JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1976, 26, 281-287 NUMBER 2 (SEPTEMBER)

PUNISHMENT OF RESPONDING UNDER SCHEDULES OF STIMULUS-SHOCK TERMINATION: EFFECTS OF d-AMPHETAMINE AND PENTOBARBITAL[1]

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Responding maintained in squirrel monkeys under 5-min fixed-interval schedules of either food presentation or termination of a visual stimulus associated with electric-shock delivery was suppressed by presenting an electric shock for every thirtieth response (punishment). In monkeys responding under the schedule of food presentation, *d*-amphetamine sulfate only further decreased punished responding, and pentobarbital sodium markedly increased punished responding, as expected from previous reports. In monkeys responding under the schedule of stimulus-shock termination, however, the effects of the two drugs were opposite: *d*-amphetamine markedly increased punished responding, whereas pentobarbital only decreased responding. Thus, the effects of these drugs on punished responding were different depending on the type of event maintaining responding. These and previous results indicate that it may be misleading and inaccurate to speak of the effects of drugs on "punished responding" as though punishment were a unitary phenomenon. As with any behavior, the effects of drugs and other interventions on punished responding cannot be accurately characterized independently of the precise conditions under which the behavior occurs.

Key words: shock termination, punishment, drugs, *d*-amphetamine, pentobarbital, fixed interval, fixed ratio, lever press, squirrel monkey

Both amphetamines and barbiturates have been shown to increase behaviors that normally occur at a low rate in a wide variety of situations (Kelleher and Morse, 1968). However, barbiturates increase low rates of schedule-controlled responding even when this low rate has resulted from suppression by response-produced electric shock (punishment), whereas amphetamines generally do not. This qualitative difference in the effects of amphetamines and barbiturates has been confirmed in a wide variety of species and experimental situations (McMillan, 1975).

In most experiments that have studied the effects of these or other drugs on punished behavior, responding is maintained under some schedule of food or water presentation, and then suppressed by presenting electric shock following some or all of the subject's responses. Recent experiments, making use of situations different from those typically used, indicate that under some conditions, amphetamines may markedly increase punished responding. In one experiment (McKearney and Barrett, 1975), responding maintained in squirrel monkeys under a fixed-interval schedule of food presentation was suppressed by presenting an electric shock for every thirtieth response (punishment). Initially, responding during alternate 10-min periods of the experimental session, in the presence of a different discriminative stimulus, had no effect (extinction). Under these conditions, *d*-amphetamine decreased punished responding, as has been reported previously. Later, when the extinction component was replaced by a schedule in which responding postponed electric shocks (avoidance), the same doses of *d*-amphetamine markedly increased responding during punishment components. This increase in punished responding stands in marked contrast to previously reported effects of amphetamines. In another experiment (McKearney, 1973) responding was maintained under a 3-min variable-interval schedule (VI 3-min) of shock presentation in one component of a multiple schedule, and suppressed under a 10-response fixed-ratio schedule (FR 10) of shock presentation in another component; methamphetamine (0.01 to 0.17 mg/kg) increased both the

[1]Supported by Grants MH-18421 (NIMH) and DA-01015 (NIDA) from the U.S. Public Health Service. I thank W. H. Morse and J. E. Barrett for helpful comments on the manuscript, E. Spencer for technical assistance, and E. Anderson for help in preparing the manuscript. Reprints may be obtained from the author, Worcester Foundation for Experimental Biology, 222 Maple Avenue, Shrewsbury, Massachusetts 01545.

maintained and suppressed responding under these conditions. These experiments show that amphetamines may increase rather than decrease punished responding in situations in which electric shock also maintains behavior.

The present experiments extended observations on the effects of drugs on punished responding to another situation in which responding is both maintained and suppressed by electric shock. Responding in squirrel monkeys was maintained under FI 5-min schedules in which the first response after 5 min either produced a food pellet (food presentation) or terminated a visual stimulus associated with periodic shock delivery (stimulus-shock termination). Then, responding was suppressed by presenting an electric shock for every thirtieth response (punishment); low rates of responding prevailed under this condition. The effects of *d*-amphetamine and pentobarbital differed depending on whether responding was maintained by food presentation or by stimulus-shock termination, indicating further that the effects of drugs on "punished responding" cannot be characterized independently of the total context in which that responding occurs.

METHOD

Subjects

Eight male squirrel monkeys (*Saimiri sciureus*) were housed individually and given free access to water. In experiments involving food presentation, availability of food was restricted to maintain body weight at approximately 80% of normal; otherwise, food was always available in the living cages. Monkey S-520 had been exposed to an avoidance schedule and to a variable-interval schedule of shock presentation about 2 yr before these experiments, but S-525 had no prior exposure to electric-shock delivery. Monkeys studied under stimulus-shock termination had not been exposed to response-produced shock before these experiments. All subjects had had extensive exposure to drug administration, but not for several months before these experiments.

Apparatus

Experiments were conducted with individual monkeys seated in a restraining chair (Hake and Azrin, 1963; Kelleher and Morse, 1964). Electric shocks were delivered through brass electrodes resting on a shaved portion of the tail. The shock was 650 V ac, 60 Hz, of approximately 200 msec duration, delivered to the electrodes through variable series resistance. The response key (BRS/LVE #121-05) was mounted on a clear panel facing the monkey. Each depression of the response key with a force of approximately 20 g (0.2 N) or more produced the audible click of a relay within the chamber, and was recorded as a response. Three pairs of 7.5-W colored lights were mounted behind this clear panel. Food pellets (250 mg SKF; Riddle, Rednick, Catania, and Tucker, 1966) could be delivered to a receptacle mounted on the same panel at waist level. The restraining chair was enclosed in a ventilated, sound-attenuating chamber placed in a room distant from the automatic programming and recording equipment. Continuous white masking noise was present.

Schedules

Except for Monkeys S-520 and S-525, all were experimentally naive when first exposed to a schedule of termination of a visual stimulus associated with electric-shock delivery (Morse and Kelleher, 1966). Under the final parameters of this schedule, when 5 min had elapsed in the presence of a white light, shocks were scheduled to occur after t sec, and every t sec thereafter. The first response to occur after 5 min terminated the white light and the possibility of shock, and instituted a 30-sec timeout, during which all lights were extinguished and no shocks were delivered (FI 5-min schedule). The t parameter was 3 sec and shock intensity was 5.0 mA for S-535, S-536, and S-538; for S-532, S-533, and S-534, t was 5-sec and shock intensity was 10.0 mA. These differences in parameters were not of direct interest in these experiments, and did not result in systematic differences in responding. Sessions were terminated after either 15 (S-535 *et al.*) or 20 (S-532 *et al.*) FI cycles. The effects of a variety of drugs were studied under the FI schedule alone before the punishment schedule was introduced (only the effects of *d*-amphetamine are reported here).

Under the punishment procedure, the FI schedule remained in effect, but, in addition, every thirtieth response during each FI produced an electric shock. Shock intensity was the same whether shock was delivered under the FI schedule or under the punishment schedule. The number of responses producing

a shock under the punishment schedule was counted from the beginning of each FI cycle.

Monkeys S-520 and S-525 had prior experience under a variety of schedules of food presentation, and were studied in these experiments under an FI 5-min schedule of food presentation; that is, the first response after 5 min had elapsed produced a food pellet. Successive FI cycles were separated by 30-sec timeout periods in which lights were extinguished and responding had no scheduled consequences. Sessions were terminated after 20 FI cycles. Under the punishment procedure, every thirtieth response resulted in delivery of a 3.0-mA electric shock (this intensity resulted in approximately the same level of punished responding as under the stimulus-shock termination schedule). Experimental sessions under all procedures were generally conducted five days weekly.

Drug procedure. *d*-Amphetamine sulfate (courtesy of Smith, Kline and French Laboratories) and pentobarbital sodium (courtesy of Abbott Laboratories) were dissolved in 0.9% sodium chloride solution. Injection volume was normally 0.5 mg/kg of body weight given in the calf muscle immediately before the experimental session. Doses are expressed in terms of the total salt. Drugs were usually administered on Tuesdays and Fridays, with Thursday's performance serving as control (no injections). Unless otherwise specified, each subject received at least two injections of each dose, given in mixed order.

Analysis of results. Drug effects are expressed both as absolute and per cent changes in response rate. Average control rates of responding were generally computed from at least five individual control sessions (no injections) under each procedure.

RESULTS

Control performances. The FI schedule of stimulus-shock termination engendered characteristic performances as described previously for this schedule (Morse and Kelleher, 1966). As under FI schedules of food presentation, performance was characterized by a period of little or no responding at the beginning of each FI cycle, followed by a gradual increase in responding. Average control rates of responding for each subject are summarized in Table 1.

Table 1

Control Rates of Responding in Individual Subjects[1]

Subject	*Responses/Sec*	*Standard Deviation*
Stimulus-shock termination (no punishment)		
S-532	0.151	0.051
S-533	0.598	0.139
S-534	0.095	0.009
S-535	0.400	0.033
S-536	0.354	0.023
S-538	0.453	0.029
Stimulus-shock termination (punishment)		
S-532	0.115	0.039
S-533	0.095	0.038
S-534	0.085	0.013
S-535	0.124	0.021
S-536	0.110	0.025
S-538	0.051	0.034
Food presentation (punishment)[2]		
S-520	0.053	0.008
S-525	0.049	0.011

[1]Mean response rates (responses/sec) in five nondrug sessions.

[2]Control rates before punishment were 0.381 (±0.119) and 0.144 (±0.029), respectively, in S-520 and S-525.

When electric shock was presented for every thirtieth response under the FI schedule of stimulus-shock termination, responding was generally suppressed relative to that before punishment was introduced (Table 1), but the overall pattern of responding, a pause and then a gradual increase, was preserved (Figure 1). A similar pattern of punished responding was observed under the FI schedule of food presentation; responding was markedly suppressed (to about 14% and 34% of nonpunished responding in S-520 and S-525, respectively), but the pattern of responding was similar to that observed before responding was punished (Figure 1).

d-Amphetamine effects under FI stimulus-shock termination. The effects of graded doses of *d*-amphetamine on responding under the FI 5-min schedule of a stimulus-shock termination are summarized in Figure 2 (unfilled symbols). As previously reported for responding under FI schedules of stimulus-shock termination (Kelleher and Morse, 1964), *d*-amphetamine produced graded increases in responding in all monkeys.

Punishment of responding under FI stimulus-shock termination. The effects of *d*-amphetamine on punished responding under the schedule of stimulus-shock termination are shown in Figure 2 (filled symbols). Figure 1

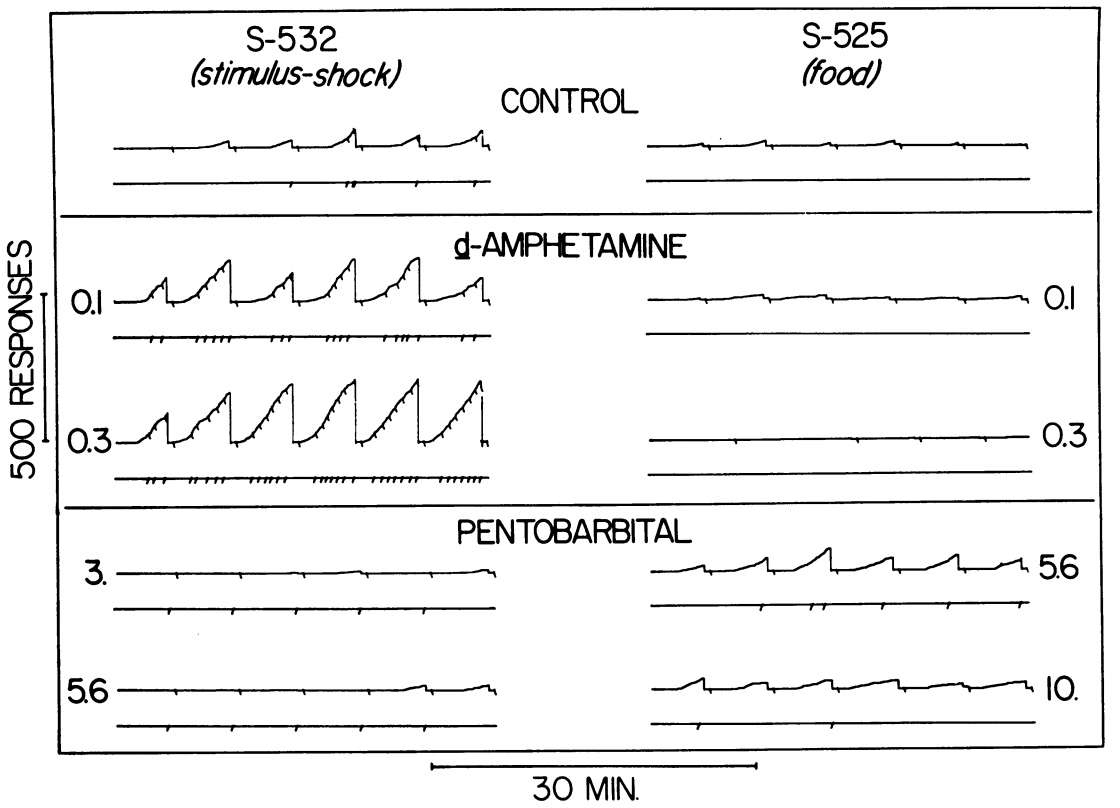

Fig. 1. Cumulative records of punished responding under FI 5-min schedules of stimulus-shock termination (S-532) or food presentation (S-525). Y-axis: cumulative responses. X-axis: time. The response pen reset at the termination of each FI. The end of 30-sec timeout periods is indicated by the first diagonal stroke on the response record. Shocks delivered under the punishment schedule (FR 30) are indicated by diagonal strokes on the event record (S-525) or on both the response and event records (S-532). Shocks delivered under the schedule of stimulus-shock termination are indicated by diagonal strokes on the event record only. With the exception of S-525 at 0.3 mg/kg *d*-amphetamine, all records represent the first six cycles of longer experimental sessions. Numbers next to each record refer to drug dose in mg/kg. Note that *d*-amphetamine increased punished responding only under the schedule of stimulus-shock termination, and that pentobarbital increased punished responding only under the schedule of food presentation.

also illustrates the effects of selected doses of *d*-amphetamine in one monkey (S-532). Though clear increases in responding were not especially evident in one monkey (S-534), *d*-amphetamine generally resulted in dose-dependent increases in punished responding.

The effects of pentobarbital on punished responding under the schedule of stimulus-shock termination are illustrated in Figure 3; cumulative response records for selected doses are illustrated in Figure 1 (S-532). In spite of its marked tendency to increase punished responding in many situations, pentobarbital only further decreased punished responding under this schedule.

Punishment of responding under FI food presentation. The effects of *d*-amphetamine and pentobarbital on punished responding under the FI schedule of food presentation are summarized in Figure 4 and Figure 1 (S-525). In contrast to the effects observed under the schedule of stimulus-shock termination, *d*-amphetamine only further decreased punished responding (filled symbols), yet there were clear dose-related increases in responding with pentobarbital (unfilled symbols).

DISCUSSION

d-Amphetamine and pentobarbital had different effects on punished responding, depending on the type of event maintaining behavior. As previously shown in a variety of species and

situations, responding maintained by food presentation and suppressed by response-dependent electric shock was increased by pentobarbital but only further decreased by *d*-amphetamine. On the other hand, when responding was maintained by termination of a visual stimulus associated with electric shock, and suppressed by response-produced shock, the effects of both drugs were exactly opposite: *d*-amphetamine produced marked increases in punished responding, and pentobarbital only decreased responding. Doses of *d*-amphetamine that markedly decreased punished responding maintained by food presentation substantially increased punished responding maintained by stimulus-shock termination; doses of pentobarbital that markedly increased punished food-maintained responding further decreased punished responding maintained by stimulus-shock termination.

These results confirm and extend previous conclusions (McKearney, 1973; McKearney and

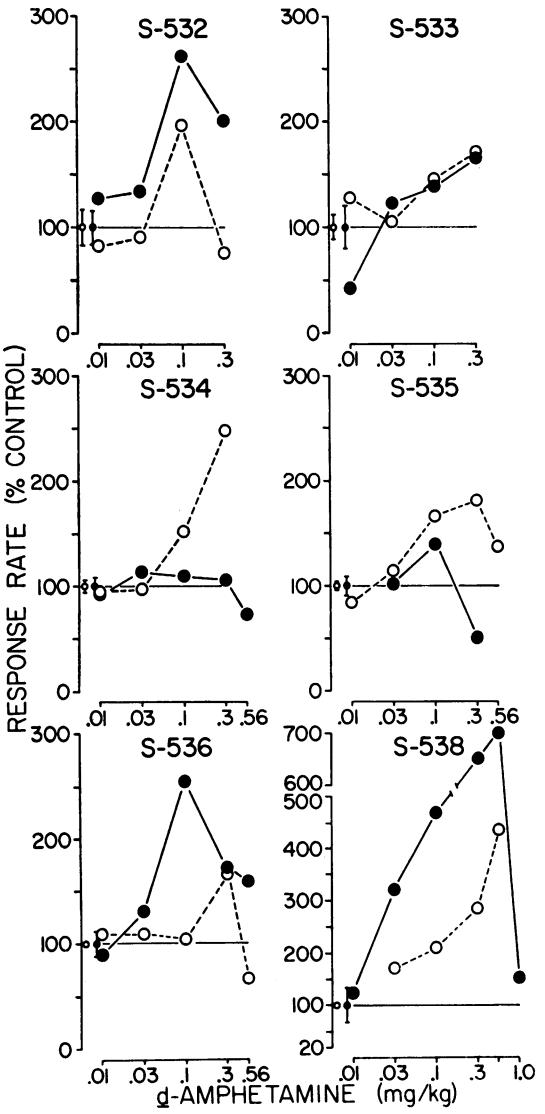

Fig. 2. Effects of *d*-amphetamine on punished and unpunished responding under an FI 5-min schedule of stimulus-shock termination. Y-axis: response rate as per cent of control. X-axis: log dose. Unfilled symbols: unpunished responding. Filled symbols: punished responding. Smaller symbols and vertical brackets at the left represent mean control response rates ± one standard error (where there are no brackets, these fall within the area covered by the symbol). All points represent the mean of at least two observations, with the following exceptions: S-535 and S-536 (unpunished) at 0.56 mg/kg; S-534 at 0.56 mg/kg, S-536 at 0.56 mg/kg, and S-538 at 0.01, 0.56, and 1.0 mg/kg (all under the punishment condition). Note the change in the scale on the Y-axis for S-538.

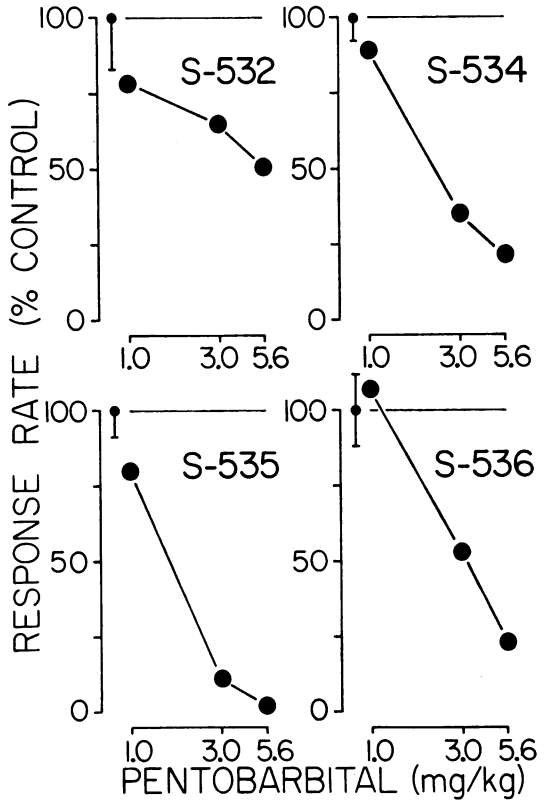

Fig. 3. Effects of pentobarbital on punished responding under an FI 5-min schedule of stimulus-shock termination. Y-axis: response rate as per cent of control. X-axis: log dose. Smaller symbols and vertical brackets at the left represent mean control response rates ± one standard error. With the exception of S-534 at 5.6 mg/kg, each point represents a single observation. Note that pentobarbital only decreased punished responding.

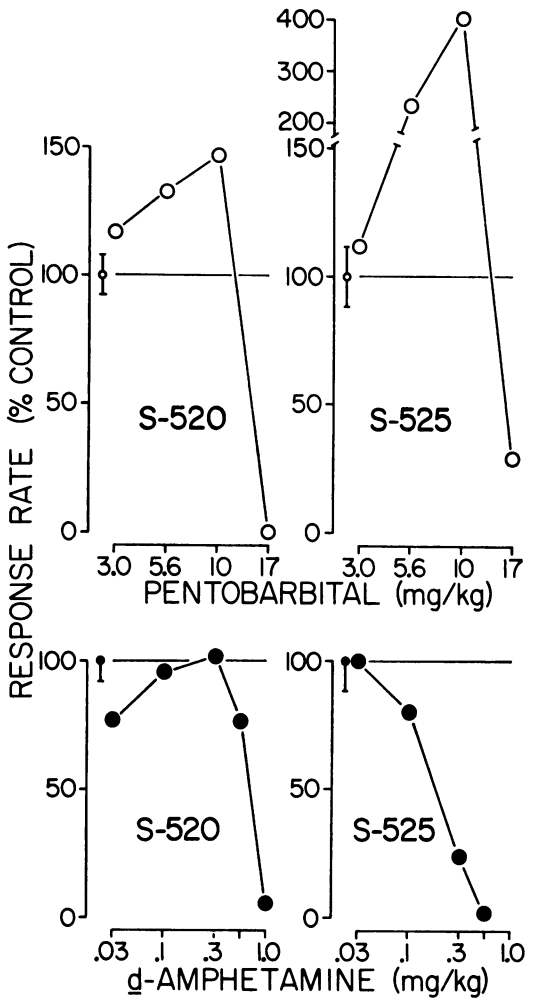

Fig. 4. Effects of pentobarbital and *d*-amphetamine on punished responding under an FI 5-min schedule of food presentation. Y-axis: response rate as per cent of control. X-axis: log dose. Smaller symbols and vertical brackets at the left represent mean control rates ± one standard error. Note the change in scale on the Y-axis for S-525. Pentobarbital (upper) increased punished responding, but *d*-amphetamine did not.

Barrett, 1975) that the effects of drugs on punished responding can depend critically on the environmental *context* in which the behavior occurs. While amphetamines are generally reported not to increase punished responding, this generalization has emerged from a somewhat restricted set of experimental conditions. Previous experiments have generally looked only at the effects of amphetamines and other drugs on punished responding maintained by food or water presentation, and have generally studied this punished behavior in relative isolation from other factors in the subject's environment. But, both the type of event maintaining responding and the context in which behavior occurs can profoundly influence the effects of drugs on punished responding. For example, although amphetamines do not generally increase punished responding maintained by food presentation, methamphetamine has been shown to increase responding suppressed by shock presentation when responding is also maintained by shock presentation in another component of a multiple schedule (McKearney, 1973). Also, *d*-amphetamine has been shown to increase punished responding maintained by food presentation in subjects also responding to postpone shock in another component of a multiple schedule (McKearney and Barrett, 1975). These findings illustrate the profound influence that characteristics of concurrently ongoing behaviors can have in determining the effects of drugs on punished responding, and the present experiments show clearly that the effects of drugs on punished responding can also be determined by the type of event maintaining responding.

The effects of drugs on punished responding seem to be very different when studied in relative isolation, as opposed to occurring in a context in which noxious events are also responsible for maintenance of behavior. Unfortunately, most of what is known about maintenance and suppression of behavior by noxious events, and about the effects of drugs on these behaviors, has come from experiments in which each process is studied separately. In contrast, natural environments may not impose one of these conditions in the absence of the other. To the extent that concurrently ongoing behaviors maintained and suppressed by noxious events may significantly interact, information derived exclusively from study of one in the absence of the other may be of limited practical applicability.

The results of the present and previous experiments indicate that it may be misleading and inaccurate to speak of the effects of drugs on "punished responding" as though punishment were a unitary phenomenon (*cf.* McMillan, 1975). It is no more justifiable to conclude that a drug has a particular effect on "punished responding" that it is to conclude the same thing about "reinforced responding". Simply knowing that a behavior is main-

tained or suppressed, or that it is controlled by either reinforcement or punishment, is not sufficient information to predict the effects of drugs accurately. As with any behavior, the effects of drugs, and other interventions, on punished responding cannot be accurately characterized independently of the precise conditions under which the behavior occurs.

REFERENCES

Hake, D. F. and Azrin, N. H. An apparatus for delivering pain shock to monkeys. *Journal of the Experimental Analysis of Behavior,* 1963, **6,** 297-298.

Kelleher, R. T. and Morse, W. H. Escape behavior and punished behavior. *Federation Proceedings,* 1964, **23,** 808-817.

Kelleher, R. T. and Morse, W. H. Determinants of the specificity of the behavioral effects of drugs. *Ergebnisse der Psysiologie,* 1968, **60,** 1-56.

McKearney, J. W. Methamphetamine effects on responding under a multiple schedule of shock presentation. *Pharmacology Biochemistry and Behavior,* 1973, **1,** 547-550.

McKearney, J. W. and Barrett, J. E. Punished behavior: increases in responding after *d*-amphetamine. *Psychopharmacologia,* 1975, **41,** 23-26.

McMillan, D. E. Determinants of drug effects on punished responding. *Federation Proceedings,* 1975, **34,** 1870-1879.

Morse, W. H. and Kelleher, R. T. Schedules using noxious stimuli. I. Multiple fixed-ratio and fixed-interval termination of schedule complexes. *Journal of the Experimental Analysis of Behavior,* 1966, **9,** 267-290.

Riddle, W. C., Rednick, A. B., Catania, A. C., and Tucker, S. J. Complete squirrel monkey diet in tablet form. *Journal of the Experimental Analysis of Behavior,* 1966, **9,** 670.

Received 25 September 1975.
(Final Acceptance 30 March 1976.)