ASSESSING THE ROLE OF EFFORT REDUCTION IN THE REINFORCING EFFICACY OF TIMEOUT FROM AVOIDANCE

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Rats responded on concurrent schedules of shock-postponement or deletion (avoidance) and timeout from avoidance. In Experiment 1, 3 rats' responses on one lever postponed shocks for 20 s and responses on a second lever produced a 1-min timeout according to a variable-interval 45-s schedule. Across conditions, a warning signal (white noise) was presented 19.5 s, 16 s, 12 s, 8 s, or 4 s before an impending shock. Raising the duration of the warning signal increased both avoidance and timeout response rates. Timeout responding, although positively correlated with avoidance responding, was not correlated with the prevailing shock rate. In Experiment 2, 3 rats' responses on one lever deleted scheduled shocks according to a variable-cycle 30-s schedule and responses on a second lever produced a 2-min timeout as described above. After this baseline condition, the avoidance lever was removed and noncontingent shocks were delivered at intervals yoked to the receipt of shocks in the baseline sessions. Timeout responding decreased when the avoidance lever was removed, even though the shock-frequency reduction afforded by the timeout remained constant. These results suggest that a key factor in the reinforcing efficacy of timeout is suspension of the requirement to work to avoid shock, rather than the reduction in shock frequency associated with timeout.

Key words: negative reinforcement, timeout from avoidance, warning signal, electric shock, rat, lever press

Negative reinforcement is defined as the strengthening of behavior that results in the postponement or prevention of an aversive stimulus (the resulting behavior is *avoidance*), or the removal or reduction of the stimulus (*escape*). Avoidance usually is studied with procedures in which a rat presses a lever to postpone (Sidman, 1953) or delete (de Villiers, 1972) brief electric shocks. Escape can be studied by providing a second lever that produces a signaled period in which the avoidance contingency is suspended, thus freeing the rat from both the possibility of shock and the requirement to press the avoidance lever. This situation is referred to as *timeout from avoidance* (Verhave, 1962).

Experiment 1 was reported in Jeff Mikorski's master's thesis. Portions of Experiment 2 were reported in an undergraduate thesis by Christopher Ferro. We are grateful for Chris's contributions to this project. We also would like to thank Philip Hinline for his feedback on an earlier draft of this manuscript. Chad Galuska is now at the College of Charleston.

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Timeout from avoidance has been shown to be an effective negative reinforcer (Baron, DeWaard, & Lipson, 1977; Baron & Trenholme, 1971; Courtney & Perone, 1992; DeWaard, Galizio, & Baron, 1979; Galizio, 1999; Galuska & Perone, 2007; Perone & Crawford, 1999; Perone & Galizio, 1987; Schrot, Boren, & Moerschbaecher, 1976; Verhave, 1962), but pharmacological studies by Galizio and colleagues suggest that the factors that maintain timeout responding are not identical to those that maintain avoidance (Galizio & Allen, 1991; Galizio, Journey, Royal, & Welker, 1990; Galizio & Liborio, 1995; Galizio, Ordroneau, & Robinson, 1994; Galizio & Perone, 1987; Galizio, Perone, & Spencer, 1986). For example, Galizio and Allen demonstrated that morphine reduced—and d-amphetamine increased—timeout responding at doses that had little or no effect on avoidance responding.

As described by Courtney and Perone (1992), a timeout involves three changes in the experimental environment: (a) removal of stimuli associated with the avoidance schedule; (b) reduction in shock delivery, from some prevailing rate based on the rat's avoidance proficiency to zero (shock-frequency reduction); and (c) suspension of the requirement to press a lever to avoid shock (response-effort

reduction). Perone and Galizio (1987) investigated whether the stimulus change associated with timeout alone was sufficient to reinforce timeout responding. When they arranged sham timeouts in which responding produced the stimulus changes associated with timeout without a suspension of the avoidance schedule, timeout responding extinguished. These results are somewhat limited because Perone and Galizio did not arrange a control condition in which responding produced timeout in the absence of a stimulus change. It is reasonable to assume that the stimuli that differentiate timeout from time-in serve important discriminative and conditioned reinforcing functions. Nevertheless, they are not solely responsible for the reinforcing value of timeout.

More attention has been paid to the potential contributions of the other two factors—the shock-frequency reduction and response-effort reduction afforded by a timeout. Courtney and Perone (1992) investigated the roles of both. Rats' responses on one lever avoided shocks according to a variable-cycle (VC) schedule of shock deletion (de Villiers, 1972). At the same time, responses on a second lever produced timeout according to a variable-interval (VI) schedule. These concurrent schedules were imbedded in a multiple schedule. Within and across conditions, the components differed in terms of the VC parameter. This generated a range of rates of programmed shock, received shock, avoidance responding, and timeout responding. Analysis in terms of the generalized matching law allowed quantitative assessment of the sensitivity of timeout responding to the environmental change that occurred when responding on the timeout lever suspended the ongoing avoidance contingency and thus eliminated the programmed rate of potential shocks, the prevailing rate of received shocks, and responding on the avoidance lever. Timeout responding was relatively insensitive to shock-frequency reduction. It was, however, sensitive to the reduction in response effort associated with avoidance responding.

Increasing the effort required to avoid shock may increase the reinforcing function of its suspension. In a study with rhesus monkeys, Krasnegor, Brady, and Findley (1971) varied the response requirements to avoid shock in successive components under

time constraints. In the absence of responding, a stimulus light was illuminated blue for 30 s, then green for 30 s, and then red for 3 s. The red light was accompanied by three brief shocks. Completion of a fixed-ratio (FR) 30 in either the blue or green component terminated this chain, avoided the shock, and produced a blackout. The response requirement reset with the stimulus change from blue to green. In the experimental conditions, the FR in either the blue or green component was varied, while the FR in the other component remained constant. Krasnegor *et al.* found that avoidance responding was inversely proportional to the prevailing response requirement. However, avoidance responding in the unchanged component was directly proportional to the manipulated response requirement in the other component. For example, when the FR associated with the blue component increased, responding during that component decreased but responding during the green component increased. These results demonstrate both that negatively reinforced responding is sensitive to effort manipulations, and that the prevailing reinforcing function of the blackout can be increased by increasing the aversiveness of the contingency in an alternate component. As discussed by Hineline (1984), negatively reinforced behavior is only partially determined by the primary aversive stimulus. It also depends on the prevailing and contextual contingencies of reinforcement, including those associated with response effort.

The present research further examined the contributions of shock-frequency reduction and response-effort reduction to the reinforcing effectiveness of timeout. In Experiment 1, rats produced timeouts from a signaled shock-postponement schedule. Across conditions, we manipulated the duration of the signal that warned of an impending shock. Because the onset of the warning signal tends to control avoidance responding (e.g., Ulrich, Holz, & Azrin, 1964), manipulating the duration of the signal alters the rate of avoidance responding and, with it, the effort reduction afforded by a timeout. As avoidance response rates change, a comparison of timeout response rates will show whether response effort influences the reinforcing effectiveness of timeout, especially if the obtained shock-frequency reduction afforded by timeout is similar across conditions. In Experiment 2, rats produced time-

outs from an unsignaled shock-deletion schedule. In some conditions the avoidance lever was removed from the chamber and noncontingent shocks were delivered at frequencies yoked to the received rate of shock when the lever was present. Here, the rats received the shock-frequency reduction associated with previous avoidance responding in the absence of a current avoidance response requirement. Under these conditions, the shock-frequency reduction afforded by timeout remained the same as in the conditions with the avoidance lever, but the timeout afforded no reduction in response effort.

EXPERIMENT 1

In an early investigation of the effects of a warning signal on avoidance responding, Sidman (1955) trained cats and rats on a schedule in which shock was delivered every 5 s in the absence of responding (shock-shock, or SS, interval), and each response postponed shock by 20 s (the response-shock, or RS, interval). Subsequently, a warning signal was presented 5 s before the impending shock. With the introduction of the warning signal, temporal response patterns changed, with most responding at the onset of the signal. Avoidance response rates decreased and avoidance proficiency increased because of this change in response pattern.

Ulrich et al. (1964) manipulated the duration of the warning signal. Across blocks of sessions, they introduced signal durations of 6, 14, 18, and 19.7 s into a 20-s RS interval (the SS interval was 5 s). The warning signal durations represent the time between the onset of the signal and shock delivery in the absence of responding. For example, after training the rats on an unsignaled shock postponement schedule, a 14-s warning signal was presented. In such an arrangement, the first 6 s of the RS interval—the period before onset of the warning signal—can be considered a signaled safety period. If there was no response within 6 s of the start of the interval, a buzzer sounded and continued through the RS interval, shock, and SS interval. A response during the warning signal terminated it, produced the safety signal, and reset the RS interval.

Ulrich et al. (1964) reported that avoidance response rates were positively correlated with the duration of the warning signal. When the

scheduled duration of the warning signal was 19.7 s, the highest response rates were obtained. As the duration of the warning signal was lowered, response rates decreased. Consistent with results obtained by Sidman (1955) and others (Keehn, 1959; Sidman & Boren, 1957; Stretch & Skinner, 1967), the majority of the responses occurred shortly after the onset of the signal. The introduction of the warning signal decreased obtained shock rates relative to the unsignaled procedure, but obtained shock rates were low and not related to the duration of the signal.

In Experiment 1, rats responded on concurrent schedules of avoidance and timeout from avoidance. By employing warning signals of different durations, we attempted to directly manipulate avoidance response rates while keeping the obtained shock rate relatively constant. The goal was to isolate the effects of avoidance-response effort reduction on the reinforcing efficacy of timeout.

METHOD

Subjects

Three male albino rats were approximately 60 days old at the onset of training. They were individually housed with free access to water under a 12-hour light/dark cycle. Experimental sessions were conducted during the dark part of the cycle, when rats are normally more active. The rats were given access to food for 1 hr each day after the daily session. This procedure has been reported to maintain body weights close to 80 % of free-feeding weights (Hurwitz & Davis, 1983) and reduced the chances that feces could interfere with the administration of shock through the grid floor of the operant chamber. This research was approved by the Institutional Animal Care and Use Committee at West Virginia University.

Apparatus

Two commercial operant chambers (Lehigh Valley Electronics) were used. The interiors were approximately 30 cm long, 21 cm high, and 19 cm wide. In each chamber, the side walls and ceiling were constructed of Plexiglas; the end walls of stainless steel, and the floor of stainless steel rods 0.5 cm in diameter spaced 1.9 cm apart, center to center. Illumination was provided by a 28-v houselight (No. 1820) mounted behind a white sheet of paper on a

Table 1

Experiment 1. Number of sessions (Sess) conducted in each warning-stimulus (WS) condition, percentage of time spent in the safety signal, avoidance and timeout responses per min (total, during safety signal, during warning signal), percentage of RS shocks avoided (avoidance proficiency), and timeouts obtained per min. Results are means (standard deviations in parentheses) based on the last 10 sessions of each condition.

Rat	WS	Sess	% Time in Safety	Avoidance Response Rate			% of RS Avoidance
				Total	Safety	Warning	
J4	19.5	37	14.7 (1.8)	16.5 (2.0)	2.6 (1.4)	19.0 (2.8)	71.3 (9.7)
	16	20	67.7 (4.0)	10.7 (0.7)	4.4 (1.0)	24.3 (4.0)	80.7 (6.4)
	12	22	76.0 (3.1)	6.2 (0.5)	2.6 (0.9)	18.2 (3.0)	77.1 (4.4)
	8	24	79.2 (2.7)	5.2 (0.2)	2.9 (0.4)	14.3 (2.5)	61.5 (6.2)
	4	23	87.7 (2.6)	4.6 (0.4)	2.5 (0.6)	21.2 (6.1)	56.0 (8.5)
	8	20	81.6 (2.6)	5.2 (0.3)	2.7 (0.5)	16.4 (3.0)	63.7 (6.1)
	16	20	65.7 (2.6)	9.7 (0.4)	1.9 (0.5)	24.8 (2.8)	82.3 (6.1)
	19.5	21	14.5 (1.4)	16.4 (1.7)	3.2 (1.5)	18.7 (2.2)	66.2 (7.0)
J6	19.5	38	5.1 (0.9)	4.7 (0.9)	0.7 (0.5)	4.9 (0.9)	91.6 (3.9)
	16	20	37.1 (3.3)	4.9 (0.6)	0.7 (0.2)	7.6 (1.3)	98.9 (0.5)
	12	22	63.5 (2.6)	4.1 (0.2)	0.4 (0.1)	10.6 (1.4)	99.5 (0.4)
	8	25	86.0 (1.6)	3.9 (0.2)	0.5 (0.2)	24.7 (3.5)	99.1 (0.6)
	4	23	90.8 (1.2)	2.9 (0.2)	0.1 (0.1)	31.1 (5.8)	95.4 (1.8)
	8	20	74.6 (2.9)	3.3 (0.2)	0.2 (0.1)	12.6 (2.5)	83.6 (8.2)
	16	24	34.5 (2.0)	4.3 (0.3)	0.4 (0.1)	6.3 (0.7)	81.7 (7.8)
	8	26	76.3 (1.9)	3.5 (0.2)	0.5 (0.1)	13.2 (1.4)	78.1 (5.4)
J9	19.5	32	10.8 (1.7)	11.9 (2.1)	6.6 (1.7)	12.6 (2.4)	79.3 (6.6)
	16	26	52.7 (3.5)	7.8 (0.6)	1.9 (0.6)	14.6 (2.1)	96.7 (1.8)
	12	24	74.1 (2.8)	5.3 (0.3)	0.8 (0.2)	18.3 (2.8)	95.7 (2.1)
	8	20	85.7 (1.6)	4.2 (0.2)	0.5 (0.2)	26.6 (3.6)	96.3 (2.3)
	4	21	95.2 (1.6)	4.0 (0.3)	1.6 (0.7)	55.5 (16.8)	96.4 (2.6)
	8	20	85.8 (2.3)	4.2 (0.1)	0.4 (0.2)	27.9 (5.6)	98.0 (0.8)
	16	22	51.3 (2.9)	7.4 (0.5)	0.6 (0.2)	14.8 (1.7)	99.1 (0.4)

side wall. Two levers were centered 10 cm apart on the front wall, 9 cm above the grid floor. In both chambers, the left lever was retractable and the right was fixed in place. The levers required a force of 0.3 N to operate. Scrambled 1-mA shocks lasting 0.5 s were delivered through the stainless steel grid floors, end walls, and levers. Each chamber was enclosed in a sound-attenuating box equipped with a fan. An 8-ohm speaker mounted on a chamber wall delivered white noise (80-dB). Control and recording operations were accomplished with microcomputers.

Preliminary Training

Avoidance. While the left lever was retracted, the rats were conditioned to avoid shock by pressing the right lever using a successive-approximation procedure described by Baron (1991, pp. 181–182). Control was then transferred to a free-operant avoidance schedule (Sidman, 1953). Initially, each response on the right lever postponed shock for 60 s (RS

interval) and suspended the white noise for 0.5 s. In the absence of responding, a shock was presented at the end of the RS interval and every 5 s thereafter (SS interval) until a response did occur. Across several sessions, the RS interval was gradually reduced from 60 s to a terminal value of 20 s.

Discrimination training. To establish a discrimination between periods of avoidance and timeout, a two-component multiple schedule was arranged. During 25-min avoidance components, the houselight and white noise were turned on and the shock-postponement schedule was operative. During 5-min timeout components, the houselight and white noise were turned off and the avoidance schedule was suspended (i.e., no shocks were scheduled during the timeout component). The components were presented in strict alternation, starting with the avoidance component, and sessions ended after each component was presented four times. A correction procedure ensured that a timeout component could not end within 1 min of an avoidance response: If

Table 1
(*Extended*)

Timeout Response Rate			Timeout Rate
Total	Safety	Warning	
2.6 (0.7)	0.2 (0.3)	2.9 (0.8)	0.9 (0.08)
2.1 (0.6)	1.9 (0.6)	2.5 (1.1)	0.8 (0.08)
1.9 (0.4)	1.9 (0.5)	1.7 (0.7)	0.8 (0.05)
2.1 (0.3)	2.6 (0.3)	0.4 (0.2)	0.8 (0.07)
1.3 (0.3)	1.4 (0.3)	0.3 (0.2)	0.7 (0.08)
1.8 (0.4)	2.2 (0.5)	0.2 (0.1)	0.8 (0.05)
1.9 (0.4)	1.7 (0.4)	2.3 (0.8)	0.9 (0.08)
2.6 (0.4)	0.4 (0.3)	3.0 (0.4)	1.0 (0.05)
4.4 (0.8)	0.5 (0.7)	4.6 (0.8)	1.1 (0.01)
5.9 (1.0)	8.7 (1.8)	4.2 (1.3)	1.1 (0.01)
4.6 (0.6)	4.8 (0.7)	4.2 (1.3)	1.1 (0.04)
3.5 (0.5)	3.8 (2.1)	5.5 (1.2)	1.0 (0.07)
2.0 (0.3)	1.5 (0.4)	6.6 (2.0)	0.8 (0.05)
1.7 (0.2)	1.4 (0.4)	2.7 (0.7)	0.8 (0.08)
3.2 (0.4)	2.2 (1.0)	3.8 (0.5)	1.0 (0.03)
1.5 (0.4)	1.2 (0.5)	2.3 (0.7)	0.7 (0.08)
4.8 (0.3)	0.2 (0.3)	6.4 (0.4)	1.1 (0.03)
3.0 (0.3)	4.2 (0.6)	1.8 (0.6)	1.0 (0.05)
1.7 (0.3)	1.3 (0.3)	2.9 (0.8)	0.8 (0.11)
0.9 (0.1)	0.8 (0.1)	1.7 (0.8)	0.6 (0.05)
1.2 (0.4)	1.1 (0.4)	1.5 (0.7)	0.7 (0.1)
0.9 (0.1)	1.0 (0.1)	0.4 (0.2)	0.6 (0.04)
1.5 (0.2)	2.7 (0.4)	0.4 (0.2)	0.8 (0.04)

an avoidance response occurred during the last minute of the timeout component, the component was extended until responding ceased for 1 min. Training on the multiple schedule continued until less than 5% of the total responses occurred during the timeout over 10 successive sessions (this required 10–14 sessions).

Timeout response. After discrimination training, the left (timeout) lever was inserted into the chamber. Responding on the right (avoidance) lever still postponed shocks for 20 s, but now a single response on the left lever produced an audible relay click as feedback and a 5-min timeout period. During these response-dependent timeouts, the houselight and white noise were turned off, the timeout lever was retracted, and the avoidance schedule was suspended. Across several sessions, the duration of the timeout was gradually reduced to 1 min, and the production of timeout changed to a leaner variable-interval (VI) 45-s schedule. The intervals comprising the schedule were obtained using the distribution

developed by Fleshler and Hoffman (1962). Once responding was reliably maintained on both levers, the first experimental condition began.

Procedure

In all experimental conditions, presses on the avoidance lever postponed shock for 20 s while presses on the timeout lever produced 1-min timeouts according to a VI 45-s schedule. Sessions lasted until the rat accrued 60 min on the avoidance schedule (i.e., until it had 60 min of time-in).

Each condition included a warning signal—onset of white noise—of a different scheduled duration. The order of warning signal durations is shown in Table 1. Note that the period before the onset of the warning signal—when the white noise was off—constituted a discriminable safety period, and we occasionally will refer to the absence of white noise (while the avoidance schedule was in progress) as a safety signal.

Because we assumed that lowering the duration of the warning signal would decrease both avoidance and timeout responding, we were concerned that responding might extinguish at short signal durations before longer durations could be assessed. For this reason, we investigated the warning signal durations in descending order.

Avoidance and timeout responses could occur during the warning signal or safety signal. Shocks could occur only in the presence of the warning signal. Avoidance responding during the safety signal postponed the warning signal and the next scheduled shock by resetting the 20-s RS interval. Avoidance responding during the warning signal terminated the signal and reset the RS interval. If no response occurred during the warning signal, a shock was presented when the RS interval elapsed and the SS interval began. The warning signal continued throughout the SS interval; a shock was delivered every 5 s until an avoidance response terminated the signal and reset the RS interval.

Whether during the safety signal or the warning signal, the first timeout response after a variable interval elapsed produced a timeout and its correlated stimulus changes: offset of the houselight, offset of the warning stimulus if it was underway at the time of the response, retraction of the timeout lever, and suspension

of the avoidance schedule. After the timeout period elapsed, the houselight was turned on, the timeout lever was inserted, and the avoidance schedule was reinstated with the RS interval reset to the beginning.

Sessions were conducted 6 or 7 days a week. Table 1 shows the number of sessions per condition for each rat. In each condition, a minimum of 20 sessions was conducted. Conditions were terminated when avoidance and timeout response rates met two stability criteria. First, there could be no visible increasing or decreasing trend across the last 10 sessions. Second, the last 10 sessions were divided into two 5-session blocks. The mean response rate for each block had to differ by less than 10 percent of the overall 10-session mean. When response rates were low, this criterion became too stringent, so low rates (under 2 responses per min) were considered stable if the difference between the two blocks was less than 0.5 responses per min.

As shown in Table 1, after the condition with the shortest warning signal, the conditions with the 8-s and 16-s signals were replicated. Rat J4 also was exposed to a replication of the 19.5-s condition to reestablish the previously seen pattern at that warning signal duration. This rat had received 16 sessions with a 0.5-s warning signal before the replication conditions began. This condition severely disrupted avoidance responding and was stopped to protect the rat. The results of this aborted condition are not reported and this warning signal duration was not investigated in the other rats. Because the 8-s signal replication occurred immediately after the 0.5-s condition, a second replication of the 8-s signal condition was conducted to assess the reliability of the first replication.

RESULTS

Figure 1 shows rates of avoidance responding, timeout responding, and received shocks as a function of warning signal duration. The results are expressed as means and standard deviations based on the last 10 sessions in each condition. Data points that are not connected to the functions show results from the replicated conditions.

Responding was directly related to the signal duration. On the avoidance lever, Rats J4 and J9 show the greatest change, with the

steepest increases occurring between the 12-s and 19.5-s conditions. On the timeout lever, Rats J6 and J9 show the greatest changes.

For Rats J6 and J9, received shock rates generally were low across the initial conditions; the exception was at the 19.5-s signal. These rats also were proficient in avoiding shock, shown in Table 1 as the percentage of RS shocks avoided. For Rat J4, the received shock rate decreased and avoidance proficiency increased as the warning signal was raised, again with the exception of the 19.5-s condition. This rat tended to receive more shocks at the beginning of the session, and at shorter warning signals this pattern was amplified.

Results in the replicated conditions were similar to the initial ones for Rats J4 and J9. By comparison, Rat J6's timeout response rates, shock rates, and avoidance proficiency all tended to differ from the initial series. Timeout response rates were lower in the replicated conditions, but they still increased with increases in the warning signal. Shock rates were higher (and avoidance proficiency lower) than the results obtained initially. These differences may be attributed to the disruptive effects of the 0.5-s warning signal condition (not shown), which produced extremely low avoidance response rates and high shock rates.

For each condition, Table 1 also shows the mean percentage of time spent in the safety signal, avoidance and timeout response rates, avoidance proficiency, and timeouts produced per minute. Avoidance and timeout response rates were calculated for the total avoidance interval (the same results shown in Figure 1) and individually for the safety and warning signal periods. Avoidance response rates always were higher during the warning signal even when most of the RS interval was spent in the safety signal. Timeout response rates did not differ as much across the warning and safety signals, and in many cases were higher in the safety signal relative to the warning signal. The rate of timeout production decreased slightly with reductions in the warning signal duration.

To explore factors that might be associated with the reinforcing effectiveness of timeout, correlation coefficients were calculated for both shock rates and total avoidance response rates versus total timeout response rates. Figure 2 shows these correlational analyses,

Fig. 1. Experiment 1: Means (and standard deviations) for total avoidance response rates, total timeout response rates, and shock rates, based on the last 10 sessions of each warning signal condition.

Fig. 2. Experiment 1: Correlations between mean timeout response rates and mean avoidance response rates, and correlations between mean timeout response rates and mean shock rates.

and includes the linear equations for each line. Positive correlations were obtained between timeout responding and avoidance responding. When timeout responding and shock rates were analyzed, however, negative correlations were obtained for 2 rats. One rat, J9, showed a positive correlation between shock and timeout rates, but this correlation may be misleading because it is influenced by one extreme data point. This data point represents the first condition (19.5-s condition). Without this point, the correlation drops to -0.22 (dashed line in Figure 2).

These correlations are consistent with the hypothesis that a timeout is reinforcing to the extent that it provides the rat a respite from the effort of avoidance responding. But there is another possible reason for the positive correlation between avoidance responding and timeout responding: The timeout response is just an alternative way to avoid shock. Accordingly, any manipulation that increases avoidance rates, such as raising the duration of the warning signal, would also be expected to increase timeout rates. To study this possibility,

we took a closer look at the temporal distribution of the two responses.

Figure 3 shows avoidance (left column) and timeout (right column) response distributions throughout the RS interval for all conditions, for one rat, J4. The RS intervals were divided into 40 bins, each lasting 0.5 s. It is important to remember that after every avoidance response the RS interval was reset. As a result, there was more opportunity to respond early in the interval than later. The analysis in Figure 3 takes into account the high level of opportunity to respond early and the low opportunity to respond later in the interval. The dependent variable, responses per opportunity, is the conditional probability of a response in any given interval based on the number of opportunities to respond in that interval. The responses and opportunities in each bin were summed over the last 10 sessions in each condition. Open bars show results during the safety signal and closed bars bars during the warning signal.

The panels in the left column of Figure 3 show that avoidance responses were improbable during the safety signal at the beginning of each RS interval and highly probable during the warning signal. The panels in the right column show distributions of responding on the timeout lever. Overall, the probabilities were low, reflecting the low absolute rates of timeout responding. The key finding is that timeout responding was more probable during the safety signal than during the warning signal.

Figure 4 displays a summary of this analysis for all 3 rats. For each condition, the open point is the mean of the conditional probabilities in the safety signal and the closed point is the mean of the conditional probabilities in the warning signal. Results during safety signal are omitted from the condition with the longest (19.5-s) warning signal; here the safety signal lasted only 0.5 s and effectively prevented responding in its presence. The mean of avoidance responses per opportunity always was higher during the warning signal relative to the safety signal. For Rats J6 and J9, the mean avoidance responses per opportunity during the warning signal decreased with increases in the warning signal. By comparison, the mean of timeout responses per opportunity was higher in the safety period relative to the warning period.

Fig. 3. Experiment 1, Rat J4: Avoidance responses per opportunity and timeout responses per opportunity for each 0.5-s bin of the 20-s RS interval. Values are based on the last 10 sessions of each warning signal condition.

DISCUSSION

Previous studies suggest that shock-frequency reduction is an important variable underlying avoidance responding in rats (e.g., de Villiers, 1974; Herrnstein & Hineline, 1966).

Fig. 4. Experiment 1: Mean avoidance and timeout responses per opportunity as a function of the warning signal duration.

In timeout from avoidance procedures, however, the shock-frequency reduction afforded by timeout usually is low, and timeout responding has been shown to be more closely associated with the response-effort reduction afforded by timeout (Courtney & Perone, 1992; Perone & Crawford, 1999; Perone & Galizio, 1987). By manipulating avoidance response rates with warning signals of various durations, Experiment 1 showed that timeout response rates were positively correlated with avoidance response rates. At the same time, negative correlations usually were found between timeout response rates and obtained shock rates. In other words, the reduction in response effort afforded by the timeout was associated with increases in timeout responding, while the amount of shock-frequency reduction afforded by the timeout was associated with decreases in timeout responding.

Avoidance responding was most likely after the onset of the warning signal. Consequently, avoidance response rates were directly related to the duration of the warning signal. This coincides with previous research (e.g., Ulrich et al., 1964) and is the very effect the present experiment was designed to exploit.

Timeout responding also was directly related to the duration of the warning signal. That the avoidance and timeout responses should change in parallel is interesting when one considers that the concurrent avoidance and timeout contingencies compete for response allocation. From this perspective, manipulations that increase avoidance responding might be expected to reduce timeout responding.

The positive correlations between timeout and avoidance responding should not be taken as evidence of substitutability. The two forms of behavior show different patterns over the course of the response-shock interval, with avoidance responding more probable during the warning signal and timeout responding more probable during the safety signal. On this basis, avoidance and timeout responding appear to be functionally distinguishable.

Experiment 1 manipulated a warning signal to alter the rate of avoidance responding across conditions. This allowed for correlational analyses between the rate of avoidance responding and the rate of timeout responding. Timeout responding was positively correlated with avoidance responding, suggesting that response-effort reduction might contribute to the reinforcing function of timeout. In Experiment 2, using a different procedure we further attempted to dissociate the role of shock-frequency and response-effort reduction as determinants of timeout responding. In the key conditions of Experiment 2, we eliminated the response-effort factor by removing the avoidance lever altogether while leaving the shock-frequency reduction afforded by timeout unchanged.

EXPERIMENT 2

Experiment 2 assessed the ability of shock-frequency reduction to maintain timeout responding when avoidance-response effort was removed. In the baseline condition, rats' avoidance responses deleted shocks according to a VC 30-s schedule. Timeout responses produced 2-min timeouts on a VI 45-s schedule. In the experimental condition, the timeout contingency remained in operation but the avoidance lever was removed and noncontingent shocks were delivered at the same rate as received in the baseline condition. The presentation of shocks in the experimental

condition was yoked to the presentation of shocks in the stable sessions of the baseline condition. The yoking procedure ensured that a timeout afforded the same degree of shock frequency reduction in the baseline and experimental conditions. At issue is how timeout responding is affected by the removal of the avoidance lever and, with it, the requirement to work to achieve low levels of received shock. If timeout responding increases or is unaffected, then response-effort reduction can be eliminated as a possible contributor to the reinforcing effectiveness of timeout from avoidance. Results consistent with an effort-reduction account of the reinforcing function of timeout would be obtained if responding decreases from baseline levels when the avoidance contingency is removed.

METHOD

Subjects and Apparatus

Three male albino rats (T1, F1, F3) were approximately 60 days old at the beginning of training. The rats were housed individually under a reversed 12 hr light/dark cycle. Sessions were conducted during the dark part of the cycle, using the same chambers as in Experiment 1. To prevent fouling of the shock grid, rats were deprived of food for at least 10 hours before each experimental session. This research was approved by the Institutional Animal Care and Use Committee at West Virginia University.

Preliminary Training

Preliminary training was conducted 3 days per week with at least 1 day in between sessions. Sessions lasted 3 hr. Avoidance responding was shaped on the right lever as described in Experiment 1. The houselight and white noise were turned on, and avoidance responses produced 0.5-s offset of white noise as a feedback stimulus. Over several sessions the RS interval was reduced to 30 s. At this point, control of avoidance responding was transferred to a VC 30-s schedule in which shocks were programmed at irregular intervals averaging 30 s using Fleshler and Hoffman's (1962) distribution, modified so that the minimum intershock interval was 5 s and the maximum was 110 s. The first response in an interval (or cycle) deleted the shock otherwise scheduled to be delivered at the end of the

interval. Further responses during the interval had no effect.

Whenever the VC schedule delivered a shock, the schedule was suspended and additional shocks were delivered every 5 s until a response occurred. The addition of this SS interval has been shown to facilitate the acquisition and maintenance of responding on VC schedules (Courtney & Perone, 1992; DeWaard *et al.*, 1979). A single response during the SS interval terminated the train of SS shocks but did not delete the next programmed VC shock. Training on the VC 30-s schedule lasted a minimum of 10 sessions, until the rats avoided at least 80 % of the scheduled VC shocks.

To next establish timeout responding, the left lever was inserted into the chamber at the beginning of the session and a single response produced a 5-min timeout in which the VC schedule was suspended, the houselight and white noise were turned off, and the timeout lever was retracted. Each timeout response also produced an audible click as a feedback stimulus. When the timeout period elapsed, the houselight and white noise were turned on, the timeout lever was inserted, and the VC schedule was reinstated. Responses on the right lever continued to avoid shocks according to the VC 30-s schedule. In Experiment 2, we omitted formal training to establish discrimination of avoidance and timeout. We reasoned that the initial preliminary training had incorporated a kind of informal discrimination training because the periods the rats spent in the chamber before and after each avoidance session were essentially timeout periods: During these periods the avoidance schedule was not in operation and the houselight and white noise were turned off.

After several sessions 2 rats (F1 and F3) had yet to press the timeout lever, so a remedial procedure was implemented. With only the timeout lever inserted into the chamber, shocks were delivered every 20 s. Lever pressing was shaped via successive approximations, with each response producing a 5-min timeout. Reliable lever pressing was obtained in two sessions. The rats then were returned to the concurrent schedules of avoidance and timeout.

Across several sessions, the duration of the timeout was reduced to 2 min and the schedule of timeout was changed to a leaner

VI 45-s schedule (Fleshler & Hoffman, 1962). Preliminary training was considered complete when the rats were reliably responding on the timeout lever and avoiding more than 80 % of the scheduled VC shocks.

Procedure

Two conditions, designated as "baseline" and "yoked-shock," were alternated in an A-B-A-B design. In the baseline condition, the VC schedule of shock avoidance and the VI schedule of timeout operated as they did at the end of preliminary training. Sessions were conducted 3 days per week, with at least 1 day in between sessions, and lasted until 60 min had accrued during the avoidance portion of the session. The condition lasted a minimum of 10 sessions, until both avoidance and timeout response rates were stable. In the absence of a trend, the mean response rates in the first three sessions and the last three sessions of the last six consecutive sessions had to be within 15 percent of the overall mean of the six sessions. In addition, session-by-session plots of shock rates were inspected visually to confirm the absence of systematic trends.

In the yoked-shock condition, the avoidance lever was removed and only the timeout lever was inserted into the chamber. Data from the stable sessions of the baseline condition were used to generate six lists of the received shocks and the time at which they occurred during the avoidance portion of each session. At the beginning of each yoked-shock session, a list was chosen to serve as the noncontingent shock schedule. The lists were sampled at random without replacement until all six had been used, at which point the sampling procedure was repeated. Judgments of stability were based on the rate of responding on the timeout lever, with calculations as described above. Stability was assessed only after every sixth session to ensure that the received shock rate in the last six sessions of the yoked-shock condition was identical to that in the last six sessions of the baseline condition. All other procedural details remained the same as in the baseline condition.

RESULTS

Table 2 shows avoidance response rates and avoidance proficiency in the baseline condi-

tions, and the number of sessions, received shock rates, and timeout production rate in every condition. Avoidance proficiency was calculated as the number of deleted VC shocks divided by the number of programmed VC shocks, and is expressed as a percentage. The results are means based on the last six sessions of each condition, with standard deviations in parentheses.

In the baseline conditions, all rats were proficient at avoiding VC shocks ($> 85\%$ proficiency). Received shock rates (including SS shocks) were low, with a maximum of 0.26 shocks per min (Rat F1). Note that the procedure was successful in matching the received shock rates in each pair of baseline and yoked-shock conditions.

Figure 5 shows mean timeout response rates across conditions. The rate of timeout production is shown in Table 2. In the baseline condition, timeout response rates were markedly lower than response rates on the avoidance lever (shown in Table 2), as usually is the case with the schedule values employed. Timeout response rates in this condition ranged from approximately 1.5 (Rat F3) to 5 per min (Rat T1), and rats produced approximately one timeout per minute. When the avoidance contingency and lever were removed, timeout responding decreased for all rats. Rates of timeout production also decreased, particularly for Rat F3. A similar pattern of results was obtained in the replicated conditions.

Figure 6 shows timeout response rates as a function of the prevailing shock rate in baseline (open circles) and yoked-shock (closed circles) sessions. Each data point represents results from a single session. The results are from the six stable sessions of each condition, including the replicated conditions, so a total of 12 sessions contribute to each function. To quantify the relation between timeout responding and shock rate, correlation coefficients and best-fitting lines are shown. In the baseline condition, timeout responding was either not associated with the prevailing shock rate (Rat F3), or was negatively associated with shock (Rats T1 and F1). In the yoked-shock condition, however, there was a positive association between timeout responding and the prevailing shock rate in Rats F1 and F3.

Table 2

Experiment 2. Number of sessions conducted in each condition, avoidance response rates and the percentage of VC shocks avoided in the baseline condition, and the received shock rates and timeout production rate (timeouts per minute). Results are means (standard deviations in parenthesis) based on the last six sessions of each condition.

Rat	Condition	Sessions	Avoidance	% VC Shocks		
			Resp/Min	Deleted	Shocks / Min	Timeouts / Min
T1	Baseline	18	26.8 (2.1)	97.1 (2.0)	0.06 (0.04)	1.1 (0.02)
	Yoked-Shock	30			0.06 (0.04)	0.9 (0.09)
	Baseline	12	29.0 (1.4)	96.8 (0.7)	0.07 (0.02)	1.1 (0.03)
	Yoked-Shock	18			0.07 (0.02)	0.7 (0.26)
F1	Baseline	21	17.5 (2.4)	89.4 (2.8)	0.26 (0.08)	1.0 (0.06)
	Yoked-Shock	12			0.26 (0.08)	0.8 (0.09)
	Baseline	11	15.8 (1.0)	89.8 (2.6)	0.23 (0.05)	1.0 (0.03)
	Yoked-Shock	28			0.23 (0.05)	0.8 (0.04)
F3	Baseline	16	22.8 (2.4)	93.0 (1.6)	0.15 (0.03)	0.8 (0.09)
	Yoked-Shock	12			0.15 (0.03)	0.3 (0.2)
	Baseline	11	27.5 (1.9)	95.6 (2.1)	0.09 (0.05)	0.8 (0.08)
	Yoked-Shock	12			0.09 (0.05)	0.3 (0.1)

Fig. 5. Experiment 2: Mean timeout response rates in the baseline and yoked-shock conditions. Error bars represent standard deviations.

Fig. 6. Experiment 2: Correlations between timeout response rates and the prevailing shock rate in the baseline (open circles) and yoked-shock (closed circles) conditions. Results include replicated conditions.

DISCUSSION

In conventional procedures, a timeout from avoidance is associated with both shock-frequency reduction and a respite from avoidance responding. In the yoked-shock condition of Experiment 2, response-effort reduction was eliminated by removing the avoidance lever altogether. The shock-frequency reduction afforded by the timeout remained the same. For all rats, timeout responding decreased, suggesting that response-effort reduction is an important determinant of timeout responding. These results are particularly striking in light of potential response competition between avoidance and timeout responses. All rats responded at higher rates on the avoidance lever relative to the timeout lever during the baseline condition. When the avoidance lever was removed, more time became available to respond on the timeout lever, yet timeout responding decreased.

An alternative explanation of these results is that timeout responding decreased in the experimental condition because approaches to the timeout lever were occasionally punished by shock delivery. While possible, we find this explanation of the results problematic for several reasons. First, the obtained shock rate during time-in was much lower than the timeout response rate. The vast majority of timeout approaches were not consequted with shock. Secondly, the possibility that timeout approaches could be consequted with shock also existed in the baseline condition. Third, if timeout approaches were punished in the experimental condition, one might expect timeout response rates to remain suppressed upon the return to the baseline condition. Overall, we argue that interpreting the changes observed in timeout responding as resulting from the presence or absence of the avoidance contingency is a more plausible account of the results.

The results from Experiment 2 also show that the response-effort reduction afforded by the timeout is not the sole determinant of timeout responding. Timeout responding persisted, albeit at lower rates, in the yoked-shock condition, and was positively associated with the prevailing shock rate in 2 rats. Caution must be exercised, however, in attributing the timeout responding in the yoked-shock condi-

tion entirely to the shock-frequency reduction afforded by timeout. Results from our laboratory (Courtney & Perone, 1992; Galuska & Perone, 2007) and those reported by Galizio (1999) have shown that timeout responding persists at low rates even when shock is discontinued. For example, Galizio used a two-lever procedure in which responses on one lever postponed shock and responses on a second lever produced a signaled 2-min timeout according to a variable-ratio (VR) 15 schedule. After the rats had been exposed to a large number of sessions with the concurrent schedules of avoidance and timeout, shock was discontinued. Although avoidance responding extinguished in approximately 15 sessions, timeout responding persisted much longer, and one rat continued to press the timeout lever for over 100 sessions. These data demonstrate that timeout responding is particularly resistant to shock-omission extinction. In light of Galizio's results, perhaps the fact that timeout responding persisted at low rates in the yoked-shock conditions is not surprising.

GENERAL DISCUSSION

Converging evidence suggests that the response-effort reduction associated with the suspension of the avoidance schedule is an important determinant of the reinforcing effectiveness of timeout from avoidance. Consistent with results obtained by Courtney and Perone (1992), Experiment 1 found that timeout response rates are positively associated with prevailing avoidance response, but not shock, rates. In Experiment 2, removing the avoidance contingency and lever altogether decreased timeout responding, even though the shock-frequency reduction afforded by timeout was unchanged.

Some may contend that the positive correlation between avoidance and timeout responding observed in Experiment 1 and previous research (Courtney & Perone, 1992) are indicative of the fact that avoidance and timeout responses are not functionally independent; that is, the shock schedule functions as an establishing operation that motivates responding on both the avoidance and timeout levers. The results from Experiment 1, however, demonstrate that the molecular patterning of avoidance and timeout responses were different. Avoidance responses were

more likely during the warning signal and timeout responses during the safety signal. These temporal differences in response patterning suggest that avoidance and timeout responding may be controlled by different variables.

Other experiments have shown a differentiation between avoidance and timeout responding. Timeout responding is more resistant to shock-omission extinction than avoidance responding (Galizio, 1999; Galuska & Perone, 2007). Drug pretreatments also have been shown to affect avoidance and timeout responding differently (e.g., Galizio & Allen, 1991). In fact, the results of some of these studies are difficult to reconcile with the view that timeout responding is controlled primarily by avoidance response-effort reduction. For example, why should timeout responding persist after avoidance responding extinguishes when shock is discontinued, and the effort-reduction afforded by the timeout approaches zero (Galizio, 1999; Galuska & Perone, 2007)? Galizio and colleagues also have shown that ethanol (Galizio *et al.*, 1986), chlordiazepoxide (Galizio *et al.*, 1990; Galizio & Perone, 1987), and d-amphetamine (Galizio & Allen) had little effect on avoidance responding at doses that reliably enhanced timeout responding. If timeout responding is maintained entirely by avoidance-response effort reduction, avoidance and timeout response rates should change in concert with one another.

Although the present results demonstrate a role for response-effort reduction as a determinant of the reinforcing effectiveness of timeout, it remains plausible that other factors also may play a role. Still, it is not clear that the prevailing shock-frequency reduction afforded by timeout is one of those factors. As Perone and Galizio (1987) noted, rats proficient at avoidance receive very few shocks, and the shock-frequency reduction afforded by timeout is low. Only studies that have arranged high rates of shock delivery (e.g., de Villiers, 1974; Herrnstein & Hineline, 1966) have reported a reliable relation between shock-frequency reduction and the rate of a negatively reinforced response. Perhaps concurrent schedules of avoidance and timeout from avoidance do not generate a sufficient range of shock rates from which to assess the role

of shock-frequency reduction in modulating timeout responding. Another possibility is that the effects of response-effort reduction may mask control by shock-frequency reduction. In Experiment 2 when effort-reduction was removed, timeout responding decreased, but the responding that did occur was positively associated with the prevailing shock rate in 2 of 3 rats.

In describing how timeout responding is maintained for many sessions in the absence of shock delivery, Galizio (1999) pointed to the conditioned reinforcing functions of the stimuli associated with timeout, and evoked a safety signal interpretation of timeout (for discussions of the role of safety signals in maintaining negatively reinforced responding, see Denny, 1991; Dinsmoor, 1977, 2001; Dinsmoor & Sears, 1973; and Gray, 1987). Perhaps the contribution of shock to the reinforcing functions of timeout is Pavlovian: Shock establishes the timeout stimulus as a safety signal. To this end, more research is needed to determine how the received rate of shock early in training affects the subsequent reinforcing functions of timeout. Although the prevailing shock-frequency reduction afforded by the timeout does not contribute greatly to its reinforcing effectiveness at steady-state, the shock-frequency reduction historically associated with timeout might. This supposition is also consistent with Hineline's (1984) views that both prevailing and historical contingencies of reinforcement modulate responding in addition to the primary aversive stimulus. Converging results from the present experiments using different methodologies as well as previous research (Courtney & Perone, 1992) suggest that in rats proficient at avoiding shock, the reinforcing effectiveness of timeout is related to the suspension of the response requirements of the avoidance schedule.

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