JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1975, 23, 429-436 NUMBER 3 (MAY)

REPEATED ACQUISITION OF RESPONSE SEQUENCES: STIMULUS CONTROL AND DRUGS[1]

DONALD M. THOMPSON

GEORGETOWN UNIVERSITY SCHOOLS OF MEDICINE AND DENTISTRY

Pigeons obtained food by making four responses on three keys in a specified sequence, *e.g.*, left, right, center, right. Under the "tandem-learning" condition, all three keys were the same color throughout the response sequence, and the sequence was changed from session to session. After total errors per session (overall accuracy) and within-session error reduction (learning) had stabilized, the effects of varying doses of phenobarbital and chlordiazepoxide were assessed. For comparison, the drug tests were also conducted under a "tandem-performance" condition, in which the response sequence was the same from session to session, and under corresponding "chain-learning" and "chain-performance" conditions, where different colored keylights were associated with the response sequence. Under all four baseline conditions, the largest dose of each drug impaired overall accuracy. Under the two learning conditions, the error rate decreased across trials within each session, but the degree of negative acceleration was less in the drug sessions than in the control sessions. In contrast, under the two performance conditions, the error rate was relatively constant across trials, but was higher in the drug sessions than in the control sessions. Of the four baselines, the chain-learning condition was the most sensitive to the drug effects.

The repeated acquisition of behavioral chains has been studied under various conditions in a series of experiments in this laboratory (Thompson, 1970, 1971, 1973, 1974). Pigeons worked for food in a chamber containing three response keys, each illuminated at the same time by one of four colors. For each session, the pigeon's task was to learn a new four-response chain by pecking the correct key in the presence of each color. Learning was defined by the decrease in errors across trials within a session.

The initial research (Thompson, 1970, 1971) indicated that after 40 to 60 sessions of repeated acquisition, each subject reached a steady state in terms of stable within-session error reduction. In short, a steady state of "transition states" was obtained (*cf.* Boren and Devine, 1968; Sidman, 1960; Sidman and Rosenberger, 1967; Weiss, 1970). The steady state was also characterized by stable levels of overall accuracy, as measured by total errors per session. In addition, the Thompson (1970) experiment demonstrated that the different-colored keylights were, in fact, controlling behavior in the chain sequence. When the different colors were removed (a "tandem" response sequence), error levels increased substantially.

In subsequent research (Thompson, 1973, 1974), the repeated acquisition of behavioral chains was used as a baseline to study the effects of drugs on learning in individual subjects. The acute effects of varying doses of phenobarbital and chlordiazepoxide were studied in the Thompson (1973) experiment. Both drugs were found to increase total errors per session as a function of dose. The error-increasing effect of chlordiazepoxide was greater than that of phenobarbital at the same doses. The largest doses of both drugs also decreased the rate of within-session error reduction (learning).

The effects of chronic administration of phenobarbital and chlordiazepoxide on repeated acquisition were studied in the Thompson (1974) experiment. For comparison, the chronic drug tests were also conducted under a "performance" condition, in which the four-response chain was the same from session to session. With the initial error-increasing effect

[1]This research was supported by Public Health Service Grants MH 22340, FR 5360, and FR 5306. The chlordiazepoxide (Librium) was kindly donated by Hoffmann-LaRoche, Inc. I wish to thank Dr. Annette S. Thompson for comments on the manuscript. Reprints may be obtained from D. M. Thompson, Department of Pharmacology, Georgetown University Schools of Medicine and Dentistry, 3900 Reservoir Road, N.W., Washington, D.C. 20007.

of each drug as the reference point, the total errors per session under the learning condition showed several different patterns during repeated drug administration (*e.g.*, incremental trend, little or no change, tolerance), depending on the dose. Overall accuracy was found to be related to rate of learning; *i.e.*, the greater the total errors per session, the slower the rate of within-session error reduction and *vice versa*. The behavior was more readily disrupted by the chronic drug regimens under the learning condition than under the performance condition.

The main objective of the present research was to determine whether the repeated acquisition of tandem response sequences would be affected by phenobarbital and chlordiazepoxide in the same way that was found with chain sequences in the Thompson (1973) experiment. A variety of other situations have shown that the behavioral effects of many drugs can be modified by the presence or absence of external discriminative stimuli (see review by Laties, *in press*). To permit further comparisons, the drug tests were also conducted under a performance condition, in which the response sequence (chain or tandem) was the same from session to session (*cf.* Thompson, 1974). In addition to the drug effects, the present research provided data on behavioral transitions and steady states involving the repeated acquisition and performance of chain and tandem response sequences.

METHOD

Subjects

Two adult male White Carneaux pigeons, both used previously in drug experiments involving the repeated acquisition and performance of behavioral chains (Thompson, 1973, 1974), were maintained within 10 g of 80% of their free-feeding weights throughout the research by food presented during the sessions and by postsession supplemental feeding. The 80% values were 460 g and 470 g for No. 6173 and No. 2276 respectively. Water and grit were always available in the home cages.

Apparatus

In a standard three-key pigeon chamber (Lehigh Valley Electronics, Model 1519B), with connecting automatic control equipment, each translucent response key required a static force of 18 g (0.18 N) to close the microswitch. Each key could be transilluminated by three Sylvania 24ESB indicator lamps, one with a red plastic end cap, one with a green cap, and the third with no cap. All three keys were illuminated at the same time by the same color, either white, red, green, or yellow. The "yellow" (actually yellow-orange) was produced by the red and green lights being on simultaneously. Events were scheduled by means of timers, steppers, and associated relay circuitry; recording was by counters and an 11-pen event recorder. White noise was continuously present to mask extraneous sounds.

Procedure

Throughout the following procedures the food reinforcer was 5-sec access to mixed grain. Presentation of the food magazine was accompanied by offset of the keylights and onset of the magazine light. The houselight was always off. Each session terminated after 40 food reinforcements. A "blackout" (all lights off) of variable duration preceded and followed each session. With few exceptions, there were seven daily sessions a week.

Baseline conditions. There were four baseline conditions. Under the *chain-learning* condition, all three response keys were illuminated at the same time by one of four colors, either yellow, green, red, or white. The pigeon's task was to peck the correct key in the presence of each color, *e.g.*, keys yellow—Left correct; keys green—Right correct; keys red—Center correct; keys white—Right correct; reinforcement. The same chain (in this case, Left-Right-Center-Right or LRCR) was repeated throughout a given session and each completion of the chain was considered a "trial". Food reinforcement was on a fixed-ratio (FR 5) schedule: completion of every fifth trial was followed by 5-sec access to grain. Completion of all other trials was followed by a 0.5-sec presentation of the food magazine. The number of correct responses per session was fixed: four-response chain on an FR 5 schedule for 40 food reinforcements = 800 correct responses. When the pigeon pecked an incorrect key (a key not included in the four-response chain), the error was followed by a 5-sec timeout. During the timeout, the keylights were off and a response had no effect. An error did not reset the chain; *i.e.*, the keylights after the timeout were the same color as before the timeout.

Under the chain-learning condition, the four-response chain was changed from session to session. The chains were carefully selected to be equivalent in several ways and their ordering was restricted across sessions (see Thompson, 1973). An example of a typical set of six chains is as follows: LRCR, CLRL, LRLC, RCRL, CLCR, RCLC; the order of the associated colors was always the same: yellow, green, red, white (food on the FR 5 schedule).

Under the *chain-performance* condition, the four-response chain was the same from session to session. Different chains were arbitrarily selected for the two pigeons: LRLC for No. 6173 and CLRC for No. 2276. In all other aspects (FR 5 schedule of food reinforcement, timeout duration of 5 sec, *etc.*), the chain-performance condition was identical to the chain-learning condition.

Under the *tandem-learning* and *tandem-performance* conditions, different-colored keylights were not associated with the four-response sequence; when the keylights were on, they were always white. (Lights were momentarily dimmed when the sequence advanced.) In all other aspects, the tandem-learning and tandem-performance conditions were identical to the chain-learning and chain-performance conditions, respectively.

The first 10 to 20 baseline sessions in the present research (chain-learning for No. 2276 and chain-performance for No. 6173) were a continuation of the baseline condition in effect at the end of the Thompson (1974) experiment. The order and duration of all subsequent baseline conditions for each subject are indicated in Figures 1 and 2.

Drug testing. After total errors per session and within-session error rates had stabilized under a given baseline condition, the next 12 to 16 weeks were used to obtain dose-effect data for phenobarbital sodium and chlordiazepoxide hydrochloride. (Other drugs were also tested during the period designated as "other experiments" in Figures 1 and 2, but these experiments will be reported elsewhere.) Four doses of each drug were tested (5, 10, 20, and 40 mg/kg) and two determinations for each dose were taken with each subject. The drug testing followed the design PCCP, where P and C represent the blocks of four doses of phenobarbital and chlordiazepoxide; within each block, the doses were tested in a random order. The drugs were dissolved in saline and injected into the pectoral muscles 30 min presession. Drug sessions were separated by five to seven days, during which time there were baseline sessions and a control session (saline alone injected intramuscularly 30 min presession). The volume of each injection was 0.1 ml/100 g body weight.

RESULTS

Figure 1 shows the total errors per session under the different baseline conditions for Pigeon No. 2276. Sessions −19 to 0 are the last 20 sessions under the chain-learning condition; the error levels were considered to have reached a steady state because they showed no systematic change across sessions. When the baseline was changed to the tandem-learning condition, error levels increased substantially. As the sessions continued under this condition, total errors per session decreased somewhat until a new steady state was reached. Error levels under the tandem-learning condition at steady state were much higher and more variable than those under the chain-learning condition. This was true even after 16 weeks of drug testing (see Sessions 161 to 170). When the baseline was changed to the tandem-performance condition, total errors per session decreased markedly and then stabilized at a relatively low level. Note that this level, both before and after the drug tests, was somewhat below the level that was produced by the chain-learning condition. Baseline recoverability was demonstrated when the tandem-learning and chain-learning conditions were re-instated (Sessions 321 to 630). Finally, when the baseline was changed to the chain-performance condition, total errors per session decreased to near zero and tended to remain at this level.

Figure 2 shows the baseline data for Pigeon 6173. This subject began the experiment under the chain-performance condition, which produced very low error levels at steady state (Sessions −9 to 0). When the baseline was changed to the tandem-performance condition, the total errors per session increased substantially and then decreased until a new steady state was reached that was well above the chain-performance error levels. When the baseline was then changed to the tandem-

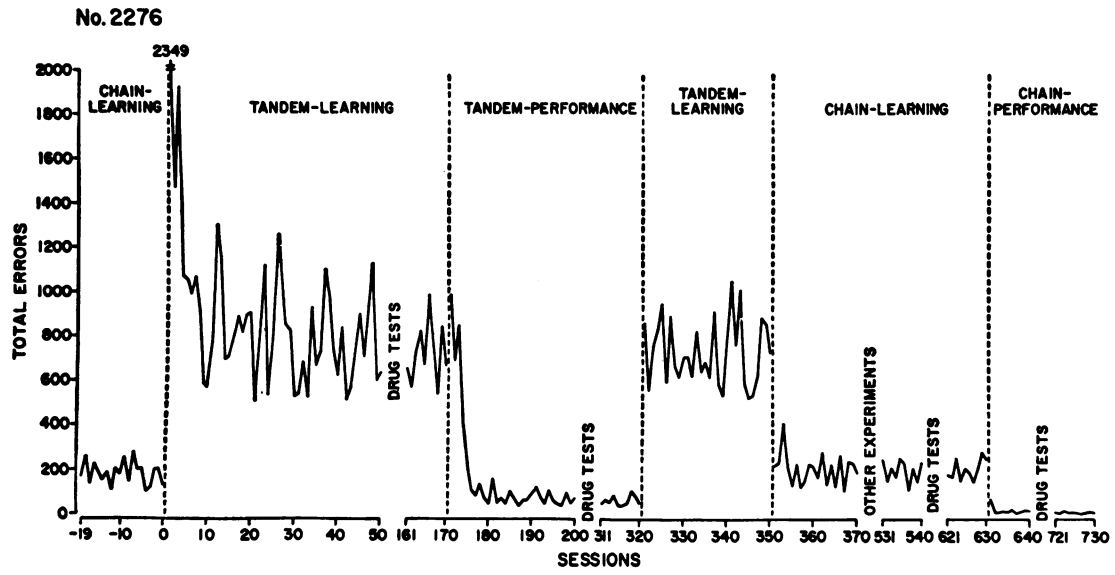

Fig. 1. Total errors per session under the four baseline conditions for Pigeon No. 2276. Sessions −19 to 0 are the last 20 sessions under the chain-learning condition. The sessions during the periods of drug testing and other experiments are omitted as indicated.

learning condition, error levels increased even more. As was the case with No. 2276, error levels for No. 6173 under the tandem-learning condition at steady state were much higher and more variable than those under the tandem-performance condition, despite the fact that the two pigeons were exposed to these conditions in the opposite order. Again, baseline recoverability was demonstrated when the tandem-performance and chain-performance conditions were re-instated (Sessions 341 to 620). Finally, when the baseline was changed to the chain-learning condition, total errors per session increased and then stabilized at a level well above that produced by the chain-performance condition.

Taken together, Figures 1 and 2 indicate that in terms of total errors per session at steady state, the four baseline conditions can be ordered from greatest to least as follows:

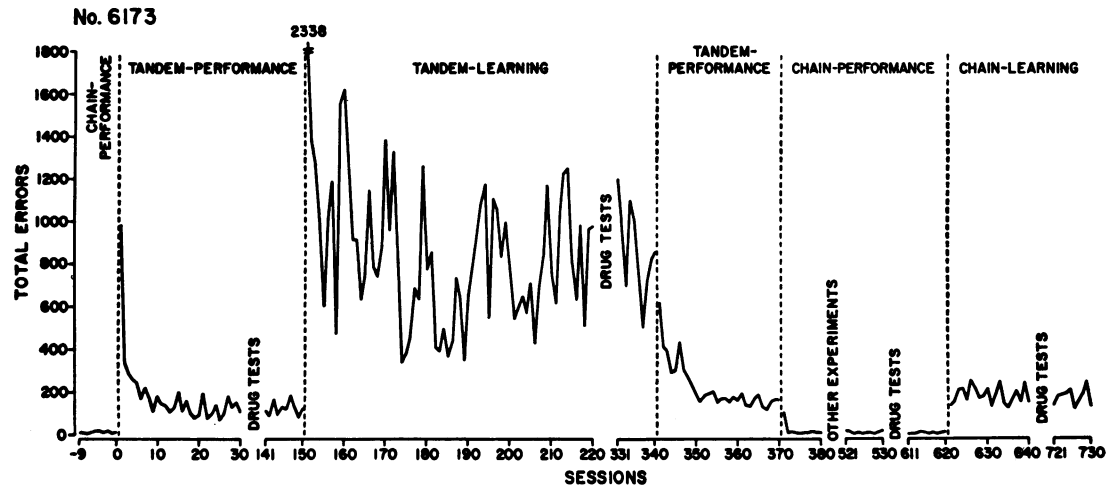

Fig. 2. Total errors per session under the four baseline conditions for Pigeon No. 6173. Sessions −9 to 0 are the last 10 sessions under the chain-performance condition. The sessions during the periods of drug testing and other experiments are omitted as indicated.

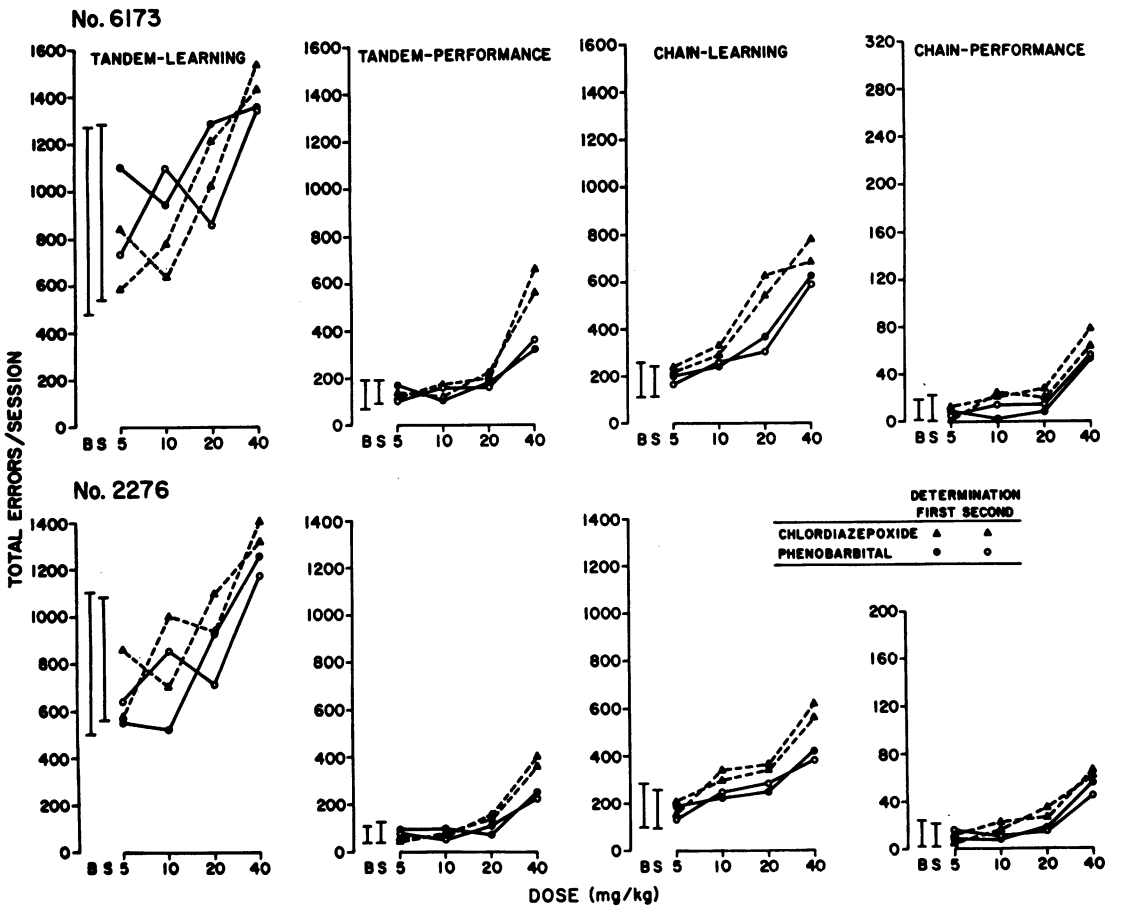

Fig. 3. Effects of chlordiazepoxide and phenobarbital on the total errors per session under the tandem-learning, tandem-performance, chain-learning, and chain-performance conditions. Note that the scale on the ordinate for the chain-performance condition is different from those for the other conditions. Four doses of each drug were tested under each condition and there were two determinations for each dose with each pigeon. The brackets indicate the ranges of variability for the baseline (B) and saline (S) sessions.

tandem-learning, chain-learning, tandem-performance, chain-performance.

Figure 3 shows the effects of varying doses of chlordiazepoxide and phenobarbital (both determinations) on total errors per session under the tandem-learning, tandem-performance, chain-learning, and chain-performance conditions. The drug data for individual subjects were analyzed by comparing a given drug session with the saline sessions and all of the baseline sessions during drug testing, except the one after the drug session. The brackets indicate the ranges of variability for the baseline (B) and saline (S) sessions. A drug was considered to have an effect on overall accuracy to the extent that the dose data fell outside of both ranges. As can be seen, overall accuracy was impaired by the largest dose of each drug under all four baseline conditions, with chlordiazepoxide having a greater error-increasing effect than phenobarbital. At the smaller doses, however, there was differential baseline sensitivity to the error-increasing effect of the drugs. Whereas the smaller doses of both drugs had no effect on overall accuracy under the tandem-learning condition, errors increased slightly at 20 mg/kg of chlordiazepoxide under the tandem-performance and chain-performance conditions. The chain-learning condition was the most sensitive baseline, in that an error-increasing effect was found at 20 mg/kg of phenobarbital with No. 6173 and at 10 and 20 mg/kg of chlordiazepoxide with both pigeons.

Figure 4 illustrates the within-session effects on accuracy obtained with the largest doses of

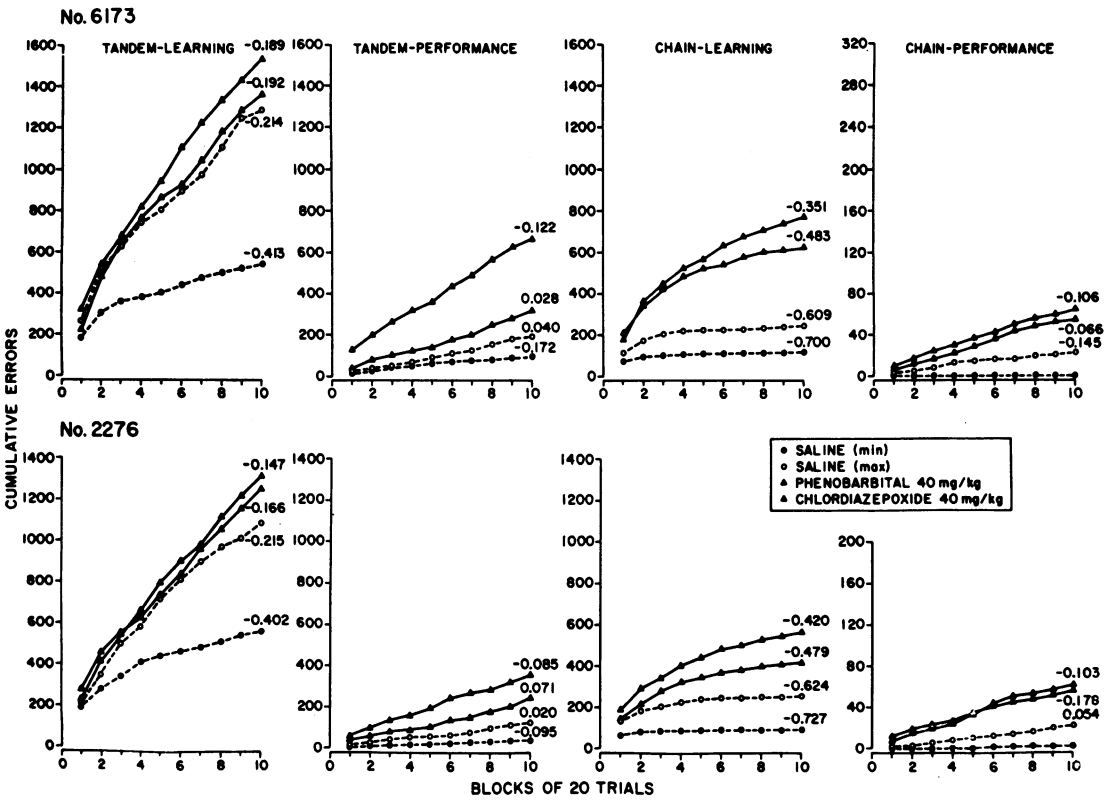

Fig. 4. Within-session effects on accuracy obtained with the largest doses of phenobarbital and chlordiazepoxide (first determinations) under the tandem-learning, tandem-performance, chain-learning, and chain-performance conditions. Note that the scale on the ordinate for the chain-performance condition is different from those for the other conditions. The saline (min) and saline (max) sessions were the sessions with the minimum and maximum total errors of all the saline sessions (16) conducted during drug testing under a given condition. The Index of Curvature value is shown for each session, except for the saline (min) session under the chain-performance condition. If all the errors in a session occurred during the first 20 trials, the Index would take on its maximum negative value of −0.900; if the error rate were constant during the session, the Index would equal 0.

phenobarbital and chlordiazepoxide (first determinations) under the tandem-learning, tandem-performance, chain-learning, and chain-performance conditions. The errors are plotted cumulatively so that the rate of errors during a given part of a session can be estimated easily from the slope of the curve. The curves for the drug sessions should be compared to the saline (min) and saline (max) sessions, which were the sessions with the minimum and maximum total errors of all the saline sessions (16) conducted during drug testing under a given condition. Changes in error rate within a session were quantified by computing the Index of Curvature (*cf.* Fry, Kelleher, and Cook, 1960; Thompson, 1973). The Index can range from −0.900 (maximum negative acceleration of error rate) to 0.900 (maximum positive acceleration), since each session was divided into tenths; a constant error rate would yield a value of zero. The Index value is shown for each session in Figure 4, except for the saline (min) session under the chain-performance condition, where virtually no errors were made.

Figure 4 indicates that under both learning conditions, error rate decreased across trials within each session, but the degree of negative acceleration was less (smaller Index values) in the drug sessions than in the saline sessions. Note also that the degree of negative acceleration was less during a given session under the tandem-learning condition than during the corresponding session under the chain-learning condition. In short, under the two learning conditions, the degree of negative acceleration generally decreased as total errors per session increased. Under the two performance con-

ditions, however, the Index values were not consistently related to total errors per session. In the saline and drug sessions under the performance conditions, there was either slight positive acceleration of error rate or less negative acceleration than that found under the corresponding learning condition. In short, error rate under the performance conditions was relatively constant across trials, but was higher in the drug sessions than in the saline sessions. The second determinations for these doses yielded similar results.

DISCUSSION

The present results indicated that repeated acquisition of tandem response sequences was affected by phenobarbital and chlordiazepoxide in a manner similar to that found with chain sequences in the Thompson (1973) experiment. Under both learning conditions, the largest dose of each drug increased total errors per session, with chlordiazepoxide having a greater error-increasing effect than phenobarbital. In both cases, the rate of within-session error reduction (learning) was less in the drug sessions than in the control sessions.

Despite the above similarities, however, the tandem-learning baseline appeared to be less sensitive than the chain-learning baseline; *i.e.*, doses smaller than 40 mg/kg of each drug did not have an error-increasing effect under the tandem-learning condition (Figure 3) but did under the chain-learning condition (Thompson, 1973). Of course, a problem in such a comparison is the order of the experiments. It is possible that the tandem-learning baseline was less sensitive to drug effects because the pigeons had been practising on four-response sequences for a longer period of time. The present research dealt with this problem by retraining the same subjects on the chain-learning baseline *after* they had been exposed to the tandem conditions, and then repeating the drug tests. When this was done, the original dose-effect curves were replicated (Figure 3), thereby strengthening the chain *versus* tandem comparison.

Similar results have been obtained with other drugs in a related "performance" situation, where two phenothiazines (chlorpromazine and trifluoperazine) had greater effects on the response rate of pigeons under a chain fixed-ratio schedule than under a tandem fixed-ratio schedule (Thomas, 1966). In a variety of other performance situations, however, it has been found that behavior under the control of external discriminative stimuli is *less* readily disrupted by drugs than behavior not under such control (see review by Laties, *in press*). In discussing this apparent discrepancy, Laties (1972) pointed out that ". . . framing an explanation of how drug action is modified by stimulus control may require one to determine just what types of behavioral changes are produced by the addition of particular environmental stimuli at particular times" (p. 12).

In the present research, switching from the tandem-learning condition to the chain-learning condition (*i.e.*, the addition of environmental stimuli) produced a decrease in total errors and less baseline variability (Figure 1). Either or both of these behavioral changes may be responsible for the greater sensitivity of the chain-learning baseline to the error-increasing effects of phenobarbital and chlordiazepoxide. Detection of a drug effect is obviously less difficult as the control variability decreases and, according to the "law of initial value" (Wilder, 1967), it should be easier to detect an error-increasing effect of a drug when the control error levels are relatively low. Although these types of behavioral changes may also explain why the tandem-performance and chain-performance baselines were slightly more sensitive than the tandem-learning baseline (see Figure 3: chlordiazepoxide, 20 mg/kg), they cannot explain why the two performance baselines were less sensitive than the chain-learning baseline. For example, with No. 6173, total errors and amount of baseline variability were quite similar under the tandem-performance and chain-learning conditions; however, an error-increasing effect was found at 20 mg/kg of phenobarbital and at 10 mg/kg of chlordiazepoxide only under the chain-learning condition (Figure 3).

The present finding that the chain-learning baseline was more sensitive to drug effects than the chain-performance baseline is consistent with the widely held view that "difficult tasks" are more susceptible to drug effects than "simple tasks" (Dews, 1955; Polidora, 1963; Thompson, 1974; Waller, 1961). The fact that the control error levels under the learning condition were much greater than those under the performance condition (Figure 3) indicates

that learning was a more difficult task. The two conditions may also be considered as representing strong *versus* weak stimulus control (*cf.* Laties, 1972). In the performance condition, the stimulus-response sequence remains constant from session to session and the animals are highly practised. One would assume that this behavior is strongly controlled by the stimuli and would therefore be resistant to disruption by drugs. In the learning condition, where the stimulus-response sequence is changed daily, stimulus control would be relatively weak and the behavior would therefore be more readily disrupted by drugs.

By the same type of argument, one would expect behavior under the tandem-learning condition ("difficult task", weak control by "internal" stimuli) to be more readily disrupted by drugs than behavior under the tandem-performance condition ("simple task", strong control by "internal" stimuli). That this was not the case (Figure 3) may be related to a point made earlier, namely, the drug effects may have been obscured under the tandem-learning condition because the control error levels were much higher and more variable than those under the other conditions.

In conclusion, despite certain similarities in the data obtained with chain and tandem sequences, it appears that the repeated acquisition of behavioral chains is a more stable and a more sensitive baseline for assessing the effects of drugs on learning in individual subjects.

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Received 10 October 1974.
(Final Acceptance 21 November 1974.)