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Optimal Training Parameters in the Two-Bar Fixed-Ratio Drug Discrimination Task

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OVERTON, D. A. AND M. W. HAYES. *Optimal training parameters in the two-bar fixed-ratio drug discrimination task.* PHARMACOL BIOCHEM BEHAV **21**(1) 19–28, 1984.—In a two-lever compartment, thirsty rats were trained to press one bar when drugged with phenobarbital and the other bar when undrugged using water as a reinforcer. Several different training procedures were employed in order to compare their effects on speed of acquisition and/or asymptotic accuracy of discrimination. Results were as follows: (1) Some shaping procedures allowed more rapid acquisition of discriminative control than others. The "traditional" shaping procedure was significantly less efficient than any others tested. (2) Several indices of degree of discriminability based on the speed of acquisition of discriminations were compared and evaluated. Some varied linearly with ln dosage. (3) Variations in session duration from 5 to 60 minutes did not alter asymptotic accuracy. (4) Fixed ratio sizes ranging from FR-3 to FR-30 resulted in similar asymptotic accuracies. Overall, the results define alterations in the fixed-ratio training procedure that will make it somewhat easier to use. However, no procedures were found that fundamentally improved the properties of the paradigm.

Drug discrimination Stimulus effects of drugs Discrimination learning

DRUG discrimination (DD) procedures are increasingly being used for the investigation of drug effects, and most of these studies use similar training procedures. Typically, presses on the correct lever in a 2-lever compartment are reinforced on a fixed ratio (FR) schedule during daily 15–30 min training sessions while presses on the incorrect lever have no programmed consequence. Although there have been only a few studies explicitly designed to determine whether this training procedure is optimal [6], it has been widely adopted because it usually results in high asymptotic accuracy of discrimination [4].

Properties of interest in any DD procedure include: 1. Speed of acquisition of the DDs, 2. Asymptotic accuracy of discrimination, 3. Amount of data that can be obtained during a single substitution test, and 4. Degree of qualitative specificity shown by the trained rats, i.e., the degree to which the rats will differentiate the training compound from pharmacologically similar compounds. A major purpose of the present study was to find ways to improve the first two of these properties by parametrically varying certain procedures in the 2-bar operant paradigm. Specifically, we varied: 1. The shaping procedures employed prior to DD training, 2. The training session duration, and 3. The size of the FR ratio.

A second purpose of this study was to identify indices that could quantify the degree of discriminability of drugs in the 2-bar operant DD task. The design and execution of many DD studies requires the use of drug conditions that have a known degree of discriminability relative to one another. Up to this time, no index of degree of discriminability has been developed for use in the 2-bar operant task. Lacking such an index, some types of DD studies are impossible to design, and the results of other studies are difficult to interpret. Previously, we used the number of training sessions before a DD was learned in a T-maze DD task as an index of discriminability [7]. In the present study we attempted to develop analogous indices for use in the two-bar task.

Direct validation of a proposed index of discriminability is impossible, at present, as there is no standard indicator of degree of discriminability against which to compare the proposed index. Hence in this study we attempted to identify indices that would covary with the training dosage of phenobarbital in a linear fashion. Hopefully the indices that were optimal in this respect will be generally applicable to a variety of drugs, and can be used to estimate the relative degree of discriminability of drugs used in the 2-bar operant DD paradigm.

METHOD

Subjects

Male Long Evans hooded rats were purchased from Blue Spruce Farms and housed with one rat per cage. Dry food was available at all times in the home cage, and water was available 30 min after training sessions for 15 min. At the beginning of the experiment the rats weighed 200–300 g.

Apparatus

Discrimination training took place in 30×32×30 cm alu-

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minum training compartments located inside sound attenuating enclosures. On the wall opposite the lucite door, two levers were mounted side-by-side 15 cm apart 4.5 cm above the steel rod floor. Reinforcement was provided via a water delivery spout mounted midway between the levers, and consisted of 0.1 cc of 0.3% saccharine sweetened water. Compartment illumination was provided by two 5-watt bulbs mounted on the ceiling. A PDP-12 computer using the SKED operating system [8] was used to control schedules of reinforcement and to record data.

An additional training compartment was used during "pretraining" sessions. This box (30×22×19 cm) contained only one lever, along with a reinforcement dispenser and house light.

Drugs

For all studies except Experiment 3, sodium phenobarbital was administered intraperitoneally 20 min before drug (D) training sessions. In Experiment 3 sodium barbital was administered 60 min before training sessions. Drugs were dissolved in isotonic saline and administered in a volume of 1 ml/kg. Saline was injected intraperitoneally 20 min before no drug (N) training sessions.

Training Procedures

Training proceeded through three phases: 1. Pretraining, 2. Shaping, 3. Discrimination training.

1. Pretraining consisted of 5 to 10 6-hr sessions conducted without drugs in the one-bar pretraining boxes. During these sessions rats were magazine trained and allowed to press to satiation under reinforcement schedules of increasing difficulty (FR-1, FR-10, FR-30).

2. Shaping consisted of the first 8–16 sessions in the two-bar training compartments, during which rats were acclimated to working for reinforcement in those boxes. Several different shaping paradigms were employed; these are described subsequently.

3. Discrimination training consisted of daily sessions in the 2-bar boxes. Drug condition (D or N) and reinforced bar (1 or 2) alternated during successive training sessions, with presses on bar 1 reinforced only during D sessions and presses on bar 2 reinforced only during N sessions. Each session consisted of four successive epochs: start period, test epoch, reinforcement period, and session-done period.

3a. The "start period" lasted from the moment the rat was placed in the training compartment until it made two responses (on either bar). Presses during the start period were not included in any subsequent data analyses. If two presses did not occur within 1.5 minutes, the start period was terminated and the test epoch automatically began. House lights were on during the start period. A single noncontingent reinforcement was available in the dispenser spout at the beginning of the start period, and usually the rat consumed it before starting to press either lever.

3b. The "test epoch" began immediately after the start period, and lasted until an additional 10 presses had occurred on bar 1 or on bar 2. No reinforcements were delivered during the test epoch which usually lasted only a few seconds. Presses during this epoch were presumed to reflect the ability of the rat to select the correct bar on the basis of the imposed drug state. The test epoch automatically terminated after 3 min if 10 presses had not occurred on one bar or the other by that time.

3c. The "reinforcement period" started immediately after the end of the test epoch, lasted 15 min (except in Groups 13 and 15), and had the following characteristics except where otherwise stated. Presses on the incorrect lever had no programmed consequence, i.e., were extinguished. Presses on the correct lever were reinforced on an interlocked FR-10/FI-90″ schedule, i.e., the ratio requirement immediately after reinforcement was 10 presses, and one press was subtracted from this requirement every 10 sec until an FR-1 requirement remained. Presses on the correct lever during the test epoch were counted as part of the first ratio of the training period. If pressing stopped entirely during the training period, a noncontingent reinforcement was administered every 120 sec to "prime" the rat.

3d. The "session-done period" began after the reinforcement period was finished. House lights were turned off and reinforcement could not be earned. The rats waited in the darkened training box for 1–5 min before being returned to their home cages. About 30 min after the end of the session, rats received ad lib water for 15 min in their home cages.

Experiment 1 Design

This experiment compared six shaping procedures to determine which would allow the fastest acquisition of DDs. In many DD studies, rats are shaped to press both lever 1 and lever 2 while undrugged and subsequently are required to discriminate presence vs. absence of drug. We reasoned that this procedure might retard the acquisition of DDs by initially training the rats to respond on either lever without reference to their pharmacological state. In this experiment we tested whether DDs would be more rapidly acquired if drug conditions corresponding to the to-be-reinforced lever were imposed from the very beginning of shaping. A total of six shaping procedures were compared. All rats were initially pretrained on an FR-30 schedule in the 1-bar pretraining boxes. Each group then received a unique series of shaping sessions as described below. Finally, D vs. N discrimination training was conducted to determine the effect of the shaping procedures on the subsequent development of DDs. Phenobarbital dosage was 50 mg/kg.

Table 1 describes the shaping sessions administered to each group. The table shows the reinforced bar and drug condition during each shaping session, the reinforcement ratio at the beginning of each session, the duration of each session, and the number of sessions of each type. In all groups, an interlocked FR/FI schedule was used in which one press was subtracted from the ratio requirement every 10 sec (down to a minimum requirement of one press). As the session progressed, the ratio was incremented by one after every tenth reinforcement, up to a maximum ratio of FR-10.

Group 1 (N2→D1) received shaping sessions in which the reinforced lever was always appropriate to the current drug state. A series of 8 N2 sessions were conducted (no drug condition with bar 2 presses reinforced), followed by 8 D1 sessions (D sessions with bar 1 presses reinforced). The objective of this procedure was to establish two partially state dependent responses (bar 1 responding in the D state, bar 2 responding in the N state) during shaping which could facilitate the subsequent acquisition of the D vs. N discrimination. Such facilitation has previously been reported when a variable-internal reinforcement schedule was employed [6], but has not been reported with FR schedules.

Group 2 (D1→N2) received state-appropriate shaping analogous to that in Group 1, except that 8 D1 sessions preceded 8 N2 sessions.

TABLE 1

DESCRIPTION OF SHAPING SESSIONS AND DISCRIMINATION TRAINING SESSIONS IN EXPERIMENT 1

Group No.	Mnemonic For Shaping Condition	Description of Successive Shaping Sessions	Phase 1			Phase 2				Description of Discrimination Training Sessions	
1	N2→D1	Reinforced Bar	2	2	2	1	1	1		2	1
		Drug or No-Drug	N	N	N	D	D	D		N	D
		Initial Ratio	2	5	10	2	5	10		10	10
		Session Duration	15′	15′	15′	15′	15′	15′		15′	15′
		No. of Sessions	3	2	3	3	2	3		(Alternating D and N)	
2	D1→N2	Reinforced Bar	1	1	1	2	2	2		1	2
		Drug or No-Drug	D	D	D	N	N	N		D	N
		Initial Ratio	2	5	10	2	5	10		10	10
		Session Duration	15′	15′	15′	15′	15′	15′		15′	15′
		No. of Sessions	3	2	3	3	2	3		(Alternating D and N)	
3	N2→D1	Reinforced Bar	2	2	2	1	1			2	1
	(Long	Drug or No-Drug	N	N	N	D	D			N	D
	Sessions)	Initial Ratio	1	1	5	3	5			10	10
		Session Duration	900′	540′	540′	50′	50′			15′	15′
		No. of Sessions	2	2	2	3	2			(Alternating D and N)	
4	N2→N1	Reinforced Bar	2	2	2	1	1	1		2	1
		Drug or No-Drug	N	N	N	N	N	N		N	D
		Initial Ratio	2	5	10	2	5	10		10	10
		Session Duration	15′	15′	15′	15′	15′	15′		15′	15′
		No. of Sessions	3	2	3	3	2	3		(Alternating D and N)	
5	R2→R1	Reinforced Bar	2	2	2	1	1	1		2	1
		Drug or No-Drug	*	*	*	*	*	*		N	D
		Initial Ratio	2	5	10	2	5	10		10	10
		Session Duration	15′	15′	15′	15′	15′	15′		15′	15′
		No. of Sessions	3	2	3	3	2	3		(Alternating D and N)	
6	Immediate	Reinforced Bar	2	1	2	1	2	1	2	1	2	1
	Alternation	Drug or No-Drug	N	D	N	D	N	D	N	D	N	D
		Initial Ratio	2	2	2	2	5	5	5	5	10	10
		Session Duration	15′	15′	15′	15′	15′	15′	15′	15′	15′	15′
		No. of Sessions	1	1	1	1	1	1	1	1	(Alternating D and N)	

*Drug sequence in Group 5 was: NNDNDNDDNNDNDNDD.

Group 3 received N2→D1 shaping sessions analogous to Group 1, except that the shaping sessions were longer in duration in order to determine whether DD acquisition would be facilitated if the rats spent more time in the training compartment during shaping. Session durations are given in Table 1.

Group 4 (N2→N1) was shaped to press on both levers without drug. First 8 N sessions were conducted with reinforcement of presses on bar 2; then 8 N sessions were conducted with reinforcement of presses on bar 1. This shaping procedure has commonly been used in previous drug discrimination studies in which responding on bar 1 and bar 2 was established before any attempt was made to establish the D vs. N discrimination (e.g., [1,3]).

Group 5 (R2→R1) was first shaped to press bar 2 during 8 sessions and then shaped to press bar 1 during 8 additional sessions. Phenobarbital and no drug were randomly administered during these 16 shaping sessions as indicated in Table 1. The objective was to provide experience pressing both levers while drugged and undrugged, without creating any association between the imposed drug state and the response that was reinforced.

In Group 6 (immediate alteration), the 8 "shaping" sessions were really the first 8 discrimination training sessions, as bar and drug conditions alternated from the first day of 2-bar training. To facilitate acquisition, the initial ratio of reinforcement was smaller than that used later in training. In all other respects, the final training conditions were instated immediately after pretraining. Henceforth this group will be referred to as having received no shaping prior to discrimination training.

Experiment 2 Design

This experiment was intended to identify indices of speed of DD acquisition that would reflect differences in the degree of discriminability of various phenobarbital doses. All rats were initially pretrained. Groups 7–9 (3 rats per group) re-

ceived N2→D1 shaping like that in Group 1, and were then required to discriminate phenobarbital 40, 20 or 10 mg/kg, respectively, vs. no drug. Groups 10–12 (3 rats per group) received no shaping sessions (like Group 6), and then discriminated the same three doses of phenobarbital. In addition to Groups 7–12, Groups 1 and 6 trained with phenobarbital 50 mg/kg were considered to be part of this experiment.

Experiment 3 Design

This experiment tested whether the duration of the training period was an important determinant of asymptotic accuracy of DDs. Groups 13–15 (4 rats per group) were pretrained, received no shaping sessions (like Group 6), and were then trained to discriminate D vs. N. The reinforcement period of the training sessions lasted 5, 15, and 60 min, respectively, in Groups 13, 14, and 15. Since the rats required 30 to 60 sec to complete the initial test epoch, total session durations approximated 6, 16, and 61 min, respectively. Sodium barbital was used as the training drug because of its long duration of action. For training sessions 1–27 the dose was 30 mg/kg; a low dosage was selected because we believed that differences in DD accuracy resulting from variations in session duration might be more apparent if relatively nondiscriminable training conditions were used. As this dose did not appear to produce reliable discriminative control, dosage was raised to 60 mg/kg after session 27.

Experiment 4 Design

This experiment tested whether the ratio of reinforcement was an important determinant of speed of acquisition or asymptotic accuracy of DDs. Groups 16–18 (4 rats per group) were pretrained, received no shaping (like Group 6), and then received D vs. N discrimination training sessions during which presses on the incorrect lever were extinguished. Presses on the correct lever were reinforced on an FR-3, FR-10 or FR-30 schedule, respectively, in Groups 16, 17 and 18. The reinforcement period was terminated after 15 min, or when 200 reinforcements had been earned. DD training was continued for 80 sessions. In these groups, no interlock reduced the ratio requirement as time passed. During the first 8 DD training sessions, lower ratio requirements were imposed to assure that responding would occur, and the ratio requirement was increased as the session progressed. Phenobarbital dosage was 15 mg/kg as we believed that the differential effects of various ratios of reinforcement might be more apparent if relatively nondiscriminable training conditions were used.

Data Recording

For each session, the number of presses on each lever during the test epoch and during each tenth of the reinforcement period were recorded on magnetic tape, along with the latency to start pressing, latency to complete the test epoch, and total number of reinforcements earned. Event records which showed presses on each lever and reinforcements were obtained using a polygraph. These allowed visual inspection of the details of performance, when necessary.

Data Analysis

For each rat, data from successive sessions were printed and plotted in formats showing indices such as percent correct presses during the test epoch, total presses on each bar, etc. Data for sessions during which rats did not press due to obvious illness, sessions when individual rats were not trained, etc., were marked for omission from subsequent analyses. Finally, various indices of performance (such as asymptotic accuracy) were computed for each rat.

Indices of Speed of Acquisition

Two types of indices were derived to reflect the speed at which discriminative control appeared. These were: 1. Sessions before the beginning of criterion performance (STC); this was the total number of shaping *and* training sessions before the beginning of criterion performance. 2. Bar reversals before the beginning of criterion performance (RTC); this was the number of times that the reinforced bar was switched prior to the onset of criterion performance. Essentially, the use of an RTC index assumed that an uninterrupted series of bar 1 (or bar 2) shaping sessions could be considered as equivalent to a single prolonged session, at least as far as their effects on the acquisition of the DD was concerned.

Several definitions of "criterion" performance were used with the STC and/or RTC indices. These were: 1. Average accuracy pooled across D and N sessions during X successive days greater than Y percent; e.g., for $X=6$ and $Y=80$, criterion would be achieved during the first block of six consecutive sessions (3N and 3D days) during which the average percentage of correct test epoch responses exceeded 80 percent. To identify the earliest occurrence of this criterion, we computed the average test epoch accuracy for days 1–6, 2–7, etc. 2. Average accuracy concurrently above Y percent in both D *and* N sessions during X successive days; e.g., for $X=10$ and $Y=60$, criterion would be achieved in the first block of 10 consecutive sessions in which average accuracy of pressing during the test epochs exceeded 60% during the five D sessions and also exceeded 60% during the five N sessions. 3. Bar "selection" pooled across D and N sessions correct on X or more sessions out of Y consecutive sessions. Bar selection was considered to be correct on sessions when more than 66% of test epoch responses were on the correct lever. As an example, for $X=8$ and $Y=10$, criterion would be achieved during the first string of 10 consecutive sessions in which test epoch accuracy exceeded 66% during 8 of the sessions. 4. Bar selection concurrently correct on X or more out of Y consecutive D *and* N sessions; e.g., for $X=4$ and $Y=5$ criterion would be achieved when test epoch accuracy exceeded 66% during 4 out of 5 D sessions and 4 out of 5 N sessions during a 10-session criterion string.

In Experiment 1, the influence of various shaping procedures on speed of acquisition was evaluated by using STC and RTC indices with a single level of criterion stringency. In Experiment 2, the influence of dosage on speed of acquisition was evaluated using only RTC indices; the utility of a variety of criterion stringencies was compared in this experiment. In Experiments 3–4, selected indices of speed of acquisition and/or asymptotic accuracy were employed.

Statistics

Various statistics were used, including one-factor analysis of variance and the Mann-Whitney U test for two independent samples. RTC and STC indices were logarithmically transformed before computations in order to reduce heterogeneity of variance [2]. Dosages were also logarithmically transformed.

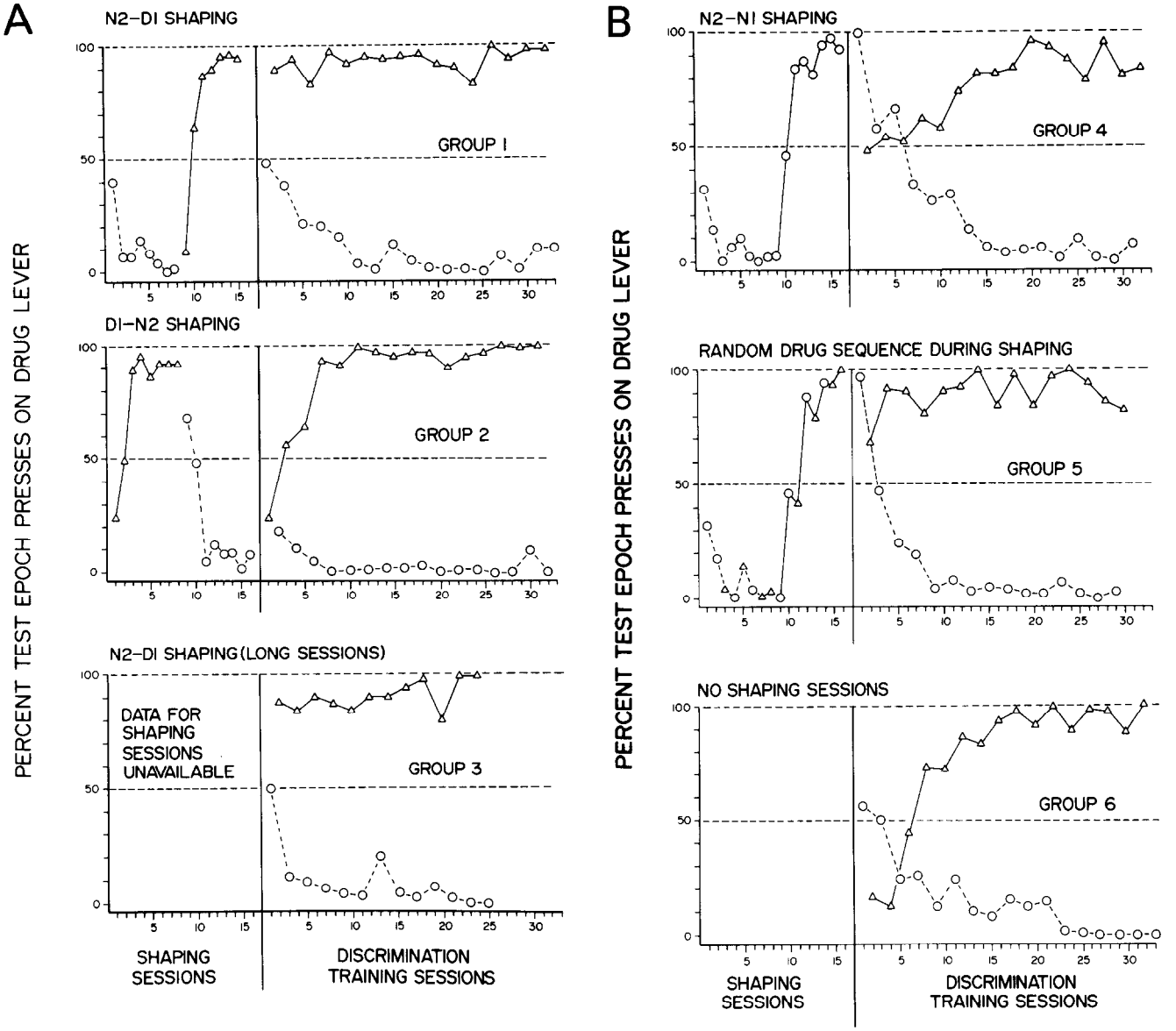

FIG. 1. Acquisition of drug discriminations in Groups 1–6 as indicated by percentage of presses during the test epoch on the drug lever (bar 1) during the test epochs of successive sessions. The left section of the figures shows performance during shaping sessions, if any were conducted. The right portion shows performance during discrimination training sessions in which the phenobarbital and no drug conditions alternated on successive days. Abscissa is successive individual sessions. Ordinate is percentage of presses on the drug lever prior to the first reinforcement of the session (excluding the first two presses). Triangles represent sessions before which drug was administered. Open circles represent sessions without drug. Solid lines connect sessions during which responses on bar 1 were reinforced. Dotted lines connect sessions during which responses on bar 2 were reinforced. Due to a programming error, test epoch performance was not recorded during shaping sessions in Group 3.

RESULTS

General Behavior

With both FR and interlocked FR/FI schedules of reinforcement, pressing occurred in short bursts separated by pauses during consumption of reinforcements. Rates of pressing reached asymptote after about 20 sessions. Latency to start pressing at the beginning of the session was 10 to 60 sec in most cases. The highest percentage of presses on the incorrect lever occurred during the test epoch at the beginning of each session. After the first reinforcer in a session was earned, rats predominantly pressed the reinforced lever. All except two of the rats trained with phenobarbital 40 or 50 mg/kg rapidly learned the required discriminations; these two rats were deleted from all data analyses as they failed to ever learn the required DDs.

Experiment 1. Effect of Shaping Procedures

Learning curves in Fig. 1 show performance during the test epochs of shaping and discrimination training sessions. In Group 3, the bar 1 and bar 2 responses learned during the

TABLE 2

INDICES SHOWING SPEED OF ACQUISITION OF PHENOBARBITAL VS. NO-DRUG DISCRIMINATION AFTER VARIOUS TYPES OF INITIAL SHAPING PROCEDURES

Group	Shaping Procedure	No. Rats	Bar Selection Criterion (9/10>66%) RTC	Bar Selection Criterion (9/10>66%) STC	Sliding Average Criterion (5-day avg>80%) (on both bars) RTC	Sliding Average Criterion (5-day avg>80%) (on both bars) STC
1	8 Bar-2 N days 8 Bar-1 D days	9	2.6 (0–9)	15.0* (9–22)	2.9 (0–14)	15.6* (11–27)
2	8 Bar-1 D days 8 Bar-2 N days	9	3.6 (2–7)	17.6‡ (16–21)	3.9 (1–9)	18.2 (15–23)
3	6 Bar-2 N days 5 Bar-1 D days (Long Sessions)	7	2.3 (0–10)	10.1†§ (7–16)	4.5 (1–13)	12.2* (9–19)
4	8 Bar-2 N days 8 Bar-1 N days	8	12.1¶ (5–20)	26.1¶ (19–34)	15.9¶ (7–32)	30.0¶ (21–46)
5	8 Bar-2 days 8 Bar-1 days (D & N random)	7	4.1†† (2–12)	17.3**†† (14–23)	5.5†† (3–12)	18.5**†† (15–23)
6	Immediate Alternation (No Shaping)	9	6.4¶ (4–13)	9.4¶ (8–15)	6.4** (3–13)	9.5¶ (6–15)

Columns 1–3 describe the experimental groups and columns 4–7 show the amount of training prior to the onset of criterion performance, using two different types of criteria.

In columns 4–5, criterion performance was test epoch accuracy greater than 66% during 9 out of 10 consecutive sessions.

In columns 6–7, criterion was average test epoch accuracy greater than 80% in each drug condition during 10 consecutive sessions (the 5 N and 5 D sessions yielded two average percentages, each of which to exceed 80% in order to meet criterion).

STC indicates the total number of shaping *and* training sessions prior to the beginning of the criterion string of sessions.

RTC indicates the number of "bar reversals" prior to the onset of criterion performance.

For each group, the table shows the mean value of each index and its range in individual rats.

Mean STC and RTC values are geometric means.

Numbers in parentheses are 100% ranges.

*Marginally significant by comparison with Group 2 ($p<0.10$).

†Significantly different than Group 1 ($p<0.05$).

‡Significantly different than Group 3 ($p<0.002$).

§Significantly different than Groups 1 and 2 pooled ($p<0.002$).

¶Significantly different than Groups 1, 2, and 3 pooled ($p<0.005$).

**Marginally significant by comparison to Groups 1, 2, and 3 pooled ($p<0.10$).

††Significantly different than Group 4 ($p<0.005$).

shaping sessions were sufficiently associated with the corresponding D and N states so that after a single discrimination training session, most rats subsequently selected the correct lever in both the drug and no drug conditions. In Groups 1 and 2, discriminations were acquired almost as rapidly. In Group 4, where all shaping sessions on each lever were conducted without drug, the onset of discrimination was slower and required about 10 discrimination training sessions. In Group 5, where drug conditions varied randomly during both bar 2 and bar 1 shaping, DD acquisition was unexpectedly rapid, requiring about 5 sessions. In Group 6, where there were no shaping sessions, drug and no drug conditions alternated from the first day of training in the 2-bar boxes, and the discrimination was learned in approximately 10 sessions.

Table 2 shows group mean values for several indices of acquisition, the range of values observed for each index in individual rats, and the levels of statistical significance of selected comparisons (Mann-Whitney U-test). These indices show the same trends described in Fig. 1. Comparison of Groups 1 vs. 2, 1 vs. 3, and 2 vs. 3, showed few significant differences between the effects of the shaping procedures used in these groups. Group 3 showed somewhat smaller bar-selection STC values than Groups 1 or 2 because fewer shaping sessions were used in Group 3. However, the number of discrimination training sessions before beginning of criterion performance (RTC-2) did not differ in these groups. The deleterious effect of conducting all shaping sessions without drug is evident in the highly significant differences between Group 4 and Groups 1, 2 and 3. Unexpectedly, RTC and average accuracy scores for Group 5 did not differ from those of Groups 1, 2 and 3, and Group 5 did differ significantly from Group 4. Finally, Group 6 (trained without preliminary shaping) showed higher scores for RTC and lower scores for STC than did groups 1, 2 and 3. Although

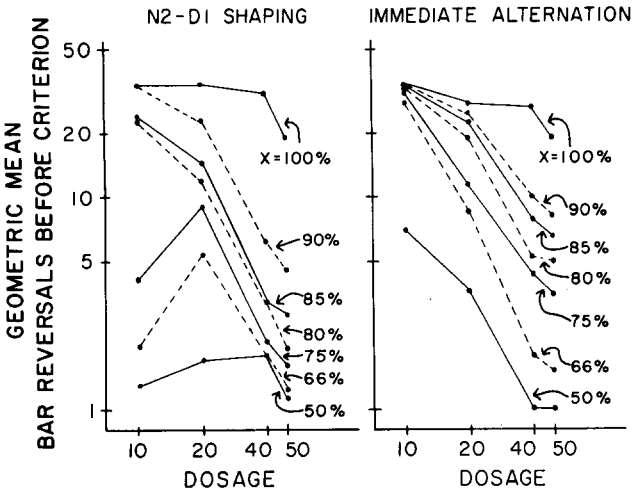

FIG. 2. Bar reversals before the beginning of criterion performance (RTC) of D vs. N discriminations of various doses of phenobarbital in rats trained with and without initial N2→D1 shaping sessions. For each curve, criterion was "8-day average test epoch accuracy at least as high as the labeled percent (X)."

TABLE 3

AVERAGE CORRELATION COEFFICIENTS SHOWING THE CORRELATION BETWEEN DOSAGE AND VARIOUS INDICES OF "BAR REVERSALS TO CRITERION"

Number of Days In Average (N)	Criterion level for sliding average (×) 50%	66%	75%	80%	85%	90%	100%
4		−.60	−.68	−.66	−.66	−.61	−.54
6		−.57	−.71	−.78	−.75	−.84	−.59
8	−.51	−.67	−.71	−.87	−.82	−.84	−.63
10		−.66	−.83	−.85	−.85	−.82	−.58

Criterion performance was defined as "N-day sliding average (both bars pooled) > × percent." For each value of N and X, and for each type of shaping, a correlation coefficient was computed from the values of ln dose and ln RTC for individual animals. The table shows the average of the correlation coefficients obtained with N2–D1 shaping and with no shaping.

Groups 1, 2 and 3 required fewer discrimination training sessions (RTC-2) than Group 6 before achieving criterion performance, they required a significantly higher number of total sessions (STC=shaping plus training sessions).

Experiment 2. RTC Indices of Degree of Discriminability

In this experiment, Groups 1, 6 and 7–12 were trained to discriminate phenobarbital 10, 20, 40 or 50 mg/kg vs. no drug, either with or without prior N2→D1 shaping sessions. To illustrate our approach to analyzing this data, Fig. 2 shows the number of bar reversals before criterion (RTC) for each group, when criterion was defined as "average test epoch performance >*X*% during 8 consecutive sessions (D and N days pooled)." The figure shows that with very low values of *X*, rats trained with 10 mg/kg met criterion after a few sessions, even though average accuracy of bar selection by these rats was only slightly above random. With very high values of *X*, some rats trained with 50 mg/kg failed to achieve criterion because of occasional incorrect test epoch presses, even though these rats obviously discriminated the training states (performance by these rats is shown in Fig. 1). When *X* was 80 or 85, mean RTC varied monotonically with dosage, and the resulting RTCs appeared to reflect the actual number of sessions before the discrimination was learned in rats trained either with N2→D1 shaping or with no shaping.

In an analogous fashion we plotted RTCs obtained with both concurrent and pooled sliding-average and bar-selection criteria based on 4, 6, 8 and 10 consecutive days of performance. Sliding average criteria were evaluated using several criterion levels (i.e., 50, 66, 75, 80, 90%). Only a 66% criterion for bar selection was employed.

In this analysis we assumed that a "good" index of degree of discriminability would vary linearly with dosage. To compare the utility of various indices, we computed the correlation coefficient between ln RTC and ln dose (each rat yielded a pair of X, Y values that was entered into each correlation computation). For example, the plots in Fig. 2 yielded 14 correlation coefficients. We reasoned that correlation coefficients would be highest for indices that varied linearly with ln dosage and had relatively little inter-animal variability at each individual dose.

Table 3 shows an exemplary set of correlation coefficients obtained with one index. The criterion for this table was "N-day sliding average (bar 1 and bar 2 days pooled) greater than *X* percent." Correlation coefficients for N2→D1 shaping and for no shaping were averaged together for presentation in this table. Row 3 (N=8) in the table corresponds to the data in Fig. 2. In general, the table shows that if the sliding-average criterion level was too high or too low, the correlation of RTC with dosage decreased. Of all the criteria used, the one based on "8-day sliding average greater than 80%" correlated most highly with dosage, and was hence the 'optimal' index of this form.

Selection of Optimal RTC Indices

As already mentioned, we applied the four types of RTC criteria described in the procedures section for N=4, 6, 8, and 10 days, computed correlation coefficients as in Table 3, and selected the parameters which yielded the highest correlation coefficients. Table 4 shows the maximum correlation coefficients obtained with each type of RTC index of speed of acquisition when 4, 6, 8 or 10 days were included in the criterion, and defines the parameters at which this coefficient was obtained. For example, the bottom left entry in the table shows that the correlation coefficient relating ln RTC to ln dosage was only −0.68 when criterion was 2 out of 2 successive sessions with test epoch accuracy greater than 66% concurrently achieved in the D and N conditions. Similarly, the top right entry in the table shows a correlation of −0.85 between dosage and the number of sessions before 10-day average accuracy (both bar 1 and bar 2 days included) exceeded 80% (or 85%); these are the "optimal" indices of this type based on 10 days of data, as previously shown in Table 3. In general, criteria based on 8–10 days of performance were superior (yielded larger correlation coefficients) than those based on 4–6 days. Criteria based on average test

TABLE 4

OPTIMAL INDICES OF SPEED OF ACQUISITION BASED ON 4, 6, 8, AND 10 DAYS OF PERFORMANCE UTILIZING VARIOUS CRITERION LEVELS AND VARIOUS ALGORITHMS FOR COMPUTING RTC

	Number of Days in Criterion String			
Type of Index	4	6	8	10
Sliding Average Criteria				
Pooled	85 (−.66)	90* (−.84)	80* (−.87)	80*,85* (−.85)
Concurrent	90 (−.66)	85* (−.84)	80 (−.84)	75*,80* (−.83)
Bar Selection Criteria (>66%)				
Pooled	4/4 (−.68)	5/6 (−.72)	8/8* (−.83)	9/10* (−.83)
Concurrent	2/2 (−.68)	3/3* (−.67)	4/4* (−.83)	4/5* (−.83)

For each type of index, the value in parentheses is the highest correlation coefficient obtained with the index.

For indices based on sliding averages the value outside of parentheses is the to-be-achieved criterion percentage.

For indices based on bar-selection the denominator and numerator outside the parentheses are, respectively, the number of days included in the criterion string and the number of days when test epoch performance had to exceed 66%.

*This criterion did not yield RTC values that were grossly incorrect for any individual rat in our sample.

epoch accuracy appeared to be slightly superior to those based on the number of sessions with correct bar selection.

We did not evaluate STC indices as it appeared that such indices, because they included the variable number of days devoted to shaping, could not reflect degree of discriminability as accurately as would indices of the RTC type.

Experiment 3. Session Duration

Table 5 shows results obtained with DD training sessions that lasted 5, 15 and 60 min, respectively. Discrimination of barbital 30 was quantified by averaging test epoch performance on days 14–27. Although group mean accuracy was lower with 15-min sessions than in other groups, the differences were entirely attributable to one or two individual rats, and were not significant, $F(2,9)=2.02$, ns. During sessions 36–48, after rats discriminated 60 mg/kg vs. no drug, the group means maintained the same rank ordering with 15-min rats showing the lowest average accuracy and 60-min rats the highest. In this case also, differences were not significant, $F(2,9)=1.03$, ns.

TABLE 5

AVERAGE TEST EPOCH ACCURACY AFTER DD TRAINING WITH SESSIONS OF VARIOUS LENGTHS

Group	Rat No.	Avg % Correct Barbital 30 Days 14–27	Avg % Correct Barbital 60 Days 36–48
13	1	74.9	84.4
(5′ Duration)	2	80.6	95.9
	3	64.2	97.7
	4	62.1	97.5
	Mean	70.5	93.9
14	5	42.9	95.8
(15′ Duration)	6	64.0	99.4
	7	69.9	82.2
	8	68.0	97.1
	Mean	61.2	93.6
15	9	66.6	100
(60′ Duration)	10	82.7	96.3
	11	79.7	100
	12	70.5	99.4
	Mean	74.9	98.9

The table shows average percent correct test epoch presses with two doses of barbital.

Experiment 4. Ratio Size

Table 6 shows indices of acquisition and asymptotic performance when correct presses were reinforced on FR-3, FR-10 and FR-30 schedules, respectively. One factor ANOVAs showed that none of the indices of accuracy differed significantly between groups ($p>0.05$). Inspection of the results for individual animals in Table 6 confirms the absence of significant differences or even obvious trends suggesting differences between groups in this experiment. Test epochs in these groups lasted until 3, 10 or 30 presses, respectively, had occurred on bar 1 or bar 2. The mean number of reinforcements earned per session were 185, 101, and 45, respectively.

DISCUSSION

Experiment 1. Shaping Procedures

The results of Experiment 1 showed that the speed of acquisition of DDs can be significantly influenced by the type of initial shaping procedures employed. In Groups 1–3, drug states appropriate to the currently reinforced lever were established during shaping sessions, and the subsequent rapid acquisition of discriminative control ($2\leq RTC\leq 5$) suggests that responding had become partially contingent on the imposed drug states during the shaping sessions. In contrast, when no shaping sessions were administered (Group 6) or when all shaping sessions were conducted without drug

TABLE 6

INDICES OF SPEED OF ACQUISITION FOR RATS TRAINED TO DISCRIMINATE PHENOBARBITAL 15 mg/kg VS. NO DRUG WITH VARIOUS RATIO SCHEDULES OF REINFORCEMENT

Rat No.	Schedule of Rf: Correct Bar	Schedule of Rf: Incorrect Bar	Bar Selection RTC (9/10 > 66%) (Both Bars Pooled)	Average % Correct Test Presses: Days 1–40	Average % Correct Test Presses: Days 41–80
1	FR-3	Extinction	36	66	80
2	FR-3	Extinction	25	72	80
3	FR-3	Extinction	34	64	94
4	FR-3	Extinction	32	59	95
5	FR-10	Extinction	36	62	86
6	FR-10	Extinction	43	68	73
7	FR-10	Extinction	29	62	90
8	FR-10	Extinction	28	67	95
9	FR-30	Extinction	34	55	94
10	FR-30	Extinction	19	76	68
11	FR-30	Extinction	25	70	95
12	FR-30	Extinction	25	67	81

(Group 4), the acquisition of drug discriminations required more DD training sessions ($6 \leq RTC \leq 16$). Hence, these results suggest that the imposition of drugs as contextual stimuli during shaping sessions can facilitate their subsequent acquisition of discriminative control. Analogous results have previously been obtained in the T-maze task [5] and in the operant task when variable interval reinforcement schedules were used [6]. The present results extend this finding by showing that facilitation of DD acquisition also occurs when fixed ratio schedules of reinforcement are employed.

Results in Group 5 were not as expected; exposure to drug during shaping sessions facilitated subsequent acquisition of drug discriminations, even though drug and reinforcement conditions were not consistently paired during shaping. We do not understand this result, which may suggest that exposure to drug, *per se*, in the training situation can facilitate the subsequent acquisition of DDs. Replication and further investigation of this effect might indicate that the development of behavioral tolerance can facilitate the acquisition of DDs, and this would in turn require a reevaluation of the factors that contributed to rapid acquisition in Groups 1–3.

Although drug-appropriate shaping sessions reduced the amount of discrimination training that was required to establish DDs, they did not reduce the total number of sessions before criterion. Indeed, the number of shaping sessions employed in Groups 1–3 was larger than the number of discrimination training sessions that were subsequently saved. This is evident if one compares the total number of shaping plus training sessions before criterion performance in Group 6 (STC=9) to the number required in Groups 1–3 (STC=10 to 18). Hence, although the effects of drug shaping sessions are in accord with our expectations, they do not provide a markedly improved method for rapidly establishing drug discriminations. If shaping sessions are to be conducted, acquisition will be most efficient if appropriate drug conditions are established starting with the very first shaping session. However, there is no loss of efficiency if one omits shaping sessions entirely, and proceeds directly to discrimination training.

Experiment 2. RTC Indices

Our analysis of various RTC indices of speed of acquisition as possible indicators of degree of discriminability revealed several general findings.

1. The stringency of a criterion is influenced both by the level of performance required and the number of days during which this performance must be maintained.

2. If the criterion is too stringent, some rats will never achieve criterion performance even though they do learn the required discrimination. RTC values for other rats will tend to be inappropriately high when such a criterion is used. This is especially noticeable with training conditions that yield low RTCs. We can describe such criteria as producing overestimated values of TRC.

3. If the criterion is too lenient, some rats will achieve criterion on the basis of transiently accurate bar selection, even though their overall performance indicates that they have not learned the discrimination. With such criteria, RTC values tend to be deflated below their "true" values—especially with training conditions that yield high RTCs.

Both of these effects are apparent in Fig. 2, where the most stringent criteria seriously inflated the RTCs obtained with high training doses, and where the least stringent criteria seriously underestimated the RTCs produced by low doses.

4. When 10 or more days of performance are included in the criterion computation, it is possible to define criteria of intermediate stringency with which neither "errors" of underestimation or of overestimation frequently occur. With such criteria, plots of RTC *may* reflect the relative degree of discriminability of various training doses. For example, in Fig. 2 criteria of intermediate stringency yielded RTC values that varied monotonically with dosage, thus presumably reflecting differences in the degree of discriminability of the training drug. When six or fewer days performance are included in the criterion computation, even the "optimal" level of stringency often yields underestimated and overestimated RTCs for individual rats. In general, the 10-day criteria in Table 5 were entirely satisfactory. Criteria based

on 6 and 8 days performance were less satisfactory, but are included for use in cases where 10 days of data cannot feasibly be collected.

The general conclusion from our results is that correct selection of criterion stringency is *very* important if a sessions to criterion index is used to reflect speed of acquisition of DDs. Table 4 lists several criterion stringencies that produced sensible results when applied to our data.

It should be obvious that we have not in any absolute sense validated the use of these particular measures of speed of acquisition as indices of degree of discriminability. Since there is no accepted method for measuring the degree of discriminability of a drug, we cannot compare the results obtained with any particular index with the "true" degree of discriminability produced by various doses of the drug. What we have shown is that certain indices of speed of acquisition yield results that vary in a reasonable fashion with dosage. The selected "optimal" criteria (based on 10 days of performance) are rarely achieved as the result of an accidental run of correct bar selections by a nondiscriminating rat. Conversely, discriminating rats rarely fail to achieve these criteria due to occasional accidental errors in bar selection. The linear dose effect curves in Fig. 2 indicate that the selected indices may reflect the degree of discriminability of various doses of phenobarbital.

In the present studies, rats were pretrained to bar press on ratio schedules of reinforcement before drug discrimination training was commenced. We think this procedure is necessary in order to obtain useful indices of degree of discriminability. During pretraining, the rats learn something about water deprivation, are magazine trained, and are accustomed to working on ratio schedules of reinforcement. This learning proceeds at a different rate in each individual rat. If pretraining of this sort were not carried out, then the number of sessions to achieve criterion DD performance would include a variable number of sessions devoted to magazine training, acquiring ratio performance, etc. It appears that this would increase the noise level of the resulting index of discriminability. However, this cannot be regarded as proven.

Experiment 3. Training Session Duration

The results of Experiment 3 failed to indicate that variations in the duration of training sessions would produce differences in the asymptotic accuracy of DDs. At a practical level, this is an important finding. A single training compartment can train 8 rats per day if one hour sessions are used, but 96 rats per day if 5 min sessions are used. Replication of our negative findings with other drugs and doses appears desirable. Additionally, in our experience a considerable number of hours in the training compartment are necessary before rats are magazine trained and accustomed to working on ratio schedules. Until these types of learning are completed, it may be disadvantageous to use extremely short training sessions.

Experiment 4. Ratio of Reinforcement

Experiment 4 indicates that ratio of reinforcement is not an important determinant of the speed of acquisition or asymptotic accuracy of DDs. We might note, however, that with any given reinforcer there is a practical upper limit to the size of the ratio that can be used. With 0.1 ml of sweetened water acting as the reinforcer, not all of our rats would regularly perform on an FR-30 schedule, and the rats in Group 18 were selected from among those who accommodated easily to high ratios during pretraining.

Summary

This study yielded three findings of moderate practical importance. First, DDs were most rapidly learned if contingencies relating the imposed drug condition to the reinforced lever were imposed at the very beginning of training in the 2-lever boxes. With such procedures, the rats were never reinforced in either the D or N state for pressing a lever that would later become the "incorrect" lever in that state. Second, the results suggest that indices based on the speed of acquisition of drug discriminations may provide useful indices of the degree of discriminability of the training conditions in the 2-bar operant DD task. Such indices of degree of discriminability have previously not been available in this task. Third, the results indicate that quite similar acquisition and performance of DDs is obtained with training session durations ranging from 6 to 60 minutes. This suggests that the commonly used 20–30 minute sessions may be longer than necessary, and that considerable efficiencies of effort might be achieved by using shorter training sessions.

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