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AD__________________________Accession No.______ Non-Classified

Institute for Behavioral Research
Silver Spring, Maryland

1. Psychopharmacology
Operant conditioning
Baboons

DRUG EFFECTS AND COMPLEX BEHAVIORAL REPERTOIRES UNDER CONDITIONS OF FULL ENVIRONMENTAL CONTROL

P. K. Levison, C. B. Ferster, J. D. Findley

Report No 3, 31 Oct 63, 17pp - 7 illus.
Contract DA 18-108-AMC-26-A-CP3-4025

2. DA 18-108-AMC
26-A-CP3-4025

A complex behavioral performance in which baboons "count" the number of objects presented to them visually is described. The effects of a CRDL drug upon the performance of a fully-trained animal are presented. Techniques for achieving and maintaining complex behavior in baboons are described. Graphs, cumulative records of behavior and photographs are included.

Non-Classified

FINAL REPORT

Drug Effects and Complex Behavioral Repertoires

Under Conditions of Full Environmental Control

Covering the Period
October 1, 1962 - September 30, 1963

Non-Classified
(Security Classification)

Contractor: Institute for Behavioral Research

Contract No.: DA 18-108-AMC-26-A-CP3-4025

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Date: October 30, 1963

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I. Introduction

The recent history of the experimental analysis of behavior has shown that behavioral techniques are being successfully applied to understand and control psychological phenomena of increasing complexity. The most favorable approach to understanding the "higher mental processes" - cognition, perception, symbolic functions, and memory - lies in making these "inner" functions accessible to study by arranging a specifiable interchange of the organism with the environment. This progress depends upon the careful establishment of explicit experimental histories in the laboratory, so that a precise account of each component of a complex process and its interrelationships with other components can be made. The step-by-step development of a complex task, completely novel to the experimental organism, provides a methodology for analyzing how complex problems are learned and how the accuracy of the performance is changed by relevant conditions. The work in our laboratory during the past year has been concerned with the development of procedures and environments leading to the establishment, maintenance and analysis in baboons of a type of complex behavior which we have called "counting". One baboon, Cowboy, now has a fully-developed counting repertoire up to the number 5, which can be consistently demonstrated at high levels of accuracy, permitting a meaningful assessment of the effects of psychologically-active drugs upon the performance. Another baboon has learned all the component behaviors of counting to 5, but at a lower level of accuracy. Two baboons are in preliminary stages of training. In the process of establishing counting behavior, new techniques have been developed which promise a more rapid acquisition of the performance in future experiments.

II. Counting as Complex Behavior

"Counting", as we use the term to describe the laboratory performance of a baboon, is limited to an elementary sample from a class of behaviors to which we refer when we attribute "the ability to count" to a person. The animals are presented with the problem, a visual pattern containing a number of identical elements (e.g., two triangles). There are at present five different patterns containing from one to five elements. To "count", the animal presses a lever producing a tone at each discrete press. In a correctly-performed problem, the baboon presses the lever until he has generated a number of tones equal to the number of elements in the visual pattern on that particular problem. A second lever is pressed to "give an answer", after the baboon "decides" that an appropriate number of tones have occurred. If the answer or <u>register response</u> is correct, a higher-pitched tone immediately results. An incorrect answer is followed by a brief "time-out" period (which is literally <u>time out</u> from the opportunity to obtain food), all the lights in the chamber go out and the levers become non-functional. After the baboon has counted on the visual problems 1 - 5 in a sequence, he is automatically reinforced or rewarded by the delivery of a food pellet. A food pellet delivered at the end of the counting sequence insures that the baboon will continue to produce counting responses. In a similar, but less-powerful fashion, the high-pitched tone after a correct response supports the animal's behavior through the sequence of problems prior to the reinforcement. At a later stage of development, the baboon may be required to go through the sequence two or three times before the pellet is delivered.

An analogy to this type of counting might be seen in a first grade classroom. The teacher shows a picture of five apples to her class and asks if anyone can count the apples. A pupil recites aloud, "one, two, three, four, five". Certain similarities and differences with respect to the baboon counting are evident. The two sets of stimulus objects can be closely equated. In the classroom, the pupil's counting performance consists of responding with five different, complex sounds--the words, "one, two, etc." in a specified sequence. For the baboon, the equivalent response to saying, for example, "five", is to press the counting lever five times, then register the count on the second lever. The baboon's task would appear to be relatively more demanding, for he must "remember" the number of tones he has produced before he makes a register response. This memory storage must be accomplished presumably without the benefit of any other numbering system; that is, if we were given the baboon's task, we would overtly or covertly label the tones "one, two, three, etc." as they were produced, and thus need only to remember the number which labels the preceding tone in the sequence. (In listening casually to the baboon performance, observers do indeed sometimes lose the count and incorrectly anticipate a register response.) We have elected to require this degree of complexity of the baboon in order to investigate memory, rhythmical pacing, and the effects of progressively more difficult problems. A complex behavioral repertoire consists of sequences of simple behaviors unified by a terminal event - the reward, or technically, the reinforcement. A simple behavior is characterized by its "on-off" properties; it is a single response, such as pushing a button, which the organism is "free" to perform or to withhold. The sequences or chains of simple behaviors which constitute a complex unit are alternatives to one another. At each stage in the performance at which another response is necessary, the animal has one or more alternative choices or options. Findley has extended the concept of the option to provide a suitable scheme of analysis for very large units of behavior.[1] In the counting experiments, the baboons are "free" to press any one of three response switches. A large number of alternative sequences are possible for responding on the three switches at the "choice points" offered by the presentation of programmed stimuli. However, a very limited number of sequences are

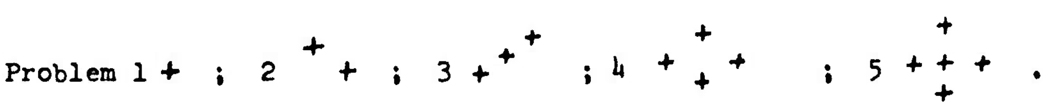
[1] Findley, J. D. An experimental outline for building and exploring multi-operant behavior repertoires, J.Exp.Anal.Behav.,1961,monograph, January, 1961.

terminated by reinforcement. Some of the options are reversible; the animal presses the wrong button or lever without any negative consequences, proceeds to the correct one, and continues the sequence. Most options are irreversible; pressing the wrong switch results in a change in conditions. The animal can proceed no further, but must return to some previous stage and try again. In the counting sequence which will be described below, there are a great many options provided by the three switches and six basic stimulus conditions.

One important property of the counting performance is that very large units of behavior (complicated sequences of responses) are produced and maintained repeatedly by single reinforcing events. In complex human endeavors, large amounts of behavior are similarly supported by an infrequent paycheck, a word of approval, or a desirable rating.

III. The Experimental Environment

The baboon chambers - The baboons live continuously in the experimental chambers which are designed to serve all maintenance functions. The chambers are approximately 48" high by 60" long and 40" wide, of heavy plywood construction inside and out, covered with stainless steel. One side is plexiglass and contains a sliding door which can be opened to transfer the animal. A cover of the same construction as the plywood walls can be lowered outside the plexiglass for greater visual and auditory attenuation. The general features of the chambers are shown in the photographs in Figure 7. Three of the photographs show the baboons facing the intelligence panels in various stages of counting. One picture depicts a drug-injection technique developed in the laboratory. There is a bench on the wall opposite the intelligence panel for sitting and sleeping. A removable bedding pan on the floor is filled with cedar shavings which are periodically replaced. The chamber is ventilated by a blower system. Water is always available from a drinking tube mounted through the intelligence panel. The intelligence panel itself contains a window in the center into which a visual display projector and screen unit (IDD unit) is mounted. The patterns which form the problems for the counting routine are projected onto the screen. In the photographs of the counting animals, it will be noted that the elements of the visual counting display are small white crosses on a dark background. The patterns used are as follows:



In order to facilitate ease of visual recognition, more differentiated patterns of white disks on dark or colored backgrounds are being used with the two new baboons. An opening on one side of the panel provides access to a food bin. Two lever action switches, one below the display window, and one above the food bin, and a plastic button switch to the right of the window define the responses when they are operated. A "house light" which provides illumination for the entire chamber is mounted at the top of the panel.

Controlling and recording equipment - The baboon chambers are connected by cables to electrical, electro-mechanical and electronic controlling and recording equipment, mounted on vertical channels in an adjacent part of the laboratory. Switching, stepping and timing circuitry is organized into flexible systems which provide extremely accurate control of both the presentation of stimuli and the recording of the baboon's behavior and its consequences. Correct register responses and error responses for the particular problems, total responses, and total reinforcements are recorded numerically on counters and graphically on cumulative recording devices. The cumulative records present a detailed description of overall changes in the number of correct responses and of error responses over time. At present, an automatic photographic system is being developed to obtain samples of the numerical response data at selected intervals over the course of an experimental session. This system will permit us to follow in detail with a high level of precision the changes in the occurrence of errors and correct responses at different phases of a drug effect. These data can now be obtained only by time-consuming and less-accurate copying of the counter readings. Photographic readings can be programmed as frequently as is necessary to provide a complete behavioral profile of the drug action.

Oral drug administration - A method for tapping into the baboon's water supply to administer accurate oral doses of drugs has been achieved. The water supply can be shut off on the night before an oral drug administration is scheduled. The baboon is therefore thirsty and strongly disposed to drink the next day. Before the drug session, the appropriate volume of the drug in solution is delivered into the drinking tube from a transparent bottle. After the baboon has finished drinking the solution, the water supply is reconnected and the apparatus is turned on to start the session. At present, this procedure is being used to train Cowboy to drink a bitter-tasting substance, quinine, in preparation for the oral administration of the tranquilizer chlorpromazine, which has a similar taste.

Transfer procedures - The animals may be easily removed from the chambers whenever necessary, through the use of a mobile transfer and holding cage. The animals' cooperation in the transfer procedure has been obtained by training them with appropriate food reinforcement techniques.

Full environmental control - There are many advantages to the system of full environmental control; that is, of maintaining the animal in the same environment in which he participates in the experiment. (1) If it is desirable, for instance, in a session in which a drug has been administered, the animal may be given continuous access to the experiment for long periods of time. Other experimental procedures which have an indirect effect upon the counting performance may be administered during the time that the counting routine is not available. (2) The extra-experimental environment is as carefully controlled as the conditions which are present during the experimental session. It is well known that events occurring between experimental sessions may have a profound effect upon the subsequent performance. (3) The possibility of the animal being disrupted by unforeseen occurrences during the process of being transferred from a living cage to an experimental cage is eliminated. (4) The novelty of entering a new situation; that is, the experimental situation, is minimized for an animal who has been living in an environment which is essentially the same, except for the absence of the specific experimental stimuli and consequences of behavior.

IV Detailed Description of Counting

The beginning of the experiment is signalled by onset of the house light. The plastic button switch is also illuminated, but the display window is empty. This condition (house light on, display out, and plastic button illuminated) occurs at the beginning of the session, after every correct register response, and after every time-out period. It will be referred to as the "set-up" condition. The baboon has learned to press the illuminated plastic button to "set up" each problem. The initial press turns off the light behind the button and produces problem 1, a single cross on the display. The baboon then presses the counting lever under the display once, producing a .3-second duration tone of medium pitch. If he presses again while the tone is on, all lights, including the house light, go out and the levers become non-functional for 1.5 seconds. This time-out condition acts as a mild punishment of the undesirable behavior, and is used to reduce the likelihood of similar occurrences in the future. Punishment for pressing during the tone results in a regular pacing or counting rhythm, which appears to facilitate accurate performance. The baboon has matched the count to the number of crosses on the display by pressing the counting lever once. If he then presses the register lever, the correct response is immediately signalled by a high-pitched tone, the display goes out, and the button stimulus light is turned on. A button press at this time results in two crosses on the display which must be matched by two tones produced by responding twice on the counting lever followed by a register response, etc. If the baboon makes a register response before producing enough tones or after too many tones to equal the number of crosses; that is, if he under-counts or over-counts, a 1.5 second time-out period results. These incorrect register responses will be designated error responses. Following the time out, the house light is turned on, the plastic button switch is illuminated and the display window is empty; that is, the set-up condition is in effect. In a typical performance, a food pellet is delivered down a tube from the automatic dispenser into the food bin after two successful completions of the counting sequence. The first correct answer to the problem of five crosses is followed by the high-pitched tone and the set-up condition. The problem sequence is automatically recycled to 1, so that the next press on the plastic button produces one cross on the screen. The successful completion of 5 on the second sequence is followed by the high-pitched tone and reinforcement, the delivery of the food pellet. The upper photographs in Figure 7 show Cowboy in two phases of counting. On the left, he is in motion on the rhythmical swing which precedes depression of the counting lever. On the right, he is depicted pressing the register lever. The other photograph of counting shows Dolores operating a modified intelligence panel which will be discussed in a later section.

V. Drug Experiment - Effects of a U.S. Army CRDL Compound upon the Counting Performance.

The entire counting performance of the male baboon, Cowboy, reached a level of proficiency and reliability which enabled us to evaluate the effects of an unknown compound supplied by CRDL on the behavior. Over the sequence of problems 1 through 5, prior to the beginning of the experiment, Cowboy was counting consistently, making less than one error response to every ten correct responses. We have used the size of the ratio of error responses/correct responses as our principal measure of the adequacy of counting; that is, as the number of errors diminishes in proportion to the number of correct responses, the size of the ratio decreases.

The CRDL drug was injected intramuscularly into the biceps muscle of the baboon. A special training procedure had preceded the experiment to "shape" Cowboy to offer his arm for injection, and to receive the drug without any disruption. The injection procedure is, in principle, suitable for intravenous administration as well. However, in the baboon, unlike the human, the appropriate vein is difficult to locate, so that any i.v. technique involves considerable risks of failure. After the injection, the experimental session was started immediately. The drug session lasted 27 1/2 hours. The experiment was run continuously for this length of time in order to account for the possibility that the drug effects would be relatively long-lasting. Normally, the experimental sessions are 8 hours in length. Graphs and records describing the drug effects are presented in Figures 1 through 6.

Figure 1 presents cumulative total responses (i.e., presses on the register lever) during the first 8 1/2 hours of the drug session. The total response curve is also divided into curves showing correct responses and error responses. A total of almost 480 responses were emitted during the first 1/2 hour of the drug session before the compound had time to become effective. The larger proportion of

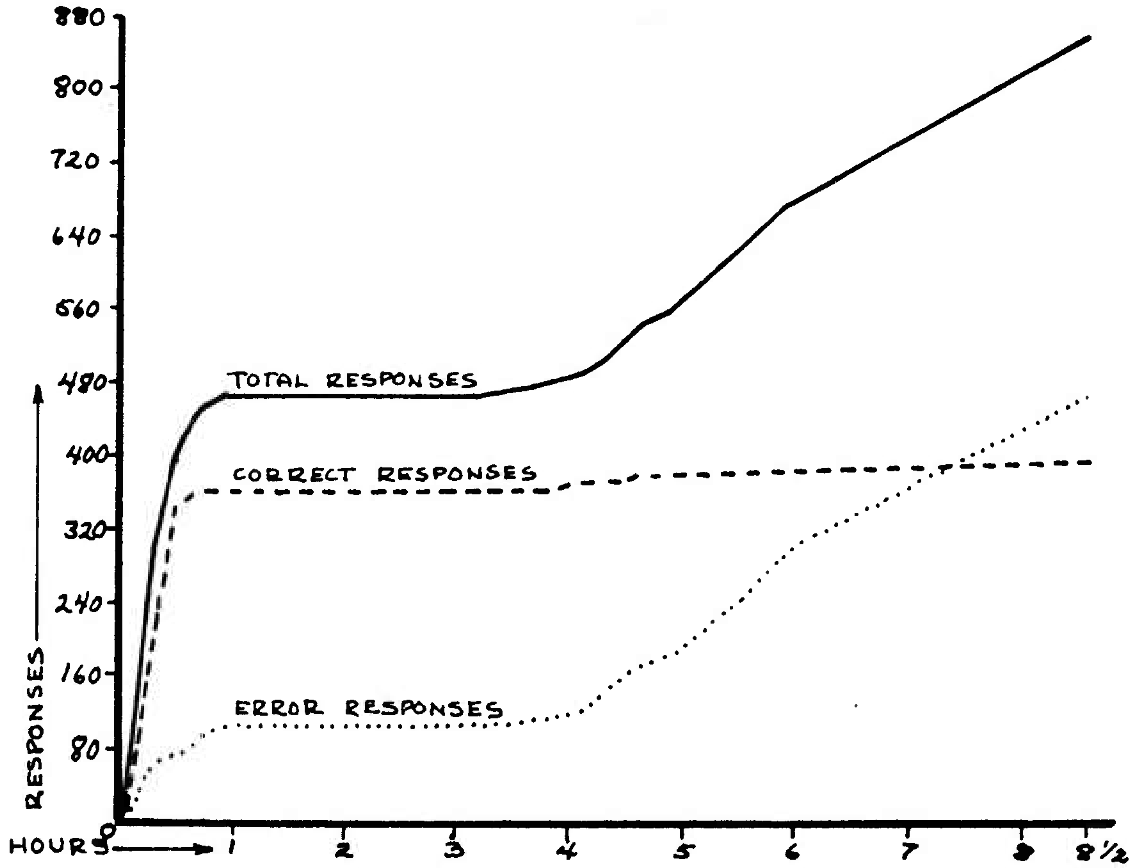


FIG. 1. CUMULATIVE TOTAL, ERROR, AND CORRECT RESPONSES OVER 8½ HOUR PERIOD FOLLOWING DRUG INJECTION.

these responses were correct responses, as indicated by the steep slope of the correct-response curve during this period. In less than an hour, all counting behavior had stopped and was essentially absent for 2 1/2 more hours. During this interval, Cowboy seemed otherwise alert and behaviorally responsive. At no time did Cowboy display abnormal drowsiness or loss of consciousness, gross loss of motor coordination, or unresponsiveness to movements of the observers outside the chamber. When counting was resumed after the third hour post-injection, the total response rate was approximately half that obtained before the onset of the drug effect. During this period, the error-response curve has almost the same slope as the total-response curve, indicating that nearly all responses emitted during the period when the animal again began to count up until 8 1/2 hours after the injection were error responses.

Figure 2 shows drug effects on the component problems of the counting schedule for the first 8 1/2 hours post-injection (it should be noted that the curve for problem 5 is discontinuous, omitting the portion from 6 1/2 to 8 hours, and that the scale on the ordinate is not linear from 2.0 to 3.0. These modifications on the graph were made in order to fit the most important data on the page). The more complex problems, that is, the higher counts, are relatively more disrupted by the drug. Except for a small inversion in the ratios of 3 and 4 which began at seven hours, the order of the problems which show increasing magnitude of the drug effect parallels the order of complexity of the problems.

The portions of the curves within the first half hour indicate that for problems 3, 4, and 5, performance improved slightly within the first half hour. This change represents improvement during an early "warm-up" effect. At the start of a session, there is frequently a temporary increase in the ratio of errors/correct responses before the baboon "settles down". The onset of the drug effect can be seen at the point at which the overall (mean) curve abruptly begins to rise after the early segment showing improvement of performance.

Figures 3 and 4 contain the cumulative correct response and error response records for the entire drug session, except for some portions in which responding was negligible. The records show in detail the behavioral changes over the drug session. A cumulative record is obtained when responses of an organism are electrically connected to a pen which moves laterally, in small steps, across a paper at the same time the paper is moving continuously from a roll at a fixed speed. In the present case, a register response operates the pen. Two cumulative recorders operate concurrently; one records correct responses (records marked A) and the other records error responses (records marked B). In effect, when the baboon is counting correctly at a high rate, Record A shows a relatively steep slope,

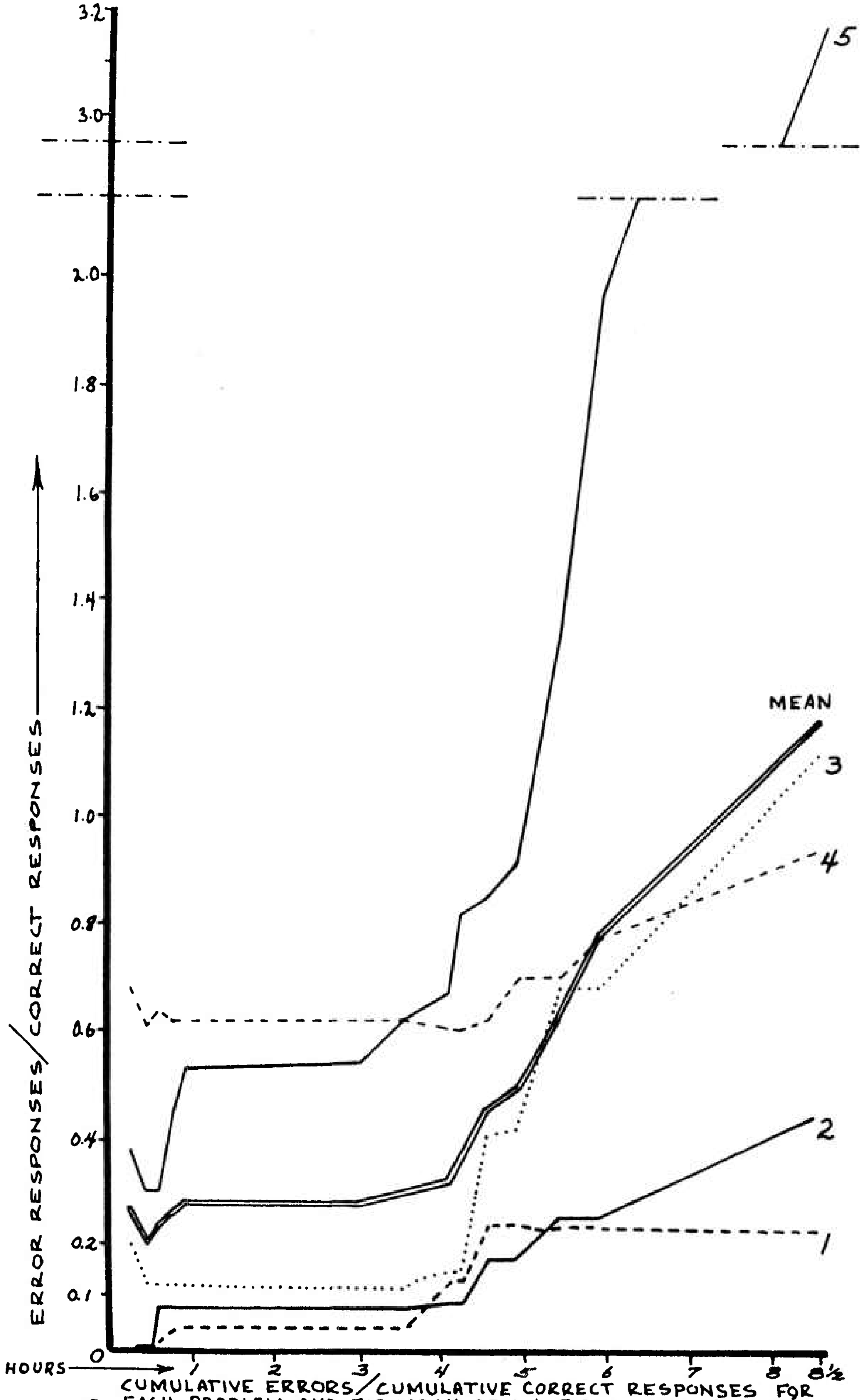


FIG. 2. CUMULATIVE ERRORS/CUMULATIVE CORRECT RESPONSES FOR EACH PROBLEM AND FOR MEAN OF ALL 5 PROBLEMS OVER 8½ HOUR PERIOD FOLLOWING DRUG INJECTION.

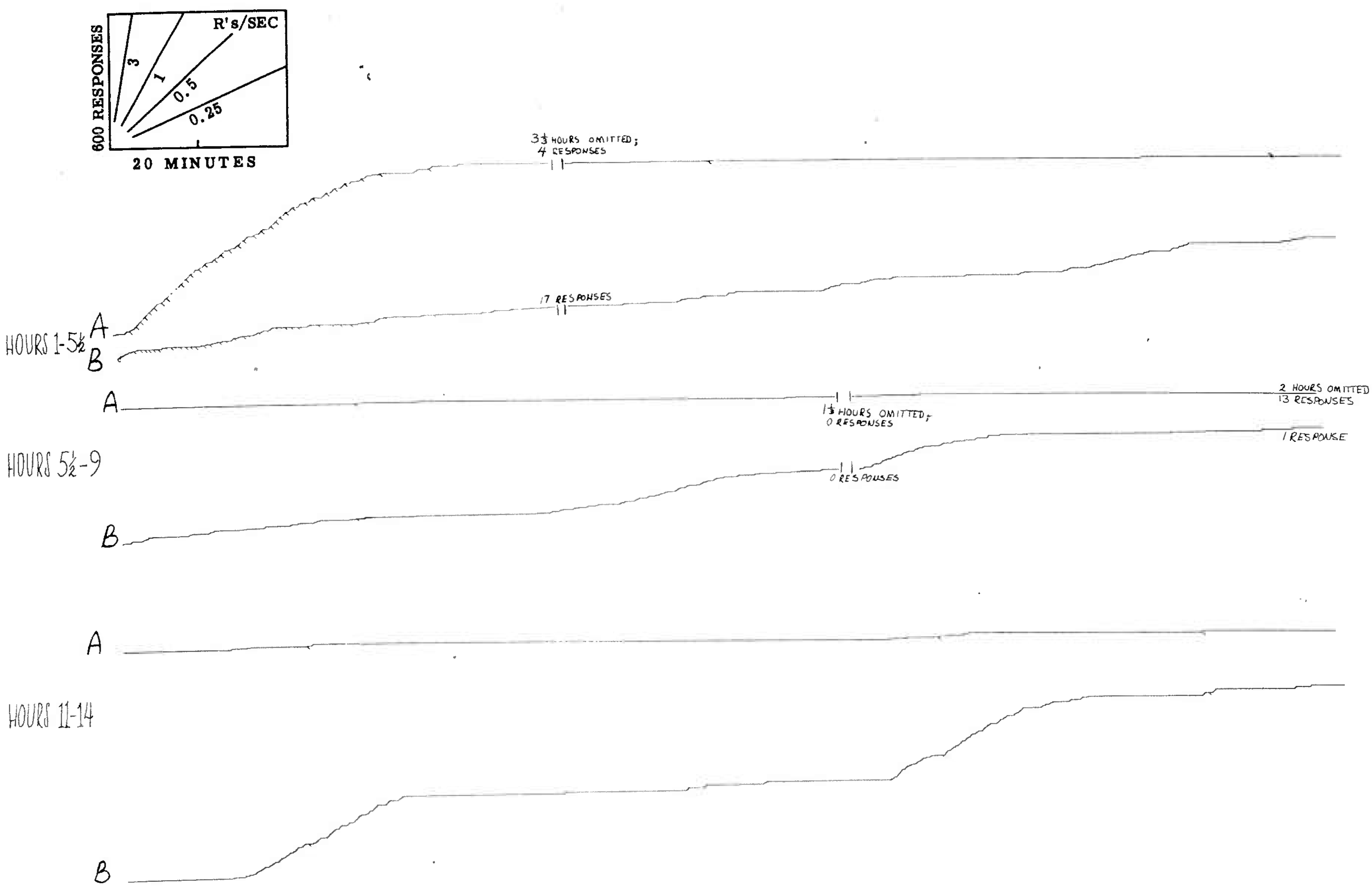


FIG 3 CUMULATIVE CORRECT RESPONSES [A] AND CUMULATIVE ERROR RESPONSES [B] FOR THE FIRST 14 HOURS OF THE DRUG SESSION

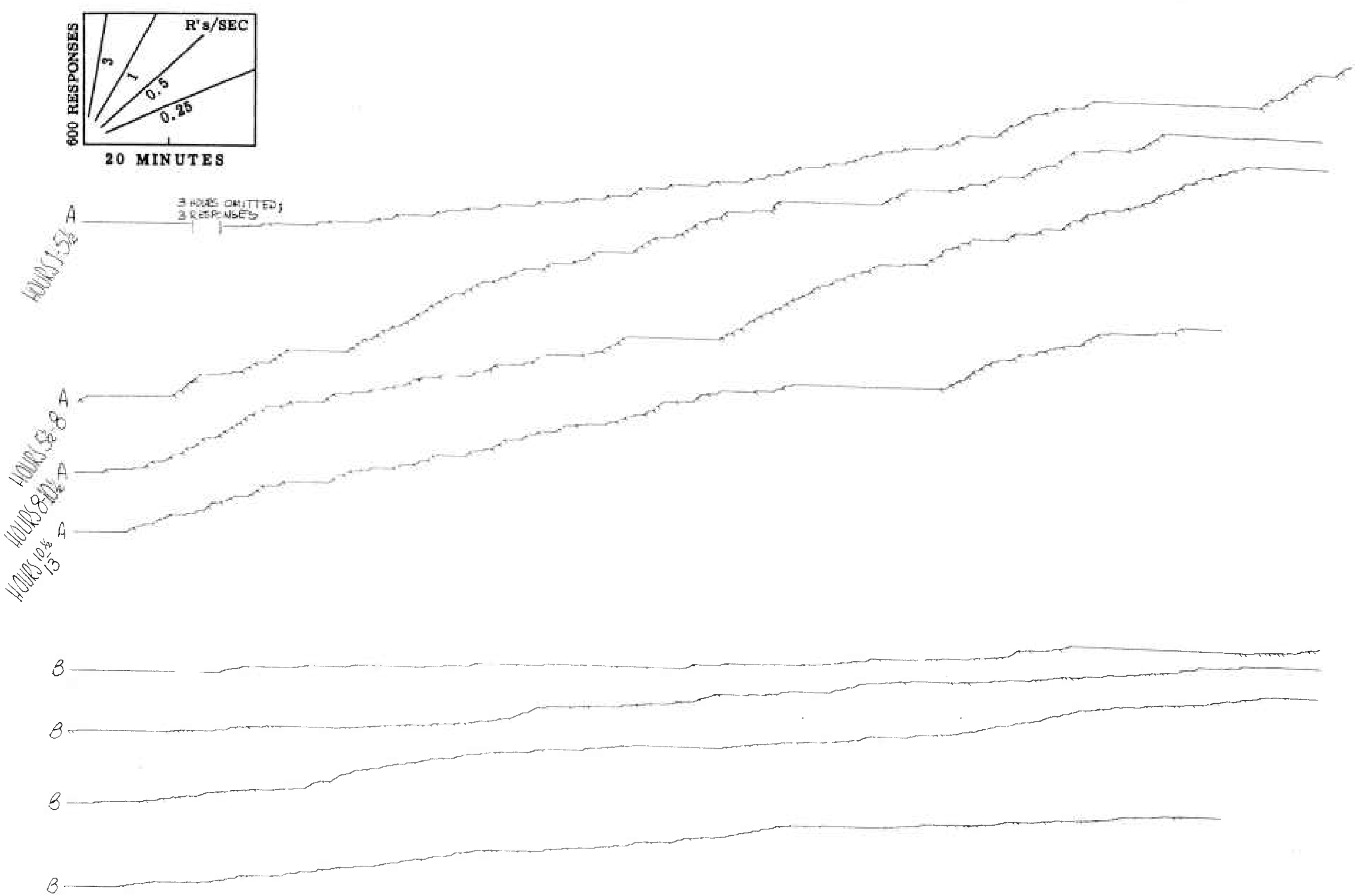


FIG 4 | CUMULATIVE CORRECT RESPONSES [A] AND CUMULATIVE ERROR RESPONSES [B] FOR THE LAST 13 HOURS OF THE DRUG SESSION e.g., the portion of the record at the beginning of the session. A horizontal line occurs on the record when no correct responses are being produced. The same relationships are true with respect to error responses on records marked B. The oblique "pips" of the pen on both A and B records occur when food pellets are delivered to the baboons.

Figure 3 shows the rapid transition from stable performance to the complete absence of counting after the first 1/2 hour post-drug. This effect appears in the two top records (A and B) in the figure. In Figure 3, which contains the first 14 hours of the drug session, the B record, or the error-response record, appears under its corresponding A, or correct-response record. Figure 3 shows that there was only a slight increase in error responding to mark the beginning of the period when Cowbody stopped counting completely. After the end of the interval in which there is no counting, error responding begins slowly at about the fourth hour post drug, and increases considerably by the sixth hour. This portion of the record represents the beginning of recovery from the acute effects of the compound.

Figure 4 presents the last thirteen hours of the drug session. The animal was beginning to show recovery during this period; therefore, the rates of correct responding were too high to permit placing the error record underneath the correct-response record in the fashion of Figure 3. In Figure 4, the top-positioned A record on the page which is marked, "hours 1 to 5 1/2" (actually, hours 14 to 18 1/2 of the drug session) corresponds to the top-positioned B record on the page, etc. Figure 4 indicates that no appreciable number of correct responses were produced until after 17 hours post injection. The last nine hours of the drug session show steady rates of correct and error responding, with considerable improvement over the earlier drug performance; that is, recovery from the effects of the compound became more rapid about 17 hours after the administration of the drug.

Figure 5 presents the ratios of total errors/total correct responses for each session over the seven days of the experiment. Volumes of normal saline equivalent to the drug dose were injected on the first and last experimental days as controls for the effects of the injection procedure. Both saline-day performance ratios of total error responses/total correct responses were about .10, indicating that there was no detectable effect of the injection procedure alone. On the drug day, there was a sharp increase in the total ratio. The greatest proportion of recovery occurred on the third day of the experiment, which was the first day after the drug session. The recovery portion of the curve is quite regular, with only one plateau occurring on the 4th to 5th days of the experiment.

Figure 6 presents the effects of the drug on the component problems over the seven sessions of the experiment. The ratios of

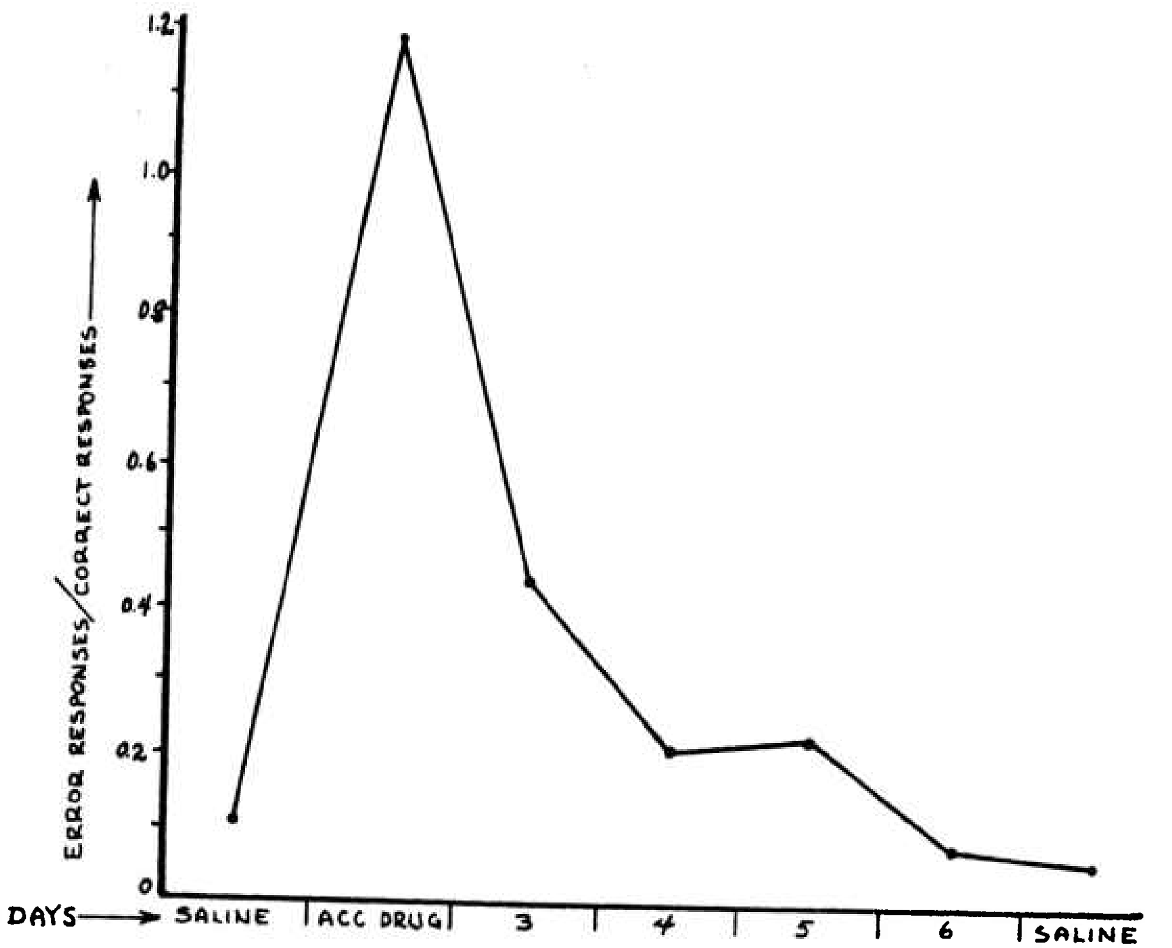


FIG. 5 TOTAL ERROR RESPONSES/TOTAL CORRECT RESPONSES FOR EACH OF THE 7 EXPERIMENTAL DAYS.

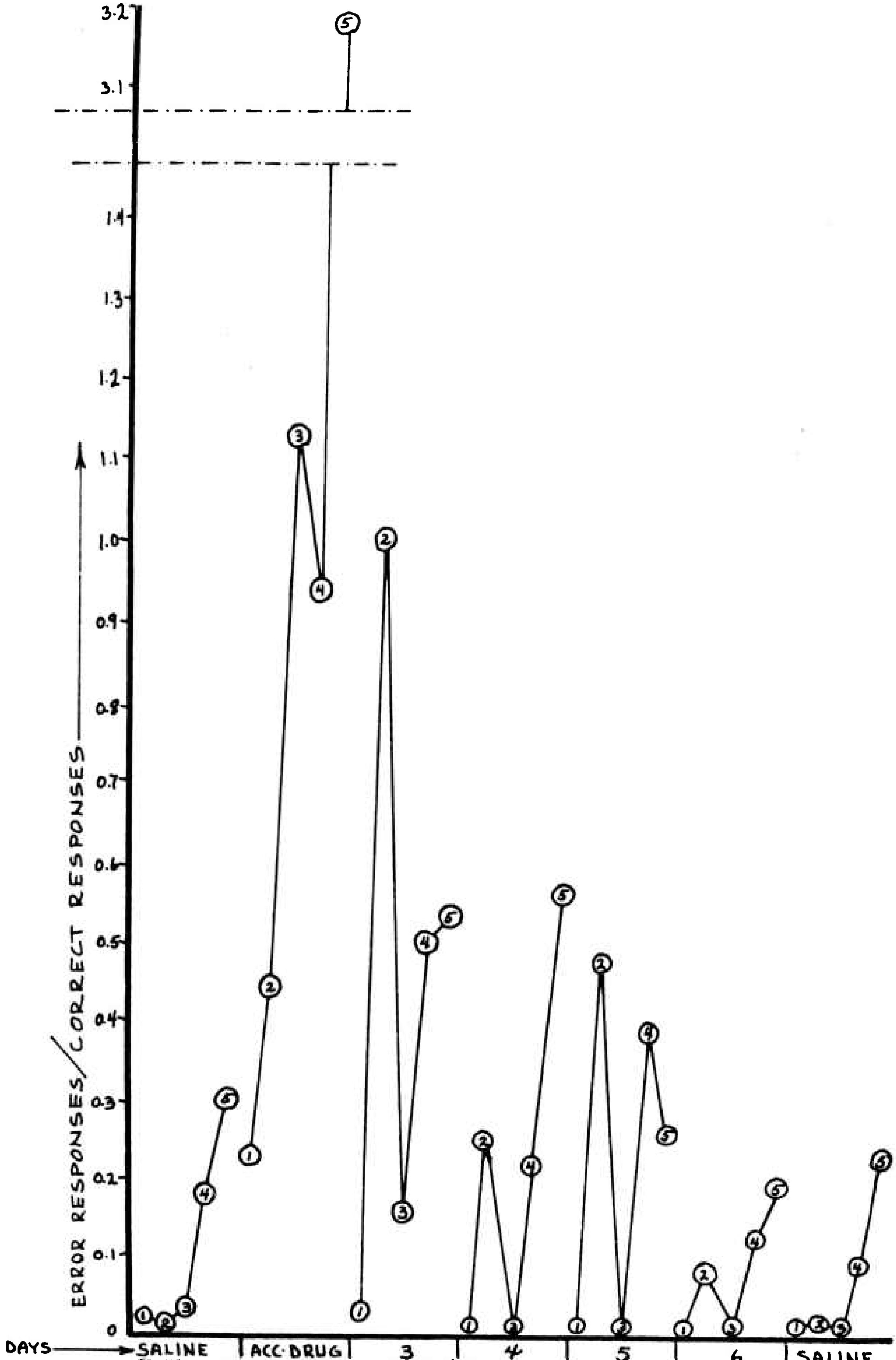


FIG. 6 TOTAL ERROR RESPONSES/TOTAL CORRECT RESPONSES FOR EACH PROBLEM ON EACH OF THE 7 EXPERIMENTAL DAYS.

total error responses / correct responses for each problem on every session are included. (The number within each circle on Figure 6 refers to the number of elements in the particular problem). The pre- and post-drug control sessions which followed the injection of normal saline have very similar curves: performance on problems 1, 2, and 3 is excellent; problem 4 produced a higher proportion of errors, and problem 5 produced the least accurate counting.

The greater sensitivity of the more complex problems to the drug which was described above for the first 8 1/2 hours, is seen even more dramatically in the totals for the entire session, presented in Figure 6. Although the values of the total error/total responses ratios increased for all problems over the control values, indicating a generalized drug effect, 3 and 4 increased more in proportion to their respective control-sessions than 1 and 2, and the proportional increase in 5 is the greatest of all the problems.

On the first post-drug (recovery) day, only counting on problem 1 had returned to control level. On the second day, 1 and 3 were at normal values, and by the fourth day only a slight elevation in the ratio for problem 2 presented any departure from control values. The marked rise in the ratio for problem 2 on the first recovery day is difficult to explain; however, the persistence of the change over the four recovery days indicates the presence of a systematic, if perplexing, effect, not the result of some uncontrolled event confined to a particular session.

Constant visual observation of Cowboy's general behavior was maintained during the first 8 1/2 hours of the drug session. The most relevant observed behaviors have been described as follows in a special report on the drug experiment:

"Three features of Cowboy's observed behavior are particularly noteworthy:

1. There was a complete absence of responding during the second and third post-drug hours. When counting was resumed, his performance, as previously demonstrated in the graphic data, was markedly impaired. The nature of the impairment is of particular interest. His behavior can be characterized as "going through the motions"of counting, but without appropriate consequences. That is, he frequently missed both the counting lever and the plastic set-up button; instead, he struck the wall or the bottom edge of the display window. He had great difficulty in locating the plastic button; the general topography or direction and sequence of counting motions was intact, but he would frequently register the inappropriate "count" after having missed both the set-up button and the counting lever on all responses in the sequence. Occasionally, he could be observed to produce the correct number of counting motions to match the number of crosses displayed, without having actually operated the counting lever once.

2. Twice during the period of observation Cowboy displayed

hallucinatory-like behavior. Within two hours post drug, he offered a baboon aggressive "challenge" to something, possibly his own reflection on the stainless steel back wall of the chamber. At about seven hours post-drug, Cowboy showed a marked fear reaction oriented toward the cedar shaving bedding on the floor of the chamber. He leaped onto his bench, stared at the floor, startled noticeably to an observer moving the bedding pan, and refused to resume responding for over an hour. Then, he climbed down very timidly, only after prolonged testing of the bedding with his fingers. Behavior resembling the "hallucinatory" episode never had been previously observed in Cowboy.

3. During the period of the drug effect in which no responding was occurring, Cowboy was offered a "free" pellet in the food bin, which he did not eat, and an orange slice, which he finally ate slowly, with very tiny bites.

In summary, the most important features of the drug effect are the following:

1. The baboon's counting performance was markedly impaired by the CRDL compound, although the animal did not observedly lose alertness or general motor ability.

2. The counting routine is differentially sensitive to drug-induced changes. The performance on more complex problems was relatively much more disturbed than on the simpler ones.

3. Two major types of disability occurred during the acute drug effect. For a period of 1 to 3 hours post injection, all counting behavior ceased and the baboon did not eat a"free" pellet when it was offered. After counting was resumed, the level of achievement was very low for several hours, although the baboon was frequently working hard on the routine. On simpler tasks, a drug effect is often evident only during the first of these phases; that is, when the animal is not disposed to respond. For example, if Cowboy's task had been simply to count on the problem <u>1</u> repeatedly, very little impairment would be in evidence after counting was resumed.

4. Two nearly identical control day performances were obtained with saline injection, one before the ACC drug session and one after the recovery was complete. The greatest impairment of counting was obtained on the drug day. The following four recovery days in general were characterized by gradual improvement to almost normal behavior. The long recovery period is an index of the sensitivity of the counting base line to intervention. The impairment on the recovery days may <u>not</u> be due to either direct action of an unmetabolized portion of the original dose remaining in the body or to some altered biochemical state consequent to the active compound which gradually returns to equilibrium; however, the recovery over four post-drug days may reflect a drug-behavior interaction. For example, Cowboy may

have learned some small but effective behavioral departure from his normal counting routine which was adaptive during the acute drug phase. Possibly, such an adaptation functions as an impairment when normal biochemical states are restored, and the behavior must be "unlearned" before previous counting efficiency can be regained.

VI. Development of New Behavioral Techniques

The behavioral aspects of our experiments during the past year developed techniques for rapid and efficient learning of the counting performance and for maintaining stable, accurate counting in the total performance. We have manipulated four major classes of behavioral variables: 1) stimuli - programmed lights and tones, controlling or "giving directions for" the counting responses, 2) responses - the arrangement and form of the response levers and buttons and the maximal rate at which counting may occur ("pacing"), 3) positive consequences - schedules of food delivery -- the correct response requirements which must precede the delivery of food reinforcements or rewards, and 4) negative consequences- punishments or extra work requirements which immediately follow the occurrence of error responses.

1. Stimuli - A baboon has two alternatives for learning the counting sequence which was described earlier in this report. (1) He may learn to recognize the differences in number and arrangement of the elements among the problems and to respond appropriately to a particular visual display, regardless of the order or sequence in which it is presented. (2) He may learn to respond correctly to the specific sequence of problems in the same fashion a child learns to say, "one, two, three, four, five" before he can correctly identify any of the respective numerals appearing on a page. In case (2) the baboon learns that two counting presses follow the correct behavior on problem 1, and that three counting presses follow the correct registration on problems 1 and 2, etc. We have deliberately maintained a procedure of adding a new problem in its proper numerical sequence once the previous problems have been mastered. The animal can therefore benefit from both the particular stimulus patterns of the problems and the sequence in which they are regularly presented. There is evidence that both kinds of stimulus control can have a beneficial influence on the performance. However, a drawback of learning the sequence is that any interruption in the regular rate of advancing through the counting chain disrupts the animal by making too great a requirement of "memory" for the previous problem when counting is resumed. Cowboy has responded successfully to both types of stimulus control. He can frequently be observed to stop and then to count correctly on the new problem after behavior is resumed. However, his proficiency on an interrupted routine diminishes with the more complex problem. A deliberate interruption by the experimenter's striking the chamber after Cowboy has finished counting 4 will quite reliably result in an incorrect count on problem 5. Dolores, the female baboon, has depended more heavily upon the problem sequence and is relatively poor at "restarting". Therefore, she is currently training on a random sequence of problem presentation in order to "force" her to make use of the differences in the arrangements of display elements. The training plans for the new baboons include

prior acquisition of the ability to count corrsctly on particular problems, regardless of the sequence. Later on, specific sequences, including *1* to *5*, will be used for several consecutive sessions in formal experiments designed to assess the extent to which dependence on either sequence or visual pattern can be controlled.

The effects of visual pattern stimulation alone upon counting can be further evaluated by making the patterns more or less similar. Obviously, the more nearly the collection of visual objects making up a problem resembles the patterns for other problems, the more difficulty the baboon has in discriminating or "telling them apart", and therefore, the more likely he is to count incorrectly. The greatest number of error responses are now obtained on problems *4* and *5* which are displayed as the patterns

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  +          +
+   +  and  + + +
  +          +
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, respectively. This pair of patterns is more alike than any other pair which, along with the increased complexity of the higher numbers, probably contributes to the high proportion of error behavior on *4* and *5*. The new baboons are being trained on displays in which problems 1 to 5 are represented by more easily discriminated patterns. Also, a specific color is associated with each pattern as the background for the white elements. The elements on this new display are white discs in place of the white crosses of the original display. The addition of colored backgrounds also offers the advantage of further manipulation of the visual stimulus control of counting. For example, either the colors or the elements can be "faded" out to increase the difficulty of the problems or to study abstraction processes.

Another source of stimulation in the experiment is the tone produced by the counting response. The tone signals that a counting response has been effectively made. It may be recalled that one of the surprising results of the CRDL compound was the loss of this component of stimulus control. Cowboy made the counting motions, but frequently failed to operate the lever. Nevertheless, he registered the count by pressing the register lever as if it had been effectively completed.

The counting tone also contributes to "remembering" how many counts have been produced in order that the correct "answer" can be given. Cowboy occasionally makes one or more poorly-directed counting motions similar to those observed regularly during the CRDL drug experiment, so that the counting switch is not operated and no tone or other consequence is produced. He consistently corrects himself, however, by continuing to count until the required number of tones have been generated. In other words, he makes too many counting motions, but registers after producing the correct number of tones. He is, in a sense, "keeping track of the number of tones". If it should be desirable to increase the difficulty of the memory component, the tones could be lengthened appropriately.

Another stimulation factor is the effect of adding a new problem after the previous problems have been learned. An obvious result is that the animal with no prior training on the new problem initially makes nothing but error responses when the new problem is displayed. The baboon will attempt to count correctly in the presence of a new problem by varying his behavior. He has learned that any visual display generally resembling the other displays is an "instruction" to count, but the correct number of counting responses must be learned from the beginning with each new problem.

A second and more interesting effect of adding a new problem is that the performance on the earlier problems is disrupted; for example, the baboon may have a good performance on 1 and 2 with an overall ratio of error responses/correct responses of .15. After the problem 3 is added, the animal must now count on 1, 2, and 3; the ratio for 1 and 2 analyzed separately rises to .60 (These are actual data taken from a retraining procedure which will be described below.) However, efficient levels of counting on 1 and 2 are regained in much less time than the original acquisition.

2. Responses - The particular movements the baboon makes in executing the counting performance are determined in part by the properties and arrangement of response switches on the intelligence panel and in part by the structure and behavioral history of the animal. The counting routine on which Cowboy and Dolores were trained closely resembles the description given earlier under Detailed Description of the Counting Performance. The two uppermost pictures in Figure 7 show, from left to right, Cowboy counting and Cowboy registering his count. Analysis of the response patterns indicated that some modifications would improve this performance. The principal problem which had developed was that the baboons, particularly Dolores, were positioning themselves in front of the register lever, orienting toward the terminal event, the food delivery, and consequently weakening their attention to the stimulus display. On some reinforcement schedules, the animals received more than one pellet on every reinforcement after completing the requisite sequence of problems. They were required to deliver the extra pellet themselves, by additional presses of the register lever. The schedule was modified so that multiple pellet delivery became completely automatic in order to reduce the disposition to press prematurely on the register lever.

Dolores had developed such strong tendencies to respond on the register lever that a complete rearrangement of responses seemed the best program for further development of good counting. A new intelligence panel was designed; a photograph of Dolores counting on it is presented in the lower left-hand corner of Figure 7. Counting responses are now executed on a plastic plate mounted in front of the stimulus display; presses on the plate mechanically operate switch contacts. The register lever was mounted below the display in the former position of the counting lever and was modified in shape and in the direction in which it moves. The plastic button switch and the food bin were also relocated.

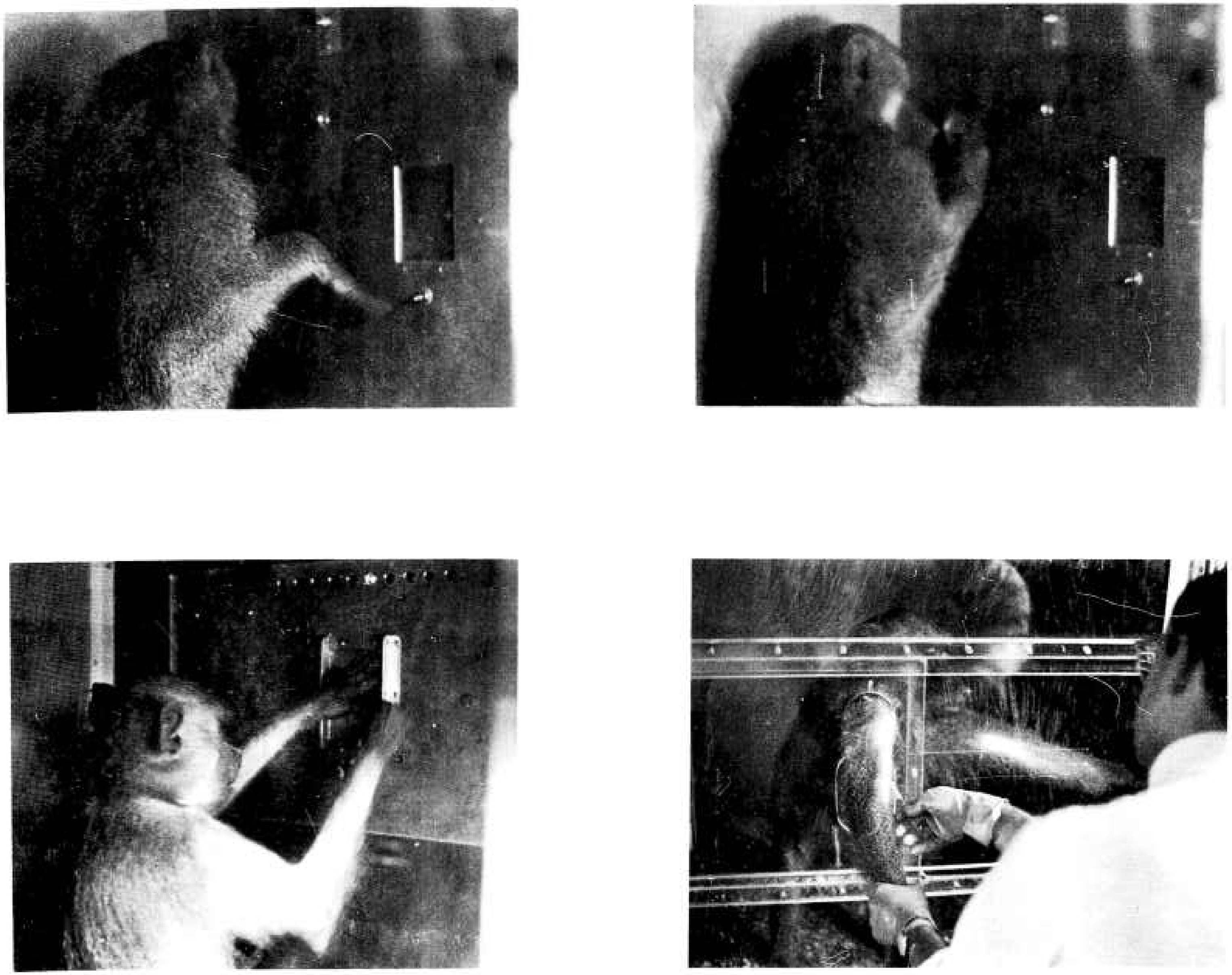

Fig. 7

Relearning was very rapid. Within a week, Dolores was counting more accurately than her performance prior to the change. This quick acquisition of a new set of movements and response switches indicates the surprising generality of this complex behavior. The baboon"knows" more than a highly specific sequence of movements in response to stimuli. She "knows" a complex routine into which presumably a wide range of motor responses could be readily assimilated.

The stimulus tone produced by the depression of the counting lever has an important consequence for one of the response properties of the counting routine. It will be recalled that if the baboon counts again before the previous tone is terminated, a brief time-out period results. This requirement forces the animal to "pace" his counting with the result that an even rate of pressing is developed. Establishing a steady pace appears to be very beneficial to good performance. For example, before the drug experiment Cowboy had a very high, even counting rate. In the disruption and reacquisition of good performance following drug administration, he developed a regular but lower counting rate. In a recent experiment, Cowboy was rested a day and given no food for 24 hours. Food deprivation appears to increase counting rate. When he abandoned the steady low rate for a higher rate, severe impairment of the performance occurred. It is noteworthy that Dolores has a much less regular counting pace than Cowboy, which probably contributes to her less-accomplished performance.

3. <u>Positive Consequences</u> - Large differences in level of performance can be obtained by changing the amount and distribution of work required for the baboon to obtain food pellets. For example, if the animal were reinforced with a pellet for <u>every</u> correct response, the overall ratio of error/ correct responses would be high. It is too "easy" for him to get food. Even an error response/correct response ratio of 1.0, which is not acceptable for a useful baseline, would possibly provide him with one pellet for every other response. We have developed and are continuing to explore schedules of work required for reinforcement which will maximize the proportion of correct responses. Some of the techniques are as follows:

a. <u>Increasing the ratio of responses to reinforcements</u>. While the animal is learning the counting routine, we require repeated performance of the particular sequence on which he is working before he can be reinforced. For example, counting from <u>one</u> to <u>five</u> is required <u>twice</u> before reinforcement follows the second successful <u>five</u>. Obviously, there are limits of work per reinforcement which can be required. If the amount of behavior per reinforcement gets too high, the animal shows marked pausing after reinforcement, and eventually may stop working almost entirely.

b. <u>Differential consequences of errorless responding</u>. One way to maintain good performance is to provide larger amounts or more frequent occurrences of reinforcement for counting to a given sequence without making any error responses. Once an error is made, the animal is presented with less-favorable reinforcing circumstances when he completes the sequence.

c. The number of reinforcements the baboon receives in a session may be partially controlled by changing the length of the session. Some of Cowboy's data suggested that relatively brief sessions produce more accurate counting behavior once the animal learns, over a succession of short sessions, that he will have to work hard and well to maintain a satisfactory food intake. An exploratory experiment investigating these factors produced no dramatic behavioral shifts when the session duration was reduced from 8 to 4 hours. It may be difficult for the baboon to learn that he is on short sessions in a relatively brief experiment. We plan to add an additional stimulus to signal short sessions. Once the stimulus difference is learned, the effect should occur immediately in a session.

4. Negative Consequences - Incorrect counting is suppressed by arranging for negative consequences (often called punishments) immediately following an error response. Events classified as negative consequences include the removal or postponement of reinforcement and the presentation of painful or unpleasant stimulation. At present, our experiments are confined to the use of the former types of negative events. Two of these events are as follows:

a. Time-out from the opportunity to work for positive reinforcement has been used extensively in the counting schedules. Typically, an undesired response is followed by a 1.5-second"blackout" period. The house lights and all stimulus lights on the intelligence panel go out. The response buttons and levers become non-functional. There is no way the baboon can change this condition or affect the counting sequence until the time-out terminates with the onset of the house lights and the set-up button stimulus light. The time-out increases the total time it takes the baboon to produce the next reinforcement and thus "punishes" mistakes.The time out also provides "feedback" to the animal that a mistake has been made, and that all the programmed negative consequences of errors will be in effect. Counting during the pacing tone and registering an incorrect count (error responses) both result in time-out periods.

b. Resetting the sequence of stimuli is another technique for punishing by postponement of reinforcement. At some stages of training, the entire sequence of problems was recycled to 1 whenever an error response occurred. If the baboon had counted errorlessly up through 4, and then made an error response on 5 problem, the display returned to 1 and the animal was required to count through the entire sequence again before being reinforced. The resetting procedure places a premium on accurate behavior, but it must be employed with caution. Animals that are producing a great many error responses may stop performing entirely, because work requirement per reinforcement becomes too great. At present, for all baboons, an error response simply resets the particular problem which is performed incorrectly. If an animal makes an error response on 3, he must attempt 3 again and complete it successfully before the fourth problem is presented.

More complex arrangements of time out and resetting the sequence have also been used. Differential durations of time out are employed to eliminate very persistent errors. A persistent error is followed by a longer time out (For example, 10 seconds), but all other error responses continue to produce a relatively short blackout period. Partial resetting in which more than one, but not all members of the problem sequence are reset after an error is used at intermediate stages of training. This schedule combines the advantages of the reset for emphasizing accuracy with the less-generalized negative consequences of the non-reset routines.

VII. Discussion and Conclusions

The research program for the past year has accomplished its principal aims. We have been able to develop a highly complicated and demanding performance in a relatively untried research organism by extending the principles of modern behavioral analysis. The end-product is not in itself a unique accomplishment. Talented animal trainers have been able to produce remarkable behavioral routines for centuries. It is the specification of objective training and recording procedures,derived from a body of scientific knowledge, for controlling complex behavior which differentiates the counting baboons from circus animals. An account, although still incomplete, of the functional relationships between classes of experimental variables and classes of complex behaviors has been obtained. There are several implications of this account for further research and development.

More animals, including new species, can now be much more readily brought under experimental control in future development of complex performances. Different kinds of complex behavior can be compared to the present performance with the scientific advantage of drawing up more general principles which have a strong experimental foundation. In this direction, two rhesus monkeys will be added to the experimental colony in the following year. Understanding of complex processes can be more knowledgeably extended to the area of human cognitive behavior.

It follows from greater understanding and control of these performances that the minor experimental changes which result in drastic shifts in form and level of complex functioning can be successfully manipulated. The most fruitful result of enhanced environmental control is the remarkably sensitive behavioral baseline for drug evaluation which can be produced. For example, the effects of a certain dose level of a compound can be compared in magnitude and pattern to the effects of a great number of interventions programmed through the experimental apparatus. Such a comparison might be, "the drug effect resembles the effect of flooding the animal with a large number of new problems". Potentially, progress toward discovering the common biochemical and physiological variables which underlie the two effects, chemical and perceptual, might be further stimulated.

Finally, differential sensitivity of components of the complex performance to a drug has been demonstrated. Predictably, the more complex requirements are the first to be affected and show the greatest magnitude of change.

VIII. Summary

A complex behavioral performance in which baboons "count" the number of objects presented to them visually was described. To date, one baboon has fully acquired the behavior, one counts to five at a lower level of accuracy, and two baboons are in the early stages of training. The effects of a CRDL drug upon the performance of the fully-trained animal were presented: counting was severely disrupted, but the more difficult components of the sequence were considerably more sensitive to the compound. A drug-behavior interaction was proposed to account for a four-day recovery period. Techniques for achieving and maintaining counting were described. Specific manipulations of (1) experimental stimuli (2) responses (3) positive and (4) negative consequences of behavior were elaborated.