REINFORCEMENT OF INHIBITION

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A differential-reinforcement-of-other-behavior (DRO) schedule with trials and delayed reinforcement was investigated. Periodically a wheel was briefly available to rats, followed six seconds later by brief availability of a bar. Variable-ratio food reinforcement of wheel turns was adjusted to give 95% turns. After variable-ratio-five reinforcement of bar presses produced 100% pressing, then separate ratio schedules were used for presses following turns (turn presses) and presses following nonturns (nonturn presses). Increasing nonturn-press reinforcements decreased turns, even though total reinforcements increased. Reversal by decreasing nonturn-press reinforcements raised turns, though with hysteresis. Thus food reinforcement increased nonturns even though delayed six to ten seconds after nonturns, a delay that greatly reduces response reinforcement. Those and other results indicate that the turn decrease was not due to reinforcement of competing responses. Evidence against other alternatives, and the reduction of responding by increased reinforcement, indicate that the term *inhibition* is appropriate for the phenomenon reinforced. *Response-specific inhibition* appears appropriate for this particular kind, since its effects are more specific to particular responses than Pavlovian conditioned-inhibition. Response-specific inhibition seems best considered a behavioral output comparable to responses (e.g., both reinforcing) but with important properties different from responses (e.g., different reinforcement-delay gradients).

Key words: inhibition, reinforcement delay, differential reinforcement of other behavior (DRO), extinction, competing behavior, contingency, wheel turn, bar press, rats

Support for the concept of inhibition in the analysis of behavior has been accumulating from investigations of gradients of inhibition (e.g., Jenkins & Harrison, 1962), conditioned inhibition (e.g., Hearst, 1972; Rescorla, 1969), and other techniques (e.g., Boakes & Halliday, 1972). Yet the concept remains controversial, probably due to the difficulties met in distinguishing inhibition from other sources of

response decrement, such as competing behavior, low motivation, etc. Reviews of conditioned inhibition (Hearst, 1972; Rescorla, 1969) have excluded response decrements produced by operant extinction and the DRO schedule (differential reinforcement of other behavior: delivery of reinforcers after a time interval without a specified response). However, a different kind of inhibition may operate in those procedures, a more response-specific one, which sometimes has less explicit stimulus control. In extinction, when responses go unreinforced, they may generate inhibition of the response as an unconditioned effect. In DRO schedules, nonreinforcement first produces a few cases of that response inhibition; then selective delivery of reinforcers only after instances of inhibition may increase the frequency of such inhibition, i.e., may reinforce it. This inhibition will be called response-specific inhibition. It originates in response-specific operant procedures, whereas conditioned inhibition affects groups of responses, since it originates from stimulus pairing in Pavlovian procedures. Before a response can be reinforced, a response must be first produced by

The research reported here was initiated with support from NSF Grant GB 27687X1 and from Biomedical Research Support Grant RR 07053 from the General Research Support Branch, Division of Research Resources, Bureau of Health Professions Education and Manpower Training, National Institutes of Health. The results were presented at the Eastern Psychological Association Meeting in New York, 1976, and at the Midwestern Association of Behavior Analysis Meeting in Chicago, 1976. The author wishes to thank Kathleen Anger, John Flanagan, Andrew Homer, William McReynolds, and Wendell Stone for valuable comments, and Michael Arky, Linda Haines, Barbara Hale, Carol Leimbach, Michael Liberton, Tom Park, Charles Schindler, Denise Schnurr, Wendell Stone, and Peggy Thompson for assistance in conducting the experiments. Reprints may be obtained from Douglas Anger, Department of Psychology, University of Missouri, Columbia, Missouri 65211.

other factors. Likewise, before response-specific inhibition can be reinforced, some inhibition must be first produced by another factor, in the DRO case by an unconditioned effect of nonreinforcement of the response. Even though there is little to see during a particular instance of nonresponse, a distinctive event may be occurring during the nonresponse time. In fact, the ability of selective reinforcement of nonresponses to increase nonresponses suggests the presence of a distinctive event that can be reinforced.

The DRO procedure can be highly effective in reducing responses to low levels (e.g., Uhl & Garcia, 1969; Zeiler, 1971). The possibility of reinforcement of inhibition does not seem to have been proposed; instead, it has been assumed that the behavior is reduced by competing responses, which are reinforced by the DRO schedule. Yet consistent competing responses have not been demonstrated, and there is little evidence to support that theory. The most cited evidence comes from studies that facilitated adventitious reinforcement of easily measured responses. Behavior was first reinforced on two different operanda; then only DRO reinforcers were given on one operandum, which could result in adventitious reinforcement of responses on the second operandum (Corley, 1977; Harman, 1973; Zeiler, 1970). Some subjects maintained the responding on the second operandum, but two of the six children studied by Zeiler and all four of Corley's pigeons did not maintain it, though their behavior on the DRO operandum was suppressed as much as that of subjects with superstitious responding on the second operandum. The absence of difference with and without the behavior on the second operandum raises doubt that it makes a major contribution to the response suppression. Furthermore, the absence of consistent maintenance of a competing response even after extensive initial training makes it difficult to accept its consistent development under the much less favorable conditions of the usual DRO procedure.

To investigate the alternative of an active inhibitory process with properties different from a response, it is necessary to control its temporal relations to reinforcers and other events. Hence we need to manipulate when it occurs by permitting the response and its inhibition only during brief trials. Such control was obtained in the following experiments by

introducing a horizontal wheel into the cage for 6-sec periods. During each introduction the rat either turned the wheel, a turn, or did not, a nonturn or $\overline{\text{turn}}$ (a line above a term negates it). Thus nonturns were measured as objectively as turns, and nonturns will be the measure of turn inhibition. Figure 1 summarizes the four events that occurred on different trials in the following experiments. The top two rows describe the established empirical effects of operant reinforcement and extinction (under conditions that minimize autoshaping effects, e.g., rats, wheel turn, infrequent food with wheel). Food after turns increases turns, and nonfood after turns decreases turns. Once nonturns occur, then food after nonturns may increase nonturns. It is reasonable that turns are decreased both by food after nonturns and by nonfood after turns, because in each sequence one term is negated. Each negation reverses the effect. A fourth possibility, double negation, is apparent: After reinforcement of inhibition, nonfood after inhibition would be expected to reduce the effect of the preceding reinforcement of inhibition, and thus increase turning. Since that effect lacks a name, the noncommittal label *dissipation of inhibition* will be used. From this viewpoint, after substantial conditioning the frequency of each operant response is controlled primarily by a response-specific inhibition variable, which depends not only on reinforcement and nonreinforcement but on all four sequences in Figure 1. It will be shown below that sensitivity to all four sequences can adjust the animal's behavior roughly to the contingency between response and reinforcer.

Not all nonturns would be due to inhibition

SEQUENCE	EFFECT ON TURNING	TERMS FOR EFFECT OF SEQUENCE ON TURNING	
		Empirical, Established	Theoretical, Controversial
TURN $\rightarrow$ FOOD	$\uparrow$	Reinforcement	
TURN $\rightarrow \overline{\text{FOOD}}$	$\downarrow$	Extinction	Inhibition
$\overline{\text{TURN}} \rightarrow \text{FOOD}$	$\downarrow$		Reinforcement of inhibition
$\overline{\text{TURN}} \rightarrow \overline{\text{FOOD}}$	$\uparrow$		Dissipation of inhibition

Fig. 1. The four possible events on wheel-introduction trials and their effects.

Before conditioning, wheel turns do not occur; shaping is required to condition turning. Inhibition does not seem responsible for those nonturns before conditioning. The particular kind of nonturns that may be produced by response-specific inhibition are those that occur when a wheel is available to a hungry, healthy, awake rat that has previously made turns at a high frequency due to reinforcement but has had nonturns appear when the reinforcement frequency decreased.

It has often been stated that the term "inhibition" should only be used when a "decrement is produced by an increment in something else" (Catania, 1968, p. 336). The something else has varied from another "structure or organ" (Brunton, 1883, p. 419; Thomas, 1972) to "some new stimulation" (Hearst, 1972, p. 10). Inhibition produced by additional reinforcement of nonresponses clearly conforms to that criterion. At first glance nonreinforcement as a source may not seem to conform, but the change from reinforcement to nonreinforcement clearly is a major change for animals, since it has a major effect on their behavior. Hence nonreinforcement is a major input, if not "new stimulation," for the animal. Furthermore, if it is accepted that inhibition produced the additional nonresponses generated by reinforcement of nonresponses, then it seems difficult to deny that inhibition produced that which was reinforced to get the additional nonresponses, namely the initial nonresponses resulting from nonreinforcement.

A case for the reinforcement of inhibition requires evidence that the response decrease is not due to reinforcement of competing responses. Hence a technique is needed that permits reinforcement of inhibition while not permitting reinforcement of competing responses. A technique is suggested by the sensory-inhibition findings (von Békésy, 1967; Ratliff, 1965) that a stimulus produces focused excitation surrounded by wider inhibition. Translation from a spatial to a temporal dimension suggests the possibility that operant reinforcements may have a more focused effect on responses than on inhibition, so the reinforcement of inhibition extends to delays too long for reinforcement of responses. A bias favoring inhibition would have survival value, since inhibition conserves energy when it produces almost as much food as responding.

The operant effect of primary reinforcers

on responses does seem to be remarkably focused. However, conditioned reinforcers have to be thoroughly eliminated, because they can maintain a response in spite of wide separation of response and primary reinforcer (Ferster, 1953; Gollub, 1977). In the widely accepted experiment by Grice (1948), where considerable effort was made to eliminate conditioned reinforcers, the reinforcing effect of food on responses dropped abruptly with delay between the response and food, and little or no effect was found with only a 10-sec delay. This finding has been challenged but apparently not successfully disproven for operant reinforcement with food. The challenges have either lacked necessary controls, have not eliminated conditioned reinforcers, have required special additional stimuli, or have involved Pavlovian conditioning. Flavor aversions do result after delays of hours (e.g., Garcia, Ervin, & Koelling, 1966), but they seem to involve Pavlovian conditioning and seem to be an adaptive specialization for particular circumstances (Rozin & Kalat, 1971). In fact, those large differences between effective delays provide a precedent for the proposal that inhibition can be reinforced after longer delays than responses.

Some evidence for reinforcement of inhibition across long delays is found in studies of reinforcement of long IRTs. Reinforcement of only IRTs over 40 sec can produce a high frequency of long IRTs and few short IRTs (e.g., Anger, 1956), even though the nonresponding immediately after the initial response of the IRT is followed by reinforcers only after 40 sec.

Thus, if nonresponses can be reinforced with food, then those nonresponses may involve distinctive behavioral events at the level of responses. If responses cannot be reinforced after a 10-sec delay, but inhibition can, then food 10 sec after a brief wheel presence could not reinforce competing responses during the wheel presence but could reinforce turn inhibition then. The nonresponses would differ in an important respect from competing responses, which would both permit experimental separation and justify the different name, response-specific inhibition. To further minimize competing responses, the delayed reinforcements for nonturns were given immediately after a different response, bar pressing, because bar pressing can be prevented from

competing with turning by keeping the bar out when the wheel is in. Furthermore, delaying those reinforcers so they do not occur during the wheel presence minimizes their Pavlovian effect on wheel turning. To minimize generalization between the two responses, the horizontal movement of the wheel was chosen to be as different as practical from the downward movement of the bar.

EXPERIMENT 1

METHOD

Subjects

The subjects were four male Sprague-Dawley rats (Upjohn colony), initially about 200 days old, and maintained at 75% of their ad lib body weights.

Apparatus

One Skinner box was employed, 32 by 21 by 22 cm. The ceiling, a side wall, and floor were .24-cm stainless-steel rods centered 1.3 cm apart. The end walls were stainless steel, and the other side was Plexiglas. The floor was divided into eight units so hinged and counterweighted that the rat's weight on a unit operated a microswitch. Total switch actuations was the activity measure.

The 5.2-cm wide stainless-steel bar was depressed by .15 N. It was on the left side (viewed from within cage) of a stainless steel end wall, 2.1 cm to the right of the Plexiglas wall and 10 cm above the floor. A motor moved the bar either out of reach or so it projected 1.3 cm into the cage. Flanagan and Anger (1976) reported further details.

The horizontal wheel was a gear 6.5 cm in diameter. It was turned (to the right only) by .3 N. A turn registered after 47° rotation on the average. A motor moved the wheel either out of reach or until it projected .32 cm into the cage through a hole in the Plexiglas wall. When in, the wheel was 4.8 cm above the floor and 6.8 cm from the bar.

The .045-g food pellets (P. J. Noyes) dropped into a sloping tray in the middle of the bar wall. The tray was 2.2 cm to the right of the bar and 7 cm below it. Thus, wheel, bar, and tray were close together in that order.

Bar introduction was accompanied by a 4000 to 8000-Hz band of white noise at 73 db above reference level. Wheel introduction was

accompanied by flickering (.5 sec on, .5 sec off) of the cage light. A blower introduced air and a masking noise into the sound-attenuating enclosure. Control circuits in a separate room were inaudible in the box room.

Procedure

Magazine and bar-press training. After two days of magazine training, the bar and noise were introduced for 14 reinforced presses (crf). Then for 16 trials, the bar was withdrawn for 50 sec between trials; after each introduction, the first press was reinforced and also stopped the noise and sent the bar out again 6 sec later. Then for 50 trials, 20 reinforcers were given with the bar procedure used on all later days: i.e., bar introductions 1 min apart, bar out and noise off after 10 sec when no press; first presses ended the noise and sent the bar out 2 sec later. Additional presses during those 2 sec were never reinforced and they soon became infrequent. Subsequent references to presses refer only to first presses during a trial. Later experimental days consisted of 60 trials/day and VR 5 until the tests.

Wheel-turn training. Turn training began on Day 9 with the bar out. Shaping was necessary but usually four to six reinforcers sufficed. Rats turn a wheel both by pulling with a paw and by pushing with the teeth. For uniformity, paw turns were shaped and teeth turns extinguished. After 80 crf reinforcers with the wheel in, 30 were given with 60-sec wheel-withdrawal after turns. The next day the final wheel procedure began: 60 trials a day on a 1-min cycle, box light flicker with wheel in, and flickering ended and wheel out after a turn or 6 sec without a turn. Hereafter *turn* refers to first turns after introduction, the only turns reinforced. Reinforcement was changed to VR 5 over two days, and 60 introductions of both operanda on a 1-min cycle began after six days. Six sec elapsed between the wheel withdrawal and the bar introduction. Hence press reinforcements could not occur closer than 6 sec after turns, but since both responses had short latencies, they usually were over 10 sec apart. Responses occurred on each operandum on every trial. For presses a VR 5 continued, but turn reinforcements were reduced until non-turns stabilized at 3 to 10 per session.

Tests. Next, press reinforcements that followed turns (TPr) were scheduled independently of press reinforcements following non-

as “no overlap” are significant at well beyond the .001 level with 10-day samples.

Figure 2 shows the daily turns and activity of Rat 876 during the baseline and $\overline{\text{TPr}}$ increase. The three reinforcement schedules are given at the top, and the numbers in parentheses give the average reinforcers per day delivered by each schedule, with the total below. With 1/30 Tr/T the nonturns stabilized at three per day (5%). On day 66 the $\overline{\text{TPr}}/\overline{\text{TP}}$ were doubled from .2 to .4, with no change in the Tr/T or TPr/TP schedules. At first only one more $\overline{\text{TPr}}$ occurred daily. Turns did not change for a week but then decreased to 36% (no overlap with preceding treatment). An increase in $\overline{\text{TPr}}$ decreased turns even though the additional reinforcements occurred at least 6 sec and usually over 10 sec after the turns.

$\bar{T}$ = WHEEL TURNED r = REINFORCEMENT (r /DAY)
 $\bar{T}$ = WHEEL NOT TURNED P = BAR PRESS (RESULTING:) (RESULTING:) (RESULTING:)

$\frac{Tr}{T}$	$\frac{1}{30}$	(2)	SAME (2)	(1)
$\frac{TPr}{TP}$	$\frac{1}{5}$	(11)	SAME (11)	(4)
$\frac{\bar{T}Pr}{\bar{T}P}$	$\frac{1}{5}$	(1)	$\frac{2}{5}$ (2)	(14)

PERCENT WHEEL-TURNS
 ACTIVITY
 DAYS
 876 B1

Fig. 2. The daily turns (filled circles) and activity (unfilled circles) of Rat 876. At the top are specified the three ratio schedules in operation: Tr/T for turns, TPr/TP for presses following turns, and $\bar{\text{TPr}}/\bar{\text{TP}}$ for presses following nonturns. For certain days, the mean reinforcements/day for each schedule are given in parentheses with their sum below them. After Day 65 the $\bar{\text{TPr}}/\bar{\text{TP}}$ were doubled while the other reinforcement schedules were unchanged. The line at an activity of 1000 is just a reference line to facilitate comparisons.

Fig. 3. Daily turns and activity of Rat 876 with the same format as Figure 2 but for the following 65 days. The first four days of this Figure repeat the last four days of Figure 2.

Total reinforcements increased 36%. The activity decreased significantly ($p < .001$) from 1037 to 593 counts/day. However, a clear decrease in turns (Days 77 to 83) developed before the activity decrease. Hence some of the turn decrease was not due to the activity decrease. Only two nonpresses occurred during the days shown in Figure 2, both during the baseline measurement.

When the turn decrease was just beginning, observation revealed the rat sometimes approached the wheel, even put his paw on the wheel, without turning it. Such behavior was not seen before $\overline{\text{TPr}}$ were increased. With further turn decrease, these incomplete turns disappeared and no change was visible in the behavior when the flickering began. Elimination of turning appeared to begin at the end of the sequence and work backward: first the turn movement, then the paw on the wheel, then approach, and finally orientation to the wheel. No behavior that appeared to be interfering with turning was seen to develop with any consistency during the nonturns. The incomplete turns were the opposite of the hypothetical competing behavior proposed to explain extinction.

Figure 3 shows the return to baseline with

decreased reinforcement of inhibition and increased dissipation of inhibition. Turns rose from 36% to 59% (last 15 days, no overlap), but 59% was well below the former 95% (no overlap). The 955 counts/day activity was only 8% below the baseline level of 1037 (not significant, $p > .05$). Thus the turns but not the activity displayed irreversibility or hysteresis (an influence of the previous history of a system on its subsequent behavior). Elimination of all $\overline{\text{TPr}}$ raised activity above the baseline and turns to 90%, close to the original 95% but still significantly less ($p < .01$). Again a decrease in reinforcements increased turns. These results add even better evidence for hysteresis specific to turns and not manifested in activity, hence hysteresis in specific inhibition.

Figure 4 presents the treatment means for the preceding results. The ordinate shows the percentage of turns for each treatment as a function of $\overline{\text{TPr}}/\overline{\text{TP}}$ on the abscissa. Lines and arrows indicate successive treatments. The four circles show the results just described. The triangles and square will be considered in Experiments 2 and 3. Results from the other rats are shown in Figures 5 to 7 with the same format. All show reductions of turns by in-

Fig. 4. The stable mean turns of Rat 876 plotted against the $\bar{T}Pr/\bar{TP}$. The four filled circles with $\bar{T}Pr/\bar{TP} = .2$ summarize the data in Figures 2 and 3. The triangles and squares show data obtained in Experiments 2 and 3 with other $\bar{T}Pr/\bar{TP}$ ratios.

creases in $\bar{T}Pr$. All show hysteresis. However, the sensitivity to $\bar{T}Pr$ and degree of hysteresis vary widely.

In Figure 5 for Rat 848, the circles show that a major stable decrease in turns did not develop until $.6 \bar{T}Pr/\bar{TP}$. A temporary turn and activity decrease did occur at $.5 \bar{T}Pr/\bar{TP}$ when for three days turns dropped to 6% and activity to 312 counts/day. However, turns gradually rose and stabilized at 73%, which was below ($p < .001$) the 82% found with $.4 \bar{T}Pr/\bar{TP}$. At $.6 \bar{T}Pr/\bar{TP}$ the turns decreased to 46% (no overlap). Activity dropped from 1402 to 1086 ($p < .001$). One nonpress occurred in 10 days.

Restoration of $\bar{T}Pr/\bar{TP}$ to $.2$ raised turns to 63% for 10 days with 1358 activity counts/day (both no overlap with preceding treatment). However, then both turns and activity abruptly dropped—turns to 22% and activity

Fig. 5. The stable mean turns of Rat 848 plotted against the $\bar{T}Pr/\bar{TP}$ with the same format as Figure 4.

to 488 counts/day for the next 13 days. Presses dropped to 82%.

Increasing $\bar{T}Pr/\bar{TP}$ to $.4$ and eliminating $\bar{T}Pr/\bar{TP}$ raised turns, and for 12 days they averaged 62% (range 53% to 68%), but then wild oscillation developed. Turns suddenly dropped to 2% for two days, rose to 66% for six days, then dropped to 3% for three days. When turns were low, presses averaged only 16% and activity only 105 counts/day; yet when turns were high, presses averaged 96% and activity 1119. Due to its instability, no point was plotted in Figure 5 for this treatment. Increasing $\bar{T}Pr/\bar{TP}$ to $.7$ restored high food pellets/session, 100% presses, high activity (1311), and stable turning at 90% (leftmost diamond in Figure 5).

Frequent nonpresses and very low activity were seen with three different treatments of Rat 848 and seem to represent a different phenomenon than the relatively turn-specific and stable inhibition seen at $.6 \bar{T}Pr/\bar{TP}$. To distinguish the former, it will be called *generalized inhibition* since all behavior (turns, activity, and even presses receiving 40% reinforcement) is decreased, in contrast to the specific inhibition of turns, where turns decrease while other responses (pressing and activity) show little change. The generalized inhibition was not a direct result of $\bar{T}Pr$ like the specific inhibition, since it did not occur at $.6$ and $.7 \bar{T}Pr/\bar{TP}$. At $.6$ and $.7$ a moderate activity decrease had occurred (from 1402 at $.5$, to 1086 at $.6$, and 843 at $.7$), but that was far less than the decrease to 300 and 100 counts/day seen with generalized inhibition. Only two nonpresses occurred during the 80 days of $.6$ and $.7$ and the behavior had been quite stable. Furthermore, the generalized inhibition persisted 23 days with $0 \bar{T}Pr/\bar{TP}$ and $.4 \bar{T}Pr/\bar{TP}$ and was eliminated only by the change to $.7 \bar{T}Pr/\bar{TP}$. The origin of the generalized inhibition is unclear and seems complex. An important contributor may have been the decrease in session food from 33 pellets/day with $.7 \bar{T}Pr/\bar{TP}$ to 13 with $.2 \bar{T}Pr/\bar{TP}$ even though the behavior decrease did not appear for 15 days after the food decrease and persisted after the feeding was increased again. Essentially the same phenomenon had appeared temporarily at $.5 \bar{T}Pr/\bar{TP}$ with 24 pellets/day, which indicates some contribution from the reinforcement schedules. The generalized inhibition was eliminated by $.7 \bar{T}Pr/\bar{TP}$.

Fig. 6. The stable mean turns of Rat 855 plotted against the $\overline{\text{TPr}}/\overline{\text{TP}}$ with the same format as Figure 4.

TP, which increased both food and reinforcements.

Figure 6 shows that the turns of Rat 855 did not decrease until $.75 \overline{\text{TPr}}/\overline{\text{TP}}$, but then dropped to zero for the last five days. The activity decreased from 2054 to 812 counts/day. Thus generalized inhibition seemed present, though less than with Rat 848 because no nonpresses occurred. Restoration of $.5 \overline{\text{TPr}}/\overline{\text{TP}}$ raised turns to 69%, the least hysteresis seen, though still 24% below the first exposure (no overlap).

Figure 7 shows that the turns of Rat 849 stayed high to $.6 \overline{\text{TPr}}/\overline{\text{TP}}$ but dropped to 2.5% at $1.0 \overline{\text{TPr}}/\overline{\text{TP}}$ with only one nonpress. This rat was unusual in that an activity increase to 1650 counts/day accompanied the turn decrease (from 741 and 735 at $.5$ and $.6 \overline{\text{TPr}}/\overline{\text{TP}}$). Thus, an activity decrease is not essential for the turn decrease. Return to $.5 \overline{\text{TPr}}/\overline{\text{TP}}$ for 30 days raised turns to only 7% (last 15 days), the largest hysteresis seen. Baseline conditions of $.2 \overline{\text{TPr}}/\overline{\text{TP}}$ for 30 days raised turns to 36% (no overlap with the last two treatments) with no nonpresses, and higher activity than before. This large hysteresis in

Fig. 7. The stable mean turns of Rat 849 plotted against the $\overline{\text{TPr}}/\overline{\text{TP}}$ with the same format as Figure 4.

turns (80% before to 36% after) without hysteresis in presses or activity indicates that the response-specific inhibition is subject to hysteresis in the absence of any generalized inhibition effects.

EXPERIMENT 2

Could the turn decrease have been due to some nonspecific effect of the increased number of reinforcements instead of the $\overline{\text{TPr}}$? For instance, negative contrast from the increase in press reinforcements might decrease turns. Experiment 2 controlled for such possibilities by increasing TPr instead of $\overline{\text{TPr}}$, which should produce as much negative contrast as a $\overline{\text{TPr}}$ increase.

METHOD

The same apparatus, basic procedure, and four subjects of Experiment 1 were used. The TPr/TP were increased from $.2$ to the same fraction as the maximum $\overline{\text{TPr}}/\overline{\text{TP}}$ employed in Experiment 1. With one rat (876) even higher TPr/TP levels were explored. In two rats (876, 848) the effect of increased TPr was measured with 0 and $.2 \overline{\text{TPr}}/\overline{\text{TP}}$; in the other two only at $0 \overline{\text{TPr}}/\overline{\text{TP}}$.

RESULTS AND DISCUSSION

All four rats showed that turns were not reduced by a TPr/TP increment equal to the $\overline{\text{TPr}}/\overline{\text{TP}}$ increment that did decrease turns. In Figure 4 for Rat 876, the two triangles show the effect of $.4 \text{ TPr}/\text{TP}$ with both 0 and $.2 \overline{\text{TPr}}/\overline{\text{TP}}$. With $0 \overline{\text{TPr}}/\overline{\text{TP}}$, a small increase occurred. With $.2 \overline{\text{TPr}}/\overline{\text{TP}}$, turns were far above (no overlap) the last measurement with $.2 \text{ TPr}/\text{TP}$ and $.2 \overline{\text{TPr}}/\overline{\text{TP}}$. The square shows that even $1.0 \text{ TPr}/\text{TP}$ did not decrease turns. In Figure 5 for Rat 848, the two diamonds at 0 and $.2 \overline{\text{TPr}}/\overline{\text{TP}}$ show that $.7 \text{ TPr}/\text{TP}$ produced as high or higher turns than baseline conditions. For Rat 855 in Figure 6, the left-most diamond for $0 \overline{\text{TPr}}/\overline{\text{TP}}$ and $.75 \text{ TPr}/\text{TP}$ shows higher turning than the last baseline measurement. For Rat 849 in Figure 7, tests with various high values of TPr/TP (all with $0 \overline{\text{TPr}}/\overline{\text{TP}}$) produced as high or higher turns than initial baseline conditions.

Thus, turns were decreased only by press reinforcements contingent on nonturns, not by press reinforcements contingent on turns. Consequently, the turn decrease produced by

increasing $\overline{\text{TPr}}/\overline{\text{TP}}$ was not just an effect of the increase in press reinforcement per se, nor was it the usual contrast effect conceived as just an effect of increased press reinforcements, because the sequential contingency was essential.

EXPERIMENT 3

A basic hypothesis of this investigation is that reinforcement of response-specific inhibition is more effective across a delay than is reinforcement of responses. Such an asymmetrical effect implies that press reinforcements delayed after nonturns should decrease turns more than press reinforcements delayed after turns can increase them. Such asymmetry has a counterintuitive implication that under appropriate conditions, when equal TPr/TP and $\overline{\text{TPr}}/\overline{\text{TP}}$ are increased together, a decrease in turning may result, because the increased effect of $\overline{\text{TPr}}/\overline{\text{TP}}$ on nonturns is greater than the increased effect of TPr/TP on turns. Approximately equal TPr/TP and $\overline{\text{TPr}}/\overline{\text{TP}}$ would also result from press reinforcements independent of turns; hence their increase should also reduce turns. Since this remarkable prediction poses a good test for the asymmetry hypothesis, it was tested in Experiment 3. Appearance of this effect would require suitable conditions, such as enough nonturns for the rat to have an adequate sample of $\overline{\text{TPr}}$ and not too high immediate turn reinforcement. To reduce chance fluctuations, separate control of TPr/TP and $\overline{\text{TPr}}/\overline{\text{TP}}$ at equal values was used.

METHOD

The same apparatus, basic procedure, and two subjects (848, 855) from Experiments 1 and 2 were used. With Rat 848, after testing .7 TPr/TP (with 0 and .2 $\overline{\text{TPr}}/\overline{\text{TP}}$) in Experiment 2, that TPr/TP was continued to provide high and stable behavior, since Rat 848 did not appear to tolerate lower food levels. Then $\overline{\text{TPr}}/\overline{\text{TP}}$ was increased first to .5, then to .7 (at which time it equaled TPr/TP), and finally to .8. Rat 855 was changed directly to .75 for both TPr/TP and $\overline{\text{TPr}}/\overline{\text{TP}}$.

RESULTS AND DISCUSSION

In both rats, the high but equal reinforcement lowered turns. The diamonds in Figure 5 for Rat 848 show the curve of increasing $\overline{\text{TPr}}/\overline{\text{TP}}$ with .7 TPr/TP . The .7 curve

dropped more slowly than the .2 curve, but the decrease from .5 to .7 $\overline{\text{TPr}}/\overline{\text{TP}}$ was substantial ($p < .001$). Consequently the 64% turns with .7 for both sequences was well below the 85% turns with .2 for both sequences (no overlap). Even with TPr/TP kept equal to $\overline{\text{TPr}}/\overline{\text{TP}}$, so that press reinforcements were essentially independent of turning, an increase in both reinforcements decreased turns. This result confirms the prediction that reinforcement of nonturns across a delay is more effective than the reinforcement of turns across the same delay. The activity changes with .7 TPr/TP were smaller than with .2 TPr/TP ; the difference between .2 and .7 $\overline{\text{TPr}}/\overline{\text{TP}}$ was only 1% and not significant ($p > .2$). Again activity changes were not essential for the turn decreases.

In Figure 6 for Rat 855, the right-hand diamond shows that .75 for both sequences reduced turns to 33% from the 74% level with .2 for both sequences ($p < .001$). The 19% activity decrease was smaller than before ($p < .05$).

These results demonstrate the asymmetry that is basic to this analysis, namely that delayed reinforcement affects response-specific inhibition more than it affects responses. That asymmetry is visible in spite of appreciable immediate reinforcement of turns, enough to keep their frequency high when the delayed effects are small. These results resemble a negative contrast even more closely, since turns were decreased by an increase in press reinforcements independent of any sequential effect. However, in the present case we have good evidence for the source of this effect; in fact the effect agrees with a prediction from independent evidence of different delay of reinforcement gradients of responses and inhibition.

GENERAL DISCUSSION

Alternative Explanations

The reported results show that food contingent on nonturns of a wheel can decrease turning even though the food occurs at least 6 sec, and usually over 10 sec, after nonturns. The Grice results (1948) indicate that such a delay should greatly reduce, if not eliminate, the ability of press reinforcements to increase competing responses while the wheel is in. Thus, it seems unlikely that the turn decrease was due to the reinforcement of competing

responses. Even the DRO literature with immediate reinforcement has remarkably little evidence for any role of competing behavior. Experiment 3 provides empirical evidence that any remaining capacity for reinforcement of responses across the delay employed here was insufficient to increase competing behavior and thereby decrease turning. To review that evidence, consider Experiment 3 from the competing-response point of view, which would say that turning responses reinforced by TPr are opposed by competing responses reinforced by $\bar{\text{TPr}}$. Then to explain the observed decrease in turning with increased press reinforcement, but with TPr/TP kept equal to $\bar{\text{TPr}}/\bar{\text{TP}}$, a competition explanation would require that the $\bar{\text{TPr}}$ by adventitious and inconsistent reinforcement could condition new blocking responses and support them throughout the 6-sec trials at a level that would block the maintenance of the brief, well-trained turn response that receives consistent reinforcement. Such suppression of turns seems highly improbable when all the differences favor turns. Hence in Experiment 3 some other process is responsible for the turn decrease besides delayed reinforcement of competing responses. The response-specific inhibition view says that the $\bar{\text{TPr}}$ reinforce an inhibition process with different properties than responses, and that view predicted the observed bias in favor of the inhibition process.

Lett (1973, 1974, 1975, 1977) has reported T-maze conditioning with one min and longer delays of reinforcement. However, Lieberman, McIntosh, and Thomas (1979) have shown that such conditioning across long delays used special stimuli, namely a salient stimulus both after the choice response and again just before the reinforcer delivery. Whatever the explanation for that conditioning (see Lieberman et al., 1979, and Denny, 1979, for proposals), the necessary double stimuli were absent from the present experiments. The wheel was removed after turns and nonturns, but wheel removal did not occur close to the press reinforcements, and even bar removal (conceivably similar to wheel removal) did not occur before press reinforcements but instead occurred after them.

In the present experiment, could a conditioned reinforcing stimulus have reinforced competing behavior? That possibility seems remote because, as described above, the conditions preceding press reinforcement with the

bar in were quite different from those following wheel withdrawal. Still, let us suppose that $\bar{\text{TPr}}$ and TPr together could somehow make wheel withdrawal a conditioned reinforcer. Such a conditioned reinforcer would change only slowly from trial to trial, and both $\bar{\text{TPr}}$ and TPr would contribute to it. Hence the very different effect on turning of $\bar{\text{TPr}}$ trials as compared with TPr trials, which was found in Experiments 1 and 2, does not agree with the action of a conditioned reinforcer. Even if a conditioned-reinforcing effect of wheel withdrawal were present, it would not selectively reinforce competing behavior during nonturns. In fact it would probably reinforce turns more effectively than competing behavior, both because initially turns were much more frequent than nonturns and because after a turn the wheel always went right out. In contrast there was no precise contingency between withdrawal and any particular competing behavior. Yet in Experiment 3, a bias was found in favor of nonturning. Thus conditions were inappropriate both for development of a conditioned reinforcer and for the production of competing behavior by a conditioned reinforcer.

Active competing responses should contribute to activity; consequently the activity decrease that often accompanied high $\bar{\text{TPr}}$ and low turning is evidence against an important role of active competing behavior. When turn decreases were still small, wheel approaches without pressing were seen. Such aborted approaches are the opposite of the competing behavior most often proposed, namely incompatible movements, such as movements away from the operandum (e.g., Dinsmoor, 1954). Instead, the association of small turn decreases with aborted approaches suggests that the latter represent a partial or long-latency inhibition of turning (i.e., late-starting inhibition cannot block early components but can block later ones in the sequence).

Although no competing responses were visible, invisible ones could be proposed; but even invisible ones would not answer the argument in terms of different delay-of-reinforcement gradients. Even invisible competing responses, since they are called responses, should have the properties of responses, and one response property seems to be rapid decline in reinforcement effect with delay between response and reinforcement. If it is

proposed that competing responses have no visible properties except for the ability to block visible responses, and that they can differ from responses in other properties such as reinforcement gradient, then the competing-response concept has been modified until it is essentially equivalent to the response-specific inhibition concept defined here, namely a phenomenon with different properties from a response that can selectively block particular responses. If a basic difference between non-responses and responses is accepted, then that difference is obscured by the use of the same concept, "responses," for both; it is clarified by a different concept for nonresponses, "inhibition."

It is not claimed that competing responses never occur or influence behavior. There is evidence for them under favorable conditions—for example, during the experiment of Hinson and Staddon (1978) or during high rates of unreinforced responses early in free-operant extinction (e.g., Terrace, 1971). However, the present procedure was designed to eliminate such sources by spacing unreinforced turns 60 sec apart, by maintaining high reinforcement and feeding levels, and by a delay to reduce food reinforcement of competing responses while the wheel was available.

Decreases in attention, excitation, motivation, etc. have complicated study of inhibition in extinction and discrimination procedures (Hearst, 1972; Rescorla, 1969). Such decreases were greatly reduced with the present procedure, because inhibition was increased without reduction of any scheduled reinforcers. Instead the total reinforcement rate increased in Experiments 1 and 3 when turning decreased. Some activity decreases did occur during the later stages of nonturn reinforcement, but the evidence is good that those decreases were not essential for a turn decrease, because under several conditions the turn decreases occurred without activity decrease: (1) A clear decrease in turning usually developed before the activity decrease; and even after the average activity had decreased, high activity occurred on some days in conjunction with reduced responding. (2) One rat (849) showed an activity increase throughout the reduced turning. (3) In Experiment 3, little change occurred in the activity when turns were reduced by high $\overline{\text{TPr}}/\overline{\text{TP}}$ along with high TPr/TP and hence with high total feeding.

The high reinforcement levels and their increase when the response decreased also minimized aversive effects from low reinforcement or low feeding, effects that have been proposed to play a role in extinction. A role of generalization decrement seems most unlikely in this experiment, because only reinforcement frequencies were changed, and the initial changes were small—often only a few reinforcements per day. Furthermore, Experiment 2 provided an excellent control for generalization decrement, since it showed that increased TPr did not decrease turns the way increased $\overline{\text{TPr}}$ did. Experiment 2 also showed that the turn decrease did not result from an increase in total reinforcements and that the decrease was not a contrast effect in the usual sense of an effect due just to the increase in reinforcement frequency of a different response or during a different stimulus. Instead reinforcement of the sequence $\overline{\text{TP}}$ was critical for the turn decrease.

Thus, the alternatives to a response-specific inhibition explanation seem minimized by the conditions of these experiments. However, this was a first exploration of the potential of a new procedure, and the various conditions were not pushed to their limits. The case for response-specific inhibition now needs to be strengthened by study of longer time separations between wheel and bar introduction to reduce further the possibility of any reinforcing effect of interfering responses. Also needed are parallel measurements of both the delay-of-reinforcement gradient for particular responses and the gradient for inhibition, using procedures as similar as practical.

Activity changes probably can be reduced by reinforcing presses only after activity between wheel removal and bar introduction. Then TP and $\overline{\text{TP}}$ sequences with intervening activity would be reinforced on separate schedules as before, but either sequence without intervening activity would not be reinforced. This improved procedure would selectively reinforce only response-specific inhibition and not generalized inhibition. The reinforcement of both by the present procedure may explain the observed activity decreases.

Although improvements are now apparent, these results demonstrate the advantages of this approach for the study of inhibition: (1) selective production of response-specific inhibition without competing responses; (2)

production of that inhibition in a context of high reinforcement, attention, motivation, etc.; and (3) continuous measurement of the development and reduction of inhibition in individual organisms so that the effect of variables can be compared in the same subject.

Contiguity and Contingency

Earlier it was suggested that response frequency may be determined by all four events in Figure 1, i.e., R_r , $R_{\bar{r}}$, $\bar{R}_r$, and $\bar{R}_{\bar{r}}$ (R for response and r for reinforcer). This view plus the response-specific inhibition concept provide a resolution of two perplexing questions: (1) What are the relative roles of individual pairings versus contingency in determining behavior (e.g., Church, 1969; Rescorla, 1967; Stadon & Frank, 1975)? (2) How can animals adjust their responding to a contingency when a contingency is not a discrete event that can directly influence behavior, as the four individual events (R_r , $R_{\bar{r}}$, etc.) can? In order to react to a response-reinforcer contingency, animals must (like us) somehow average the individual frequencies of R_r , $R_{\bar{r}}$, $\bar{R}_r$, and $\bar{R}_{\bar{r}}$ over a substantial time interval and combine the four averages in a certain way. For present purposes a contingency between R and r can be said to occur when $R_r/(R_r + R_{\bar{r}})$ is significantly different from $\bar{R}_r/(\bar{R}_r + \bar{R}_{\bar{r}})$ (Church, 1969; Gibbon, Berryman, & Thompson, 1974; Rescorla, 1967). It is proposed that the response-specific inhibition of a particular response may be a single variable that is influenced in such a way by each of the four sequences, R_r , $R_{\bar{r}}$, $\bar{R}_r$, and $\bar{R}_{\bar{r}}$ —that the inhibition both averages those four frequencies and combines them into one variable that roughly estimates for the animal the sign and degree of contingency and adjusts the response frequency appropriately. Not only are those four events reasonable as primary inputs for the animal, but in addition countless studies have shown the major effects of R_r and $R_{\bar{r}}$ while DRO studies and this one have shown the effect of $\bar{R}_r$. Furthermore this study indicates that those events act on a response-specific inhibition. The ability of $R_{\bar{r}}$ and $\bar{R}_r$ to increase specific inhibition, and of R_r and $\bar{R}_{\bar{r}}$ to decrease it, would give response-specific inhibition at least a rough relation to the degree of contingency. That the relation is not exact, but only approximate, is indicated by several lines of evidence: (1) Since there are several

different contingency measures (e.g., Gibbon et al., 1974), inhibition could be exactly correlated with only one of them. (2) In Experiment 3, turns decreased as press reinforcements increased even though the degree of contingency was constant (at no contingency). Some sensitivity to all four events and to contingency should increase the survival of animals by decreasing superstitious behavior, but other factors such as conservation of energy may affect survival too, and hence may lessen the control by contingency. (3) Superstitious behavior is direct evidence of imperfection in contingency control.

Functional Properties of Inhibition

Although individual nonresponses have minimal properties, response-specific inhibition appears rich in functional properties—ones describing the influence of other variables on inhibition. The reinforceability of inhibition, its delay of reinforcement gradient, and its specificity to a particular response are three such functional properties. A fourth is the hysteresis seen here, and which has also been reported for extinction (e.g., Flanagan & Anger, 1976). A fifth property may be a tendency to oscillate under some conditions, as seen in the generalized inhibition of Rat 848 and in the response-specific inhibition during transitions (e.g., Figure 2).

Conditioned Inhibition, Response-Specific Inhibition, and Generalized Inhibition

Pavlov originated the conditioned-inhibition procedure, and it continues to be treated as a kind of Pavlovian conditioning, e.g., Rescorla (1969) and Hearst (1972). Both those reviewers excluded operant extinction and DRO from the procedures leading to conditioned inhibition. The present results support that separation but suggest that a different kind of inhibition is present in operant extinction and DRO. The two kinds of inhibition seem best distinguished by their different response specificities, which stem from their different conditioning procedures. The response-specific inhibition studied here resulted from operant processes: It originated in operant extinction and was amplified by operant reinforcement with food. Response specificity is a basic property of operant conditioning, due to the intrinsic contingency of reinforcer on response. This study shows that the con-

tingency of reinforcers on particular non-responses can be just as specific and can produce response-specific effects. In contrast, Pavlovian excitatory conditioning lacks a response contingency and hence does not produce selective effects on individual responses; instead it conditions groups of responses controlled by food, shock, or other USs. Well-developed Pavlovian inhibition would likewise inhibit those groups of responses produced by Pavlovian excitatory conditioning. Thus, Hearst (1972) concluded that the effects of "conditioned inhibitors may be specific to either appetitive or aversive behavior, but fairly general within each category" (p. 22), and Rescorla (1969) said their effects were "largely confined to responses normally elicited by conditioned excitors based upon the same US" (p. 92). The empirical evidence is minimal but supports this view. Brown and Jenkins (1967) have shown that a conditioned inhibitor developed during extinction of pecks to one side of a split key did decrease pecks to the other side. Rodnick (1937) has shown that a conditioned eye blink established with an air puff was depressed during the delay period of a delayed GSR to shock.

Where does the generalized inhibition fit, with its low stimulus and response specificity? Its differences from response-specific inhibition in characteristics and origin were described earlier. Although closely related to conditioned inhibition, and often occurring in similar procedures, generalized inhibition seems to have still less stimulus and response specificity. Many modern conditioned-inhibition experiments (e.g., Rescorla, 1969; Wagner & Rescorla, 1972) show good stimulus specificity and specificity to classes of responses, results incompatible with the extremely generalized inhibition reported here. Even Pavlov (1927), with some conditions and some dogs, showed quite stimulus-specific effects of inhibitory stimuli (pp. 74, 80), which he maintained for years (pp. 80, 240). However, with other dogs and conditions (e.g., frequent CS and long CS-US), the inhibition spread to salivation, activity, eating, and produced sleep or unresponsive states (Chapters 14, 15, and 16). His reports are quite similar to our findings with Rat 848. Later experimenters seem to have selected conditions that avoid this generalized inhibition, though scattered reports of it occur (e.g., Dworkin, 1939; Liddell, 1947;

Turner, 1941). A generalized inhibition of all movements can be produced in many ways: electric shock stimuli (e.g., Blanchard & Blanchard, 1969; Bolles & Riley, 1973), other aversive stimuli (e.g., Higginson, 1930), the conditioned suppression procedure (e.g., Brady & Hunt, 1955), physical restraint (e.g., Gallup, 1974), and stimulation of certain brain loci (e.g., Kaada, 1951). Study is needed to determine how similar these phenomena are.

When one focuses on conditioned inhibition, a definition of inhibition in terms of a kind of stimulus control of behavior or a conditioning process is appropriate. However, if there are three or more kinds of inhibitory behavior, several unconditioned sources (unreinforced responses, shock, etc.), and different conditioning processes (operant, Pavlovian), then definition in terms of a behavioral output may be more appropriate. Such a definition is needed for situations where a controlling stimulus is not easily identifiable, as with nonreinforcement, punishment, DRO, DRL, etc. The behavioral definition, like Skinner's definition of the operant response, eliminates the requirement of a controlling stimulus throughout, even though controlling stimuli usually develop.

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Received February 25, 1981

Final acceptance September 30, 1982