less than 30 sequences and Subject 3 had two. None of the subjects required intervention from the experimenter to be able to complete the sequence for Phase III. This sequence was presented for 48 sessions before the pigeons reached a consistent accuracy which was longer than any of the other sequences except for the first sequence during acquisition.

Data for the percentage of correct choices and the percentage of correct trials are displayed in Figure 3 for Condition I and Condition II. All subjects were able to make the transition to novel sequences and less experimenter control (removal of correction trials for Condition I and removal of punishment for changeover responses in Condition II) while maintaining an accuracy that greatly exceeded chance performance.

Color errors

The percentage of correct choices was also broken down to show patterns of responding between the three colors. The average percent correct response to yellow, green and red for each sequence is shown in Table 2. Percentage of correct responses to each color was determined by calculating the number of correct responses to the actual color and the number of times the subject re-
Figure 2. Percentage of Correct Choices and Correct Trials for Each Subject During Sequences 1, 2, and 3 of the Training Condition.
Figure 3. Percentage of Correct Choices and Correct Trials for Each Subject During Conditions I and II.
sponded to the color by correctly pecking the changeover key to peck past the color. Both responses were considered to be a correct response to the particular color.

No significant differences or trends were determined to have occurred. Any differences noted between colors and sequences appeared to be due to individual differences among the subjects. Poorer responding to a specific color did not hold across sequences or conditions for any particular subject. There were also no significant differences based on length of a sequence (sequence length varied from five to nine responses required for completion) or position of a color within a sequence.

Latencies

Average latencies to a correct and an incorrect response for each sequence is shown in Table 3. Differences between latencies for correct and incorrect responses decreased across conditions. Latency of responding appeared to be based on differences between individual subjects rather than any changes in sequences or experimental conditions.
Table 2

Average Percent of Correct Color Choices for Each Sequence

<table>
<thead>
<tr>
<th>Color</th>
<th>Subject</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
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<tbody>
<tr>
<td>Yellow</td>
<td>1</td>
<td>94</td>
<td>85</td>
<td>88</td>
<td>97</td>
<td>83</td>
<td>81</td>
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<td></td>
<td>3</td>
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<td>91</td>
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<td>96</td>
<td>75</td>
<td>75</td>
<td>100</td>
<td>97</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>90</td>
<td>87</td>
<td>90</td>
<td>98</td>
<td>83</td>
<td>93</td>
<td>100</td>
<td>99</td>
<td>100</td>
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<tr>
<td>Green</td>
<td>1</td>
<td>89</td>
<td>91</td>
<td>88</td>
<td>96</td>
<td>96</td>
<td>95</td>
<td>73</td>
<td>90</td>
<td>86</td>
</tr>
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<td>87</td>
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<td>87</td>
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<td>89</td>
<td>77</td>
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<td>91</td>
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<td></td>
<td>4</td>
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<td>94</td>
<td>95</td>
<td>95</td>
<td>65</td>
<td>83</td>
<td>92</td>
</tr>
<tr>
<td>Red</td>
<td>1</td>
<td>96</td>
<td>95</td>
<td>91</td>
<td>96</td>
<td>97</td>
<td>95</td>
<td>87</td>
<td>82</td>
<td>89</td>
</tr>
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<td>98</td>
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<td>93</td>
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<td>91</td>
<td>87</td>
<td>79</td>
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<tr>
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<td>4</td>
<td>97</td>
<td>98</td>
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<td>90</td>
<td>98</td>
<td>86</td>
<td>89</td>
<td>96</td>
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Table 3
Average, High and Low Latencies

<table>
<thead>
<tr>
<th>Subject</th>
<th>Training Condition</th>
<th>Condition I</th>
<th>Condition II</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Seq 1/2</td>
<td>Seq 2/3</td>
<td>Seq 4/5/6</td>
</tr>
<tr>
<td>Ave</td>
<td>59  94</td>
<td>62  74</td>
<td>73  79</td>
</tr>
<tr>
<td>High</td>
<td>85  172</td>
<td>75  95</td>
<td>89  100</td>
</tr>
<tr>
<td>Low</td>
<td>46  71</td>
<td>54  60</td>
<td>65  60</td>
</tr>
<tr>
<td>Ave</td>
<td>133  175</td>
<td>93  114</td>
<td>98  115</td>
</tr>
<tr>
<td>High</td>
<td>365  339</td>
<td>118  153</td>
<td>116  146</td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
DISCUSSION

The purpose of the present experiment was to extend the study of sequential responding in pigeons by using a changeover key procedure which made the necessary stimulus scanning behavior of the subjects more explicit and thus more observable. This purpose was achieved since the birds learned to perform at a high level of accuracy and generalized the performance to novel arrangements of the stimuli on the color key. These results, along with those of Straub et al. (1979) certainly support the view that such sequential responding is not limited to humans or the higher primates. This finding should constitute encouragement for further efforts to study complex behavior in less expensive and easier maintained organisms, possibly even the kind of behavior that underlies human language.

In this experiment, as with Straub et al. (1979) there were no external stimulus changes produced by each correct response in the sequence, which makes the ordinary chaining interpretation difficult. However, a behavioral interpretation very similar to the one given earlier of the Straub et al. (1979) experiment would seem to apply. Here, instead of visual scanning consisting of movements of the head and eyes across the panel containing the keys, it consists of pecking the changeover key. This is a ma-
jor advantage of the present procedure since such scan-
ning can be more easily observed and experimentally mani-
pulated. The only difference between the two procedures
would seem to be the increased time required for scanning
in the present procedure as compared with that of Straub
et al. (1979). Presumably a pigeon can observe the four
lit keys in a fraction of a second when the behavior
involves only eye and head movements, all of which have
been previously well learned and are well maintained.
Scanning by pecking the changeover key is slower and only
gradually becomes well practiced. This would be expected
to have a detrimental effect in that the relevant unique
stimulus condition in each stage of the sequence of re-
sponses vanishes after each changeover response and its
control would presumably grow weaker with time since it
was last experienced. This, however, did not appear to
be a major problem in the present procedure as the
pigeons were able to learn the sequence and generalize it
to novel arrays while performing the individual responses
at high speed and accuracy.

Although a direct comparison with the procedure of
Straub et al. (1979) is not easy because of a number of
procedural differences, it seems clear that their sub-
jects achieved their final level of performance after
considerably less exposure to the training conditions
than did the subjects of the present experiment. Of
course, it is possible that this difference in ease of learning is due to some other difference between the two experiments, but the increased demand on memory of the present procedure seems the most likely explanation.

It would seem that the next step in this line of investigation would be to attempt to refine the procedure so as to generate effective sequential responding quicker, and thus to generate longer and more complex sequences. A possible approach would be to provide the birds with an opportunity to "refresh their memories" by having another key which permits a brief display of the relevant last stimulus condition. Thus, after pecking the changeover key at the beginning of a trial until yellow appeared on the color key, and then pecking the yellow color key the bird must next peck the changeover key until green appears on the color key. Assume that the first response on the changeover key resulted in red appearing on the color key, and also assume that it took the bird a few seconds to achieve this point in the performance--possibly due to distractions, irrelevant behavior, etc. At this point in time the control by having pecked yellow with the key and house lights staying on may have become weak. If there was another key that could be pecked which would briefly show a yellow color somewhere, such pecking might occur as long as it was useful, but would be expected to drop out of
the sequence naturally as the behavior came to be executed without it. If responding on the "memorandum key" did not drop out, such responding could be made more effortful by requiring multiple responses on it.

Another step might be to look at conditioning observing (or scanning) responses. From personal observation of the subjects in the present experiment, it appears that subjects which through accidental conditioning developed good observing responses, responded more accurately and showed a higher rate of generalization than those which did not. Possibly an analysis of those variables which control observing responses and the implementation of a procedure that would train the development of those responses would enable the consistent use of procedures requiring more complicated behavior from pigeons.

It seems that efforts such as those described above would be of value irrespective of theoretical interpretations of sequential responding, and would be expected to contribute information relevant to any potential interpretation.
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