Pergamon

Pharmacology Biochemistry and Behavior, Vol. 48, No. 2, pp. 491–495, 1994
Copyright © 1994 Elsevier Science Ltd
Printed in the USA. All rights reserved
0091-3057/94 $6.00 + .00

0091-3057(94)E0002-Y

Shock Postponement Reverses the Effects of Cocaine on the Punished Pecking of Pigeons

THOMAS A. TATHAM,*[1] ANN M. GYORDA* AND JAMES E. BARRETT†

*Department of Psychiatry, Uniformed Services University of the Health Sciences, Bethesda, MD 20814
†Lederle Laboratories, Pearl River, NY 10965

Received 26 October 1993

TATHAM, T. A., A. M. GYORDA AND J. E. BARRETT. *Shock postponement reverses the effects of cocaine on the punished pecking of pigeons.* PHARMACOL BIOCHEM BEHAV 48(2) 491–495, 1994.—The effects of cocaine on punished and unpunished key peck responding of pigeons was examined before and after a history of treadle pressing maintained by shock postponement. In one schedule component, the first peck after 3 min produced grain. The alternate component was similar, but every 30 responses was also punished by a mild shock. Punished responding occurred at approximately 25% of the rate of unpunished responding. Cocaine (0.1–10.0 mg/kg IM) did not affect or decrease punished responding; unpunished responding was not systematically affected. Next, a foot treadle was installed and treadle presses postponed shocks for 25 s; shocks occurred every 5 s in the absence of pressing. The treadle was removed when shocks were reliably postponed. Next, the multiple schedule of key pecking was reinstated. At least one dose of cocaine now increased punished pecking; unpunished responding was not systematically altered. These results complement related findings with monkeys and show that pigeons are suitable subjects for studying the reversal of the effects of cocaine on punished responding by a history of postponing shock.

Cocaine Behavioral history Shock postponement Punished responding Key pecking Treadle pressing Multiple schedule Fixed-interval schedule Pigeons

PSYCHOMOTOR stimulants, such as *d*-amphetamine, normally decrease the rate of occurrence of punished responding despite the more general tendency of these drugs to increase low-rate responding [e.g., (7,14)]. However, the punished responding of squirrel monkeys can be increased by *d*-amphetamine following a history of responding under a shock postponement schedule (3). The effects of *d*-amphetamine were reversed even though there was no discernible alteration in response rate during nondrug control sessions. This finding demonstrates that under some circumstances the behavioral effects of drugs may be controlled by historical as well as current contingencies.

Recent work has improved our understanding of historical influences on the behavioral actions of drugs and the generality of these effects by systematically examining the effects of behavioral history on punished responding. For example, the effects of *d*-amphetamine and cocaine on punished responding are reversed even when two distinctly different response topographies are utilized during the punishment and shock postponement phases (20). The rate-decreasing effects of cocaine on punished responding have also been shown to be reversible by a history of shock postponement responding (19), and the altered effects of *d*-amphetamine slowly attenuate when amphetamine is administered before every session in which responding is punished (2). It has also been shown that a history of responding on a differential reinforcement of low rate schedule—a behavior which, like that of shock postponement, is increased by cocaine—does not reverse the effects of cocaine on punished lever pressing (19). All published investigations of this general phenomenon have utilized squirrel monkeys as subjects (2,3,5,13,19,20).

The present research determined whether a behavioral history of postponing shock can reverse the effects of cocaine in a nonprimate species. Pigeons were used in this project because of the many similarities between the effects of drugs on the behavior of pigeons and squirrel monkeys and the relative

[1] Requests for reprints should be addressed to Thomas A. Tatham, Ph.D., Department of Psychiatry, Uniformed Services University of the Health Sciences, 4301 Jones Bridge Road, Bethesda, MD 20814-4799.

ease with which their responding may be punished by shock presentation and maintained by shock postponement. Psychomotor stimulants decrease the punished responding of both squirrel monkeys and pigeons (8,15,18) and increase responding maintained by shock postponement in both species (6, 12,13). Pigeons do not appear to have been used in very many experiments investigating responding maintained by shock postponement or the effects of drugs on this baseline. This may be attributable to the apparent difficulty of training pigeons to postpone shock when key pecking is the operant response [e.g., (10)]. Key pecking has been successfully employed as the shock-postponing response, but only when fairly sophisticated and time-consuming techniques have been used to establish responding [e.g., 9,16,22)]. In contrast, several authors have reported that it is fairly easy to establish responding when treadle pressing is the operant (11,17). In addition, the effects of drugs on treadle pressing maintained by shock postponement in pigeons have been investigated. For example, *d*-amphetamine dose-dependently increases treadle pressing maintained by shock postponement (12). Collectively, these factors make pigeons reasonable candidates for exploring behavioral history in nonprimates.

In phase 1 of the present experiment, key pecking in one schedule component was reinforced by a fixed-interval (FI) 3-min schedule of food presentation. Key pecking during a second component was maintained by both an FI 3 schedule of food presentation and a conjoint fixed-ratio (FR) 30 schedule of shock presentation. The effects of cocaine on responding under the multiple schedule were determined during this phase. In phase 2, treadle pressing was maintained by a shock postponement schedule. In phase 3, the effects of cocaine were redetermined within the context of the initial multiple schedule.

METHOD

Subjects

Three adult male White Carneau pigeons with no prior experimental history were maintained at 85% (440–474 g) of their free-feeding body weights. Subjects were individually housed in cages furnished with freely available water and grit. Food earned during experimental sessions was supplemented by pigeon chow delivered in the home cage several hours after experimental sessions.

Apparatus

Experimental sessions were conducted in a Plexiglas chamber. The chamber dimensions were 27.0 cm (length) × 27.0 cm (width) × 32.0 cm (height). A single response key was centered on the stainless steel response panel, 25.0 cm above the wire mesh floor. The translucent response key required a response force of approximately 0.20 N for operation and could be transilluminated by red, green, or white lamps mounted behind the key. Mixed grain could be presented through an aperture centered beneath the key, 4.0 cm above the floor. A 7.5-cm^2 Plexiglas treadle was installed on the left wall (relative to the response panel) during sessions in which responses postponed shock delivery. The treadle entered the chamber at a 45° angle relative to the wall and terminated approximately 0.5 cm above the mesh floor. The center of the treadle was located 4.0 cm from the junction of the left wall and the response panel. Constant current, 200-ms electric shocks could be delivered via a plug to stainless steel electrodes implanted under the pubis bones (1). The pigeons wore jackets at all times to protect the electrodes. The chamber was equipped with a relay that produced computer-controlled clicks following key pecks and treadle presses. All experimental events were controlled and recorded by MED-PC 2.0 (21).

Procedure

Fixed-interval training. Key pecking was established by the method of successive approximations. After key pecking was established, two to three sessions were conducted during which each key peck produced 4 s access to mixed grain; sessions terminated after the delivery of 100 reinforcers. The key was white during these sessions and each peck produced a brief click from the feedback relay. Pecking was subsequently reinforced according to a multiple FI schedule. Sessions began with the center key illuminated white for 10 min. Next, the key was dark for 30 s, during which key pecking produced no scheduled consequences and did not operate the feedback relay (time-out). The time-out was followed by 10 min of illumination of the key by red light. This cycle was then repeated. An FI schedule was in effect during the white and red compo-

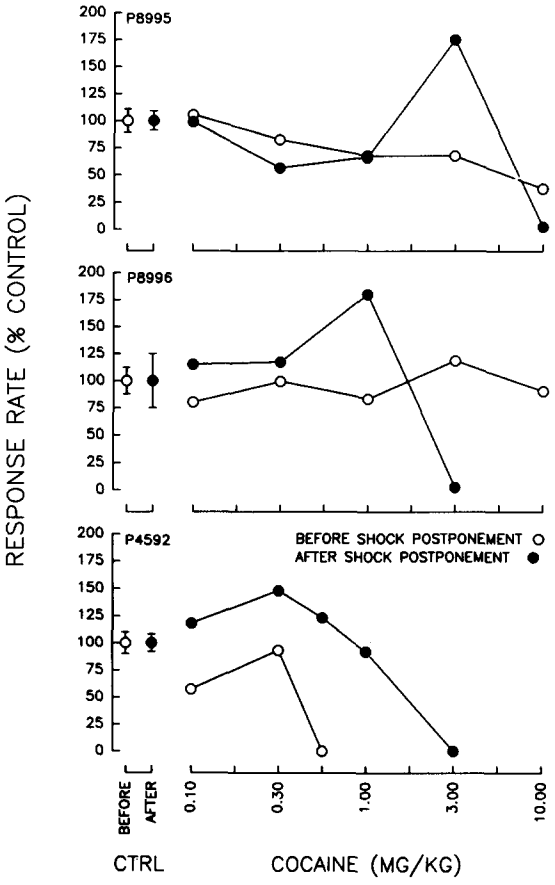

FIG. 1. The effects of cocaine on punished key pecking before and after treadle pressing was maintained by shock postponement. Open circles denote responding prior to the history of treadle pressing, whereas closed circles indicate responding following the history. Points to the left of the dose-response curves indicate the standard deviation of response rate during nondrug control sessions. All data are expressed as a percentage of response rate during nondrug control sessions. Response rates differing from 100% of control by more than two standard deviations are considered statistically meaningful.

nents, and the temporal parameter of the FI schedule was equal in both components. The FI parameter was increased from 15 s to 180 s at the beginning of successive sessions. The FI parameter remained at 180 s for the remainder of the experiment as training on the multiple schedule continued until response rates in the presence of the white and red stimuli were approximately equal and showed no systematic trend across sessions.

Phase 1: Multiple schedule of punished and unpunished responding and initial determination of drug effects. Sessions consisted of a multiple schedule of strictly alternating components in which the key was either white or red. Responding was reinforced by 4 s access to mixed grain under an FI 3-min schedule when the key was white. In the presence of the red key, responding was also reinforced according to an FI 3 schedule, but every 30 pecks also produced a 200-ms electric shock. The shock intensity was adjusted to reduce the response rate during the red component to approximately 25% of the rate during the white component. The shock intensity was 3.0 mA for P4592 and 1.0 mA for P8995 and P8996. Components were separated by 30-s periods during which the chamber was dark and key pecks produced no programmed consequences. Components alternated after three reinforcers or a maximum of 10 min, whichever came first. Each component was presented twice, in alternation, with the white component presented first. Key pecks produced a brief relay click when the key was illuminated. The effects of various doses of cocaine on responding during the two components were determined when there were no trends in response rate during the red component (in which responding was punished).

Phase 2: Treadle pressing maintained by shock postponement (no drug administration). During this phase the key was red but key pecking did not produce relay clicks or any programmed consequences. The treadle was installed and each depression of the treadle produced a feedback click. In the absence of treadle presses, 5.25-mA shocks occurred every 5 s, whereas each press postponed shock for 25 s. All shocks could be avoided by pressing at least once every 25 s. The response-shock and shock-shock intervals were set to values as low as 10 s and 2 s, respectively, during several sessions at the beginning of this phase and then were gradually raised to the stated parameters. Explicit shaping of treadle pressing was not necessary, and occasional observations indicated that the pigeons were operating the treadle by pressing it with the left foot (as opposed to pecking the treadle). This phase remained in effect until the rate of shock delivery was not more than 0.03 shocks/s for at least three consecutive sessions and there was no systematic trend in this measure.

Phase 3: Multiple schedule of punished and unpunished responding and redetermination of drug effects. The schedule conditions were identical to those in phase 1. Testing with cocaine began when the rate of punished responding showed no systematic trend and approximated rates obtained during phase 1.

Data analysis. Response rates are presented in figures as a percentage of the mean response rate obtained during nondrug control sessions. Changes in response rate exceeding two

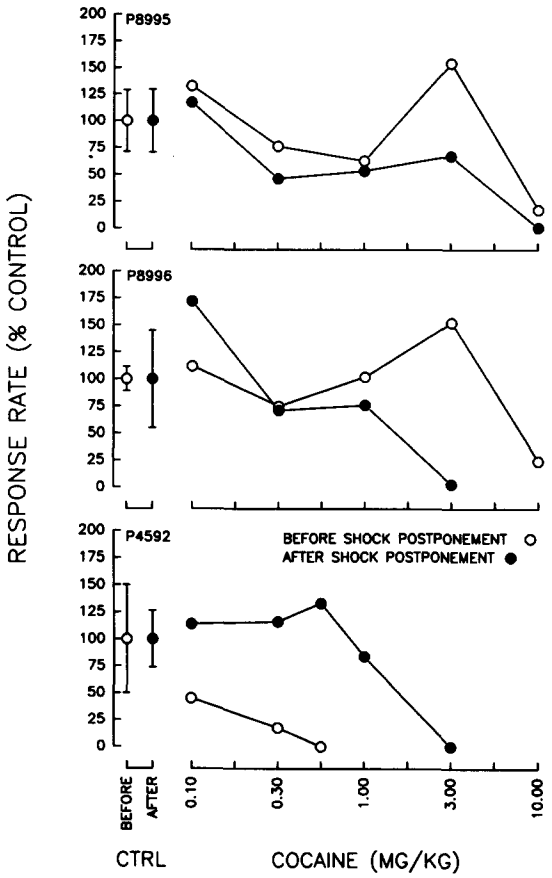

FIG. 2. The effects of cocaine on unpunished key pecking before and after treadle pressing was maintained by shock postponement. Open circles denote responding prior to the history of treadle pressing, whereas closed circles indicate responding following the history. Points to the left of the dose-response curves indicate the standard deviation of response rate during nondrug control sessions. All data are expressed as a percentage of response rate during nondrug control sessions. Response rates differing from 100% of control by more than two standard deviations are considered statistically meaningful.

TABLE 1

NUMBER OF SESSIONS AND RESPONSE RATE DURING FIXED-INTERVAL (FI) COMPONENTS BEFORE AND AFTER TREADLE PRESSING POSTPONED THE OCCURRENCE OF SHOCK

			Responses/s†	
Pigeon	Phase	Sessions*	FI Responding	Punished FI Responding
P8995	1. Before shock postponement	47	0.30 (0.09)	0.09 (0.01)
	3. After shock postponement	42	0.60 (0.18)	0.14 (0.01)
P8996	1. Before shock postponement	19	0.49 (0.05)	0.09 (0.01)
	3. After shock postponement	46	0.24 (0.11)	0.04 (0.01)
P4592	1. Before shock postponement	50	0.36 (0.18)	0.09 (0.01)
	3. After shock postponement	52	0.47 (0.12)	0.07 (0.01)

*The number of sessions the phase was in effect. †Response rates are the mean of Thursday control sessions, and standard deviations are in parentheses.

standard deviations of the mean response rate during control sessions are considered significantly different from control values.

Drugs. Cocaine HCl was dissolved in saline and injected into the breast muscle in a volume of 1 ml/kg. All doses are expressed in terms of the salt. Experimental sessions were conducted Monday through Friday, with Thursday sessions providing nondrug control data. Cocaine was administered immediately prior to Tuesday and Friday sessions provided that the rate of punished responding during the preceding session was within the range of values obtained during nondrug control sessions.

RESULTS

The effects of cocaine on punished responding are presented in Fig. 1. Cocaine initially decreased or did not alter the rate of punished responding (○). There were considerable variations in the effects of cocaine across pigeons. The punished responding of P8996 was not appreciably altered across a 100-fold range of doses (0.10–10.0 mg/kg). In contrast, the punished responding of P4592 was suppressed to less than 75% of control by 0.10 mg/kg and completely suppressed by 0.56 mg/kg. The responding of P8995 was gradually reduced from 100% of control by 0.10 mg/kg to less than 50% of control by 10.0 mg/kg.

All pigeons rapidly acquired treadle pressing during Phase 2. During the last five sessions of this phase P8996 received an average of 0.03 shocks/s and P8995 and P4592 received an average of 0.02 shocks/s (see Table 1), with shocks postponed for several consecutive minutes. The effects of cocaine on punished and unpunished responding were redetermined after the multiple schedule was reinstated. No systematic changes in response rate during control sessions occurred as the result of the shock postponement history (Table 1). At least one dose of cocaine now increased the punished responding of each pigeon. This contrasts with phase 1, when punished responding was not increased by any dose of cocaine in any pigeon. P8995's punished responding was initially decreased to less than 70% of control when 3.0 mg/kg of cocaine was injected, but the same dose increased responding to 175% of control following the shock postponement phase. Injection of 1.0 mg/kg of cocaine increased the punished responding of P8996 to greater than 180% of control following the shock postponement history, compared to 75% of control during phase 1. The punished responding of P4592 was significantly increased by 0.10 to 0.56 mg/kg of cocaine during phase 3. Punished responding was completely suppressed by 0.56 mg/kg of cocaine prior to the shock postponement history, but a dose of 3.0 mg/kg was required to produce a comparable effect following the shock postponement history.

Data from the component in which responding was not punished are presented in Fig. 2. Unpunished responding during control sessions (Table 2) was not consistently affected by the shock postponement history, and the effects of cocaine on unpunished responding were inconsistent across subjects. During phase 1, at least one dose of cocaine initially increased the responding of two pigeons (P8995 and P8996), but the responding of P4592 was decreased or unchanged by all doses tested (0.10–0.56 mg/kg). The unpunished responding of P8995 and P8996 was no longer increased by any dose of cocaine (0.1–10.0 mg/kg) following the shock postponement history. Following the shock postponement history, the unpunished responding of P4592 appears to have become less sensitive to rate-decreasing effects of cocaine, and the curve shifted to the right.

DISCUSSION

Cocaine initially decreased or did not alter the punished key pecking of all pigeons, an effect that replicates the results of numerous previous studies (14). Following a history of treadle press avoidance responding, the effects of cocaine were reversed; punished key pecking of all pigeons was increased significantly by at least one dose of cocaine that previously decreased or did not alter responding. These results are consistent with those of related studies conducted with squirrel monkeys (2,3,19,20).

It is particularly interesting that the effects of the shock postponement history generalized across responses. Two previous experiments have demonstrated generalization of behavioral history across responses using squirrel monkeys as subjects (4,20). In both experiments the responses consisted of chain pulling and lever pressing. These experiments might be criticized for employing responses with overlapping topographies, for both chain pulling and lever pressing entail downward displacement of the forepaws. In contrast, there appears to be virtually no topographical overlap between treadle pressing with the left foot and key pecking with the beak. Unequivocal demonstration of generalization across responses is theoretically important, for it increases the range of circumstances under which behavioral history is likely to be a determinant of drug effects. This also suggests that the critical aspect of the shock postponement history is the contingency

TABLE 2

CHARACTERISTICS OF RESPONDING MAINTAINED BY SHOCK POSTPONEMENT

Pigeon	Total Sessions	Sessions With Terminal Parameters*	Responses/s†	Shocks/s	Lognest Shock-Free Period (s)
P8995	50	46	0.135 (0.066)	0.020 (0.013)	207 (23)
P8996	59	52	0.120 (0.018)	0.030 (0.002)	90 (16)
P4592	19	12	0.174 (0.022)	0.020 (0.004)	188 (85)

*The total number of sessions this condition was in effect was greater than the number of sessions in which the terminal parameters were in effect because shorter response-shock and shock-shock parameters were utilized during some preliminary sessions. †Data for Responses/s, Shocks/s, and Longest Shock-Free Period (s) are the means of the last five sessions of the condition during which treadle presses postponed shock for 25 s and shock occurred every 5 s in the absence of responding. Standard deviations are in parentheses.

per se, rather than alteration of a specific response topography. It is also unlikely that the effect is due merely to exposure to shock (5).

It is noteworthy that the level of proficiency in postponing shock attained by the pigeons was sufficient to alter the subsequent effects of cocaine on punished responding. The pigeons' treadle pressing reduced the frequency of shock occurrence from the 0.2 shock/s that would have been delivered in the absence of responding to approximately 10% of this level (0.02–0.03 shocks/s). In contrast, squirrel monkeys typically receive a much lower percentage of shocks [e.g., less than 1% (20)]. High efficiency in postponing shock may not be a prerequisite to altering the effects of psychomotor stimulants on punished responding.

Unpunished responding in the present experiment was not consistently increased by cocaine, and there was no reliable effect of the shock postponement history. These findings may partially reflect the relatively high level of response rate variability during this component and the fact that the stability criteria used to determine whether or not to administer cocaine were based on the rate of punished responding. Although it is unusual that cocaine did not reliably increase unpunished responding, this finding is not without precedent. For example, one study found that both the punished and unpunished responding of squirrel monkeys were decreased by *d*-amphetamine (8).

The present findings emphasize again the point that drug effects on operant behavior are controlled by historical as well as current contingencies. This result is of theoretical importance because it reemphasizes the important contribution of behavioral history as a determinant of the effects of drugs. The results of the present study also demonstrate that the reversal of the effects of psychomotor stimulants on punished responding is not restricted to nonhuman primates. This finding is of practical importance because it may reduce the cost and complexity of exploring this line of research. The availability of a nonprimate preparation may also facilitate the exploration of the interaction between the behavioral and neurological substrates of this phenomenon; it will be possible to utilize methods that would be impractical with nonhuman primates.

ACKNOWLEDGEMENTS

Supported by NIDA grant RO1-DA06828 to J.E.B.

REFERENCES

1. Azrin, N. H. A technique for delivering shocks to pigeons. J. Exp. Anal. Behav. 2:162–163; 1957.
2. Bacotti, A. V.; McKearney, J. W. Prior and ongoing experience as determinants of the effects of *d*-amphetamine and chlorpromazine on punished behavior. J. Pharmacol. Exp. Ther. 211:80–85; 1979.
3. Barrett, J. E. Behavioral history as a determinant of the effects of *d*-amphetamine on punished behavior. Science 198:67–69; 1977.
4. Barrett, J. E.; Stanley, J. A. Prior behavioral experience can reverse the effects of morphine. Psychopharmacology 81:107–110; 1983.
5. Barrett, J. E.; Witkin, J. M. The role of behavioral and pharmacological history in determining the effects of abused drugs. In: Goldberg, S. R.; Stolerman, I. P., eds. Behavioral analysis of drug dependence. New York: Academic Press; 1986:195–223.
6. Davis, T. R. A.; Kensler, C. J.; Dews, P. J. Comparison of behavioral effects of nicotine, *d*-amphetamine, caffeine, and dimethylheptyl-tethrahydrocannabinol in squirrel monkeys. Psychopharmacologia 32:51–65; 1973.
7. Gonzalez, F. A.; Goldberg, S. R. Effects of cocaine and *d*-amphetamine on behavior maintained under various schedules of food presentation in squirrel monkeys. J. Pharmacol. Exp. Ther. 201:33–43; 1977.
8. Hanson, H. M.; Witoslawski, J. J.; Campbell, E. H. Drug effects in squirrel monkeys trained on a multiple schedule with a punishment contingency. J. Exp. Anal. Behav. 10:565–569; 1967.
9. Hineline, P. N.; Rachlin, H. Escape and avoidance of shock by pigeons pecking a key. J. Exp. Anal. Behav. 12:533–538; 1969.
10. Hoffman, H. S.; Fleshler, M. Aversive control with the pigeon. J. Exp. Anal. Behav. 2:213–218; 1959.
11. Klein, M.; Rilling, M. Effects of response-shock interval and shock intensity on free-operant avoidance responding in the pigeon. J. Exp. Anal. Behav. 18:295–303; 1972.
12. Leander, J. D. Effects of *d*-amphetamine, pentobarbital, chlorpromazine and promazine on electric shock postponement responding by the pigeon. J. Pharmacol. Exp. Ther. 198:4–11; 1976.
13. McKearney, J. W.; Barrett, J. E. Punished behavior: Increases in responding after *d*-amphetamine. Psychopharmacologia 41: 23–26; 1975.
14. McKearney, J. W.; Barrett, J. E. Schedule-controlled behavior and the effects of drugs. In: Blackman, D. E.; Sanger, D. J., eds. Contemporary research in behavioral pharmacology. New York: Plenum Press; 1978:1–68.
15. McMillan, D. E.; Leander, J. D. Drugs and punished responding suppressed by response-dependent and response-independent electric shock. Arch. Int. Pharmacodyn. 213:22–27; 1975.
16. Rachlin, H. C.; Hineline, P. N. Training and maintenance of key pecking in the pigeon by negative reinforcement. Science 157: 954–955; 1967.
17. Smith, R. F.; Keller, F. R. Free-operant avoidance in the pigeon using a treadle response. J. Exp. Anal. Behav. 13:211–214; 1970.
18. Spealman, R. D. Comparison of drug effects on responding punished by pressurized air or electric shock delivery in squirrel monkeys: Pentobarbital, chlordiazepoxide, *d*-amphetamine and cocaine. J. Pharmacol. Exp. Ther. 209:309–315; 1979.
19. Tatham, T. A.; Barrett, J. E. Shock avoidance but not DRL history reverses the effects of cocaine on punished behavior of squirrel monkeys. Behav. Pharmacol. 4:159–166; 1993.
20. Tatham, T. A.; Gyorda, A. M.; Barrett, J. E. Generalization of behavioral history across responses in the reversal of the effects of *d*-amphetamine and cocaine on the punished responding of squirrel monkeys. Behav. Pharmacol. 4:61–68; 1993.
21. Tatham, T. A.; Zurn, K. R. The MED-PC experimental apparatus programming system. Behav. Res. Med. 21:294–302; 1989.
22. Todorov, J. C.; Ferrari, E. A.; De Souza, D. G. Key pecking as a function of response-shock and shock-shock intervals in unsignalled avoidance. J. Exp. Anal. Behav. 22:215–218; 1974.