RESPONSE-INDEPENDENT MILK DELIVERY ENHANCES PERSISTENCE OF PELLET-REINFORCED LEVER PRESSING BY RATS

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If, during training, one stimulus is correlated with a higher rate of reinforcement than another, responding will be more resistant to extinction in the presence of that higher rate signal, even if many of the reinforcers have been presented independently of responding. For the present study we asked if the response-independent reinforcers must be the same as the response-dependent reinforcers to enhance the response's persistence. Twelve Long-Evans hooded rats obtained 45-mg food pellets by lever pressing (variable-interval 100-s schedules) in the presence of two discriminative stimuli (blinking vs. steady lights) that alternated every minute during daily sessions. Also, in the presence of one of the stimuli (counterbalanced across rats), the rats received additional response-independent deliveries of sweetened condensed milk (a variable-time schedule). Extinction sessions were exactly like training sessions except that neither pellets nor milk were presented. Lever pressing was more resistant to extinction in the presence of the milk-correlated stimulus when (a) the size of the milk deliveries during training (under a variable-time 30 s schedule) was 0.04 ml (vs. 0.01 ml) and (b) 120-s or 240-s blackouts separated components. Response-independent reinforcers do not have to be the same as the response-dependent reinforcers to enhance persistence.

Key words: resistance to change, behavioral momentum, variable-time schedule, persistence, milk reinforcers, lever pressing, rats

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If a response is reinforced at a relatively high rate in the presence of one discriminative stimulus and at a relatively low rate in the presence of another (e.g., a multiple variable-interval [VI] VI schedule), the response rate will usually be higher in the presence of the former (rich-reinforcement signal) than in the presence of the latter (lean-reinforcement signal) (Davison & McCarthy, 1988; Williams, 1988). Moreover, if conditions are made less favorable to responding (if, e.g., the schedules are changed to extinction), the response rate will decline more slowly in the presence of the former rich-reinforcement signal than in the presence of the former lean-reinforcement signal (for reviews, see Nevin, 1992; Nevin & Grace, 2000).

From such results it might appear that

these two characteristics of responding—rate and resistance to change—are correlated effects of the reinforcement of a response. It turns out, however, that the rate of a response and its resistance to change depend on fundamentally different types of contingencies. The rate of a response in the presence of a stimulus depends on the relative reinforcement of that response. That is, it is an increasing function of the rate of reinforcers that are dependent on the response but a decreasing function of the rate of reinforcers that are independent of the response (Herrnstein, 1970; Williams, 1988). The resistance of the response to change, in contrast, depends largely on whether the prevailing discriminative stimulus has been correlated with the higher or the lower rate of reinforcers during training, regardless of whether all or only some of the reinforcers presented during the stimulus have been dependent upon the designated response (Mace et al., 1990; Mauro & Mace, 1996; Nevin, Tota, Torquato, & Shull, 1990). In other words, the tendency of a response to persist under unfavorable conditions depends largely on the stimulus–reinforcer (i.e., Pavlovian) contingency that has been in effect during training (Nevin, 1992; see Nevin & Grace, 2000, for a review and consideration of exceptions).

One recent account of these findings is that resistance to change in the presence of a discriminative stimulus is related to the value of that stimulus as measured by relative choice (Grace & Nevin, 1997; Nevin & Grace, 2000). Both resistance and choice are determined by the conditions of reinforcement (e.g., rate of reinforcement) in the presence of a stimulus, and both can, in a sense, be considered measures of the reinforcing value of the stimulus. According to this account, the value of the stimulus, and therefore the persistence of the response that occurs in the presence of that stimulus, will be enhanced by any reinforcer that occurs during a stimulus. If so, perhaps the response-independent reinforcers could be different from the response-dependent reinforcers and still enhance persistence.

The evidence, however, is unclear on this point. Some results from research with verbally competent humans indicate that response-independent reinforcers might, indeed, enhance persistence even if they are different from the dependent ones that maintain the response (Tota-Faucette, 1991). But verbal competencies can complicate the interpretation of reinforcement-like effects (Shull & Lawrence, 1998). The present study was designed to address the question with nonhuman animals under conditions typical of those used to study resistance to change. Rats obtained food pellets at the same rate in the presence of two different discriminative stimuli by lever pressing. In the presence of one stimulus, they also received response-independent deliveries of sweetened condensed milk. Following blocks of such baseline training sessions, the rats were given extinction sessions (neither pellets nor milk available) to assess the relative resistance to change of lever pressing in the presence of the two discriminative stimuli. The aim was to determine if lever pressing would persist longer in the presence of the signal of pellets plus milk than in the presence of the signal of pellets alone.

METHOD

Subjects

Twelve male Long-Evans hooded rats served as subjects. They were housed sepa-rately in plastic boxes with metal grate tops in a room that maintained a 12:12 hr light/dark cycle, with dark beginning about 6:00 p.m. Experimental sessions were conducted during the light period. Water was continuously available in each rat's home cage.

At the onset of the experiment, the rats weighed 335 ± 15 g, and they were maintained within this weight range throughout the project by giving them access to blocks of food in their home cages for 1.0 to 1.5 hr after their experimental sessions (Ator, 1991). The rats in Squads A and B were members of the cohort for an undergraduate laboratory in the spring of 1999; those in Squad C were in the next year's cohort and so participated in the present project a year later.

Apparatus

The experiment was conducted in four identical operant chambers (Colbourn Instruments) measuring 29 cm high by 29 cm wide by 25.5 cm deep. The chambers were placed, unshielded, on tables in a room that was darkened during sessions, except for low-level ambient light that entered the room through a translucent window. Each chamber had two clear plastic side walls and two walls of sheet-metal panels. The rear (metal) wall contained an opening, 7 cm above the floor, through which the spout of a water bottle protruded 0.5 cm into the chamber. The rats had continuous access to water during all experimental sessions.

On the front wall were two identical response levers, one 5.5 cm to the left of center and the other 5.5 cm to the right of center, 6 cm above the grid floor. The levers were 3.5 cm across and extended 2 cm into the chamber. A downward force on the lever of at least 0.3 N operated a switch that was connected to the lever and thereby generated a recordable response. Three small lightbulbs (5 mm diameter; one each of yellow, red, and green), arranged in a horizontal row 1.5 cm apart center to center were located 2.5 cm above each lever. These bulbs could be programmed to be illuminated continuously (steady) or to blink in a square wave fashion of 256 ms on and 256 ms off. There was no houselight.

Centered on the front wall, 2 cm above the floor, were two adjacent rectangular openings (each 4 cm high and 3.5 cm wide) through

which the rat could obtain the reinforcers (dry food pellets or milk) when delivered. Behind the opening on the right was a small metal box with a hole at the top through which food pellets (45-mg Noyes Formula A) were delivered; behind the opening on the left was a metal box with a hole (0.75 cm diameter) in the bottom through which a small dipper could be presented. The pellet feeder made a distinctive click whenever a pellet was delivered. The liquid feeder made a soft whirring noise when activated, accompanied by the illumination of a bulb in the feeder opening. The liquid dipper normally rested in a reservoir outside the chamber. The size of the liquid (milk) reinforcer could be changed by using different-sized dipper cups (0.01 ml or 0.04 ml) and by varying the time that the rat had access to the raised dipper (from 2.5 s to 1.0 s; see below).

The milk solution was made by diluting ordinary commercial sweetened condensed milk with tap water to make a milk and water mixture whose proportions were 50:50 (Squads A and B) or 70:30 (Squad C). Based on published reports (e.g., Baron, Mikorski, & Schlund, 1992) and our own pilot work with other rats that obtained milk by lever pressing, we expected these mixtures to be effective as reinforcers, the 70:30 mixture more so than the 50:50 mixture. Shortly before each daily session, the reservoirs were filled with the appropriate milk solution. The reservoirs were cleaned daily. The milk solutions were made fresh every 3 days and were stored in a refrigerator overnight.

A computer running software and interface modules supplied by Colbourn Instruments (LabLinc) controlled all experimental events and data recording.

Procedure

Baseline rates of lever pressing first were established in the presence of two discriminative stimuli (blinking vs. steady lights) that alternated during daily sessions. Both of the stimuli signaled the same VI schedule of pellet reinforcement for lever pressing, but one of the stimuli also signaled additional response-independent presentations of milk (i.e., a variable-time [VT] schedule of milk deliveries). Then, after several daily sessions, the procedure was changed to extinction (neither pellets nor milk was presented) to

determine if lever pressing was more persistent in the presence of the discriminative stimulus that had signaled the additional milk deliveries than in the presence of the stimulus that had signaled pellets alone. If results from the 1st day of extinction suggested increased persistence in favor of the pellets-plus-milk stimulus (as described below), then extinction was continued for an additional 2 days. If results from the first day did not suggest differential persistence, then training conditions were altered and baseline training continued. This sequence of baseline training followed by extinction was carried out several times, with variations in the details of the baseline conditions. It took some exploration with various VT milk schedules, dipper sizes, VI pellet schedules, and blackout intervals between the discriminative stimuli to obtain clear evidence of differential persistence. The three squads differed in the details of these exploratory conditions, as summarized below.

Squad A (Two Levers)

Sessions began and ended in darkness. For the first condition, during a session either the three bulbs above the left lever were blinking together at a rate close to two per second (256 ms on and 256 ms off) or the three bulbs above the right lever were illuminated continuously (steady). These two light-status components alternated every 60 s throughout the session for a total of approximately 50 cycles. While the left lever bulbs were illuminated (blinking), pressing the left lever was reinforced by food pellets on a VI 60-s schedule; right lever presses had no programmed consequence. While the right lever bulbs were illuminated (steady), pressing the right lever was reinforced by food pellets on a VI 60-s schedule; left lever presses had no programmed consequence. Also, during one of the light-status components (blinking for Rats A1 and A3 and steady for Rats A2 and A4) a VT 20-s schedule provided access to the loaded dipper independently of responding. For this first condition, the size of the dipper (0.01 ml) was the smaller of the two that we used, and the access duration was 2.5 s.

Training continued under this condition for 49 daily sessions–substantially more sessions than necessary for response rates to appear stable. Following the 49th session, the procedure was changed to extinction for one

50-cycle session. For this session, milk was placed in the reservoirs and the discriminative stimuli alternated as before, but neither pellets nor milk (nor the associated clicks and whirring sounds) was delivered.

As will be described later in the Results section, this first extinction test provided no evidence that the free milk deliveries enhanced the persistence of lever pressing. Such results might suggest that response-independent food deliveries do not enhance the persistence of a designated response unless they are the same type as the dependent reinforcers. Alternatively, our finding of no enhanced persistence might have resulted from non-optimal training procedures. It seemed possible, for example, that the milk-presentation schedule provided insufficient additional reinforcement. It seemed possible as well that the rats were not discriminating sufficiently (i.e., their responding was not controlled fully by) the status of the lights (blinking vs. steady). Accordingly, we explored the effects of a number of variables that seemed likely either to enhance the relative reinforcing value of the schedule of response-independent milk or to increase the degree of stimulus control by the blinking versus steady status of the lights. For example, we increased the frequency of milk deliveries and decreased the frequency of pellet deliveries (i.e., by reducing the mean VT schedule of milk deliveries and by increasing the mean VI schedule of pellet reinforcers). We also increased the size of the dipper from 0.01 ml to 0.04 ml. Further, we attempted to reduce or eliminate some suspected sources of competing stimulus control (see Durlach, 1989; Williams, 1994) by reducing the duration of dipper access and by eliminating the dipper light. In addition, fairly long blackout periods (as long as 240 s) were scheduled between presentations of the discriminative stimuli. During blackouts the chambers were darkened and neither pellets nor milk was presented. Based on the effects of analogous procedures on stimulus control in Pavlovian-like preparations (Gibbon & Balsam, 1981; Lattal, 1999) and on what is known about the conditioned reinforcement of observing (attentional) behavior (Dinsmoor, 1983, 1995), we expected that adding long blackouts would enhance stimulus control by the status of the lights. Table 1 summarizes these various training

conditions and lists the number of sessions devoted to each. Table 1 also summarizes the session durations. Extinction tests (as described above) were given after some, but not all, of these conditions, as indicated in Table 1. Most conditions were followed by a single extinction session because the results of that extinction did not merit additional days of extinction (the method of assessment used to determine this will be discussed in the Results section); the last condition was followed by three consecutive extinction sessions.

The VI and VT schedules were generated by arranging a constant probability of reinforcement assignment at the end of each consecutive 3-s interval during the prevailing discriminative stimulus. The expected mean time between assignments equals the time unit divided by the assignment probability. Thus, for example, a probability of .05 should result in a mean VI or VT schedule of 60 s. For the VI schedules, once a reinforcer was assigned, it remained available until it was collected by a response; no more assignments were made until the assigned reinforcer was collected. For the VT schedules, the milk was delivered immediately when assigned. Reinforcers assigned by the VI schedule but not collected during a discriminative stimulus component were canceled at the end of that component.

Squad B (One Lever)

The basic training procedure for Squad B was similar to that for Squad A except that for Squad B both the steady and blinking lights alternated above the left lever only, and all pellet reinforcers were dependent upon pressing the left lever. Pressing the right lever had no programmed consequence. For Rats B1 and B3, the blinking lights signaled pellets (VI) plus milk (VT); for Rats B2 and B4 the steady lights signaled the pellets plus milk. Training for the two squads also differed in some of the specific exploratory procedures (see Table 2). As noted in Table 2, extinction sessions (one or three) were programmed following some of the training conditions as determined by the results of the first day of extinction.

Squad C (One Lever, No Exploratory Conditions)

The final conditions for Squads A and B generated differential persistence in favor of

Table 1

For the rats in Squad A, the order of training conditions (grouped by the rationale for the manipulations), the number of sessions devoted to each, the number of consecutive extinction sessions that followed the last session of the training condition, the VI schedule of pellets in the presence of the two discriminative stimuli (blinking and steady lights), the additional VT schedule of milk delivery in the presence of one of the discriminative stimuli, the size (in milliliters) of the dipper cup for milk deliveries, the amount of time (in seconds) that the milk cup was raised per delivery (dipper access), whether or not a bulb was illuminated during the operation of the dipper, duration (in seconds) of a blackout inserted between the two 60-s discriminative stimulus components, and indexes of relative resistance to change for the first extinction session per condition. Two indexes of relative resistance are presented for each rat and the mean. The top value is log relative resistance to change; the bottom value is the slope of the best fit line over the first 10 points (see text for details). Daily sessions were usually 1.67 hr long for Conditions 1 through 4, 2 hr long for Condition 5a, and 3 hr long for Condition 5b.

Condition	Training sessions	Extinction sessions	VI for pellets in both components	VT for milk in pellets + milk component	Size of milk dipper	Dipper access	Light in liquid feeder	Blackout duration	Relative resistance for first extinction session				
									A1	A2	A3	A4	M
1: To decrease rates of scheduled events													
1a	49	1	VI 60 s	VT 20 s	0.01	2.5	Yes	0	−0.137	−0.587	−0.228	0.316	−0.159
									−0.013	−0.015	−0.024	0.004	−0.012
1b	34	1	VI 100 s	VT 30 s	0.01	2.5	Yes	0	−0.181	−0.794	−0.383	−0.580	−0.485
									0.020	−0.076	−0.014	−0.027	−0.025
2: To reduce stimulus competition from dipper													
2a	26	1	VI 100 s	VT 30 s	0.01	2.5	No	0	0.217	−0.290	−0.215	−0.422	−0.178
									−0.007	−0.072	−0.035	−0.008	−0.027
2b	9	0	VI 100 s	VT 30 s	0.01	1.5	No	0					
2c	21	1	VI 100 s	VT 30 s	0.01	1.0	No	0	0.041	−0.765	−0.290	−0.345	−0.340
									−0.006	−0.288	−0.044	−0.054	−0.098
3: To enrich VT schedule for milk													
3a	2	0	VI 100 s	VT 15 s	0.01	1.0	No	0					
3b	63	1	VI 100 s	VT 10 s	0.01	1.0	No	0	−0.568	−0.197	0.162		−0.201
									−0.024	0.017	0.0002		−0.002
3c	65	1	VI 100 s	VT 5 s	0.01	1.0	No	0	0.140	0.033	−0.216	0.036	0.002
									0.070	−0.024	−0.040	−0.034	−0.007
3d	41	0	VI 100 s	VT 30 s	0.01	1.0	No	0					
4: To enhance reinforcer potency of milk (increase dipper size and duration)													
4a	12	1	VI 100 s	VT 30 s	0.04	2.5	No	0	−0.465	0.290	0.382	−0.207	0.000
									−0.029	0.026	0.062	−0.009	0.013
5: To enhance control by discriminative stimuli (blackouts between components)													
5a	7	0	VI 100 s	VT 30 s	0.04	2.5	No	60					
5b	6	3	VI 100 s	VT 30 s	0.04	2.5	No	120	0.728	0.683	0.088	0.360	0.465
									0.102	0.058	0.011	0.022	0.048

the signal of pellets plus milk. We doubted that the sequence of earlier training conditions was necessary for this effect. But to be sure, we introduced 4 new rats (Squad C) directly to training conditions similar to those that were effective for the rats in Squad B (Condition 4b, Table 2). The rats in Squad C experienced none of the earlier training conditions.

Specifically, as with Squad B, the lights alternated between blinking and steady above the left lever, and only the left lever was effective. Both discriminative stimuli signaled the same VI 100-s schedule for pellets; one of the stimuli (blinking for rats C1 and C3, steady for rats C2 and C4) also signaled a VT 30-s schedule of milk delivery. The dipper-access time was 2.5 s, and the dipper-cup size was 0.04 ml. In the hope of further enhancing the reinforcing contribution of the re-

Table 2

For the rats in Squad B, the order of training conditions (grouped by the rationale for the manipulations), the number of sessions devoted to each, the number of consecutive extinction sessions that followed the last session of the training condition, the VI schedule of pellets in the presence of the two discriminative stimuli (blinking and steady lights), the additional VT schedule of milk delivery in the presence of one of the discriminative stimuli, the size (in milliliters) of the dipper cup for milk deliveries, the amount of time (in seconds) that the milk cup was raised per delivery (dipper access), whether or not a bulb was illuminated during the operation of the dipper, duration (in seconds) of a blackout inserted between the two 60-s discriminative stimulus components, and indexes of relative resistance to change for the first extinction session per condition. Two indexes of relative resistance are presented for each rat and the mean. The top value is log relative resistance to change; the bottom value is the slope of the best fit line over the first 10 points (see text for details). Daily sessions were usually 1 hr long for Conditions 1 through 3, 2 hr long for Condition 4a, 3 hr long for Condition 4b, and 5 hr long for Condition 4c.

Condition	Training sessions	Extinction sessions	VI for pellets in both components	VT for milk in pellets + milk component	Size of milk dipper	Dipper access	Light in liquid feeder	Blackout duration	Relative resistance for first extinction session				
									B1	B2	B3	B4	*M*
1: To enrich VT schedule for milk													
1a	28	1	VI 100 s	VT 10 s	0.01	3.5	No	0	0.340	0.080	−0.140	−0.040	0.060
									0.062	0.072	−0.011	0.014	0.034
2: To reduce stimulus competition from dipper													
2a	12	1	VI 100 s	VT 10 s	0.01	2.0	No	0	0.373	−0.081	0.234	−0.079	0.112
									0.051	−0.043	0.029	0.057	0.024
3: To enhance reinforcer potency of milk (increase dipper size and duration)													
3a	10	1	VI 100 s	VT 30 s	0.04	2.5	No	0	−0.157	−0.453	0.175	−0.074	−0.127
									−0.026	−0.011	0.026	−0.015	0.007
4: To enhance control by discriminative stimuli (blackouts between components)													
4a	7	0	VI 100 s	VT 30 s	0.04	2.5	No	60					
4b	6	3	VI 100 s	VT 30 s	0.04	2.5	No	120	0.538	0.150	0.191	0.238	0.279
									0.075	0.034	0.027	0.007	0.036
4c	22	3	VI 100 s	VT 30 s	0.04	2.5	No	240	0.304	0.406	0.345	0.086	0.286
									0.045	0.051	0.034	0.007	0.034

sponse-independent milk schedule, the ratio of milk to water in the solution was increased to 70:30.

During the first baseline training condition for Squad C, a 120-s blackout separated the discriminative stimuli. This condition was in effect for 21 3-hr sessions (approximately 30 cycles each), followed immediately by three consecutive sessions of extinction. Extinction sessions were arranged exactly like training sessions (3 hr in duration, alternating 60-s periods of blinking and steady lights separated by 120-s blackouts, milk in the reservoir) except that neither pellets nor milk was delivered.

Following extinction, the rats were given nine sessions of further exposure to the same training conditions except that the blackout duration was increased to 240 s and the ses-

sion duration was increased to 3.3 hr (approximately 20 cycles). After this additional baseline training, the rats were given three consecutive sessions of extinction, again programmed exactly like the immediately preceding baseline training except that neither pellets nor milk was delivered.

Control Discriminative Stimulus Components

Adding a VT schedule of food delivery commonly reduces the rate of a designated response (Burgess & Wearden, 1986; Rachlin & Baum, 1972). Although this effect is usually interpreted as a learned adjustment to the degraded operant contingency, it could be due, in part, to interfering behavior evoked by the presentation of the response-independent reinforcers. To distinguish these two possible effects of the VT schedule of milk delivery, we

arranged for 10% of the milk-correlated stimuli to, in fact, contain no milk deliveries. In essence, 60-s intervals were targeted when pellets would be delivered as usual, but when rates of lever pressing could be assessed without the interfering effects of milk deliveries. These will be referred to as *control components.* These control components were programmed during the last condition for the rats in Squad A and the two conditions for the rats in Squad C.

RESULTS

Resistance to Extinction

A common way to assess resistance to extinction is to plot the response rates that occurred in the presence of each of the discriminative stimuli during baseline training and during several consecutive sessions of extinction. The *y* axis (response rate) is scaled logarithmically so that the slope of each plot indicates the change in response rate relative to its baseline level. Our intent was to obtain such extinction plots. We were concerned, however, that if we exposed the rats repeatedly to several consecutive sessions of extinction, they might learn, in effect, that one session of extinction is followed by more sessions of extinction and, as a result, cease responding in extinction sessions after the first. As it turned out, in hindsight, there was surprisingly little evidence of this kind of learning. But at the time, given this concern and because we were unsure that our training conditions were optimal for demonstrating differential persistence, we wanted some indication that three consecutive sessions of extinction would generate clear results before actually exposing the rats to a block of extinction sessions. To this end, our strategy was to give the rats a single session of extinction, assess the results, and decide on the basis of those results either to continue the extinction series for two more sessions or to return to baseline training after modifying the training procedures.

Figure 1 illustrates this strategy and provides some examples of the course of extinction within a single session. The panels in the top row show the results of the first extinction test—the one that followed Training Condition 1a—for the rats in Squad A. (Again, because the *y* axis is scaled logarithmically, the slopes of the plots indicate *relative* change in response rate.) If the VT presentations of milk during training had enhanced resistance to extinction, the slope of the response-rate plot would have been less steep for responding in the presence of the signal of pellets plus milk than in the presence of the signal of pellets alone. That is, the two response-rate plots would have diverged. There is little evidence in the top row of plots of such a systematic divergence, and as a consequence we did not continue the extinction series but instead returned to further baseline training under the modified procedure of Condition 1b (see Table 1). The panels in the third row show the same type of extinction plots, but for the first extinction session that followed training under Condition 5b, in which 120-s blackouts separated the components of the multiple schedule. The patterns are different from those shown in the top row in that the plots diverge as extinction progresses, with the slope being less steep for responding in the presence of the signal of pellets plus milk. This diverging pattern is most apparent for Rat A2 and least for Rat A3. For Rat A1, the response rates diverge over about two thirds of the extinction session, and then converge toward the end of extinction. We have found this pattern to be fairly common and suspect that the secondary convergence exemplifies emotional reactions engendered by extinction. We expected the within-session extinction plots to be rather variable, and they were. But the diverging patterns shown in the third row were sufficiently encouraging that we decided to continue extinction for two more sessions, the results of which will be described shortly.

Our decision of whether or not to continue an extinction series was based on visual inspection of plots like those in the top and third rows of Figure 1. It is possible, however, to generate quantitative indexes that summarize the degree to which the two response-rate plots separate. Imagine taking the two plots—such as those shown for Rat A1 in the third row of Figure 1—and sliding one of them up or down until the leftmost points superimpose. Then measure the vertical distance (i.e., the difference) between each of the corresponding points in the two plots. We calculated these difference scores based on
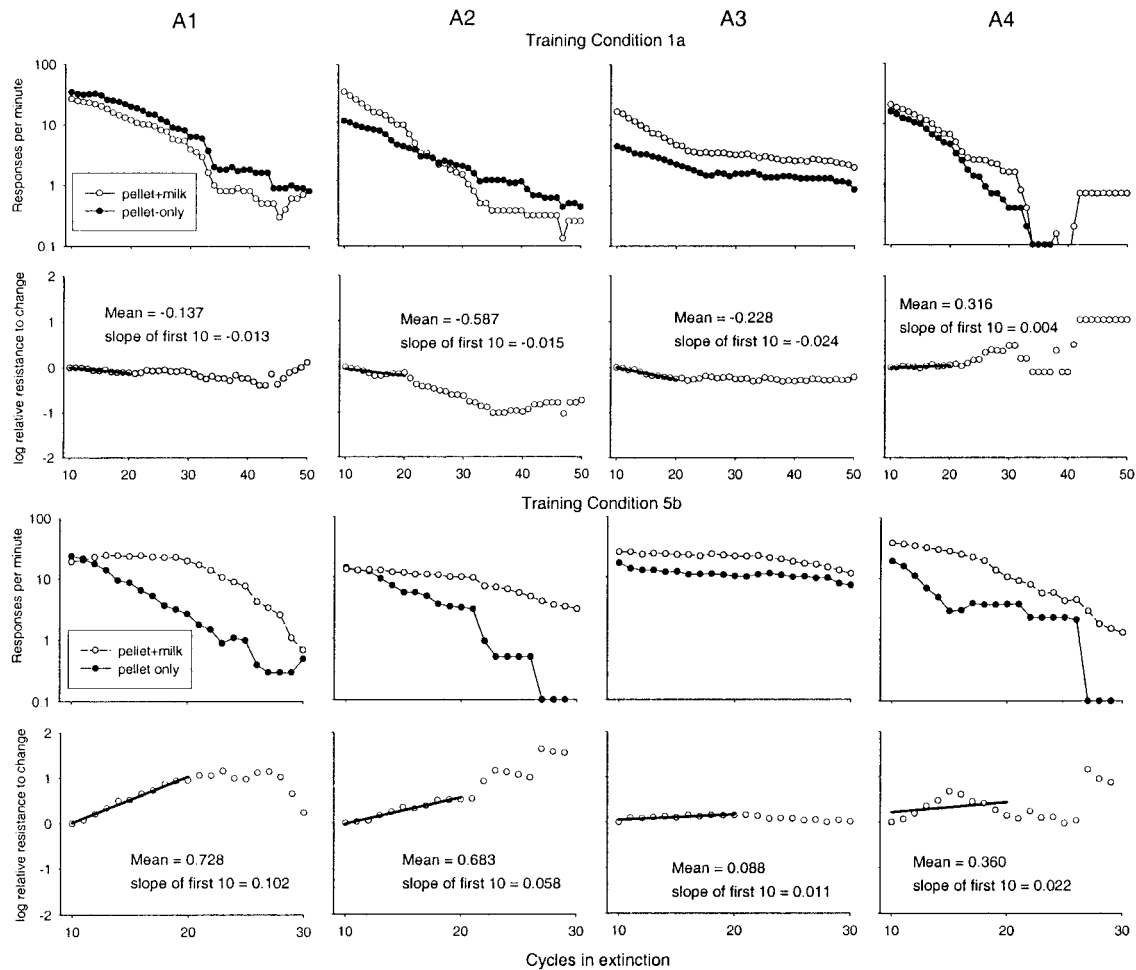
Fig. 1.   The top row is the within-session extinction plots for the 4 rats in Squad A following Training Condition 1a (VI 60 s [pellets] vs. VI 60 s [pellets] + VT 20 s [0.01 ml milk]). Response rate (log scale) is plotted as a function of consecutive 60-s presentations of the discriminative stimuli (i.e., cycles) during a single extinction session. Each point represents a 10-cycle moving average. Open circles show response rates during the signal of pellets (VI) plus milk (VT); filled points show response rates during the pellet-only (VI) stimulus. Each panel shows data for 1 of the 4 rats. For 2 rats (A1 and A3) the blinking light above the left lever signaled pellets (VI) plus milk (VT); for the other 2 rats (A2 and A4) the steady lights above the right lever signaled pellets (VI) plus milk (VT). For each pair of rats the other stimulus signaled pellets (VI) alone. The second row shows the log relative resistance to change for the data in the panel above it. The numbers in each panel are the mean of the log relative resistance to change values and the slope of the best fitting line over the first 10 points. The third row is the within-session extinction plots following training in which a 120-s blackout (Condition 5b) was inserted between the two components of the multiple schedule of reinforcement (i.e., VI 100 s [pellets] vs. VI 100 s [pellets] + VT 30 s [0.04 ml milk]). The fourth row shows the log relative resistance to change for the data in the third row.

the logarithms of the response rates, after dividing each response rate in a plot by the response rate at the start of extinction (i.e., by the value of the first point in the plot). Formally, this measure, which is similar to what Grace and Nevin (1997, 2000) called the *log relative resistance to change,* can be expressed as $\log(M_x/M_0) - \log(P_x/P_0)$, where *M* indicates

a response rate in the presence of the signal of milk plus pellets and *P* indicates a response rate in the presence of the signal of pellets alone. The subscript 0 indicates the response rate at the start of extinction, and the subscript *x* indicates the response rate represented by any of the points further to the right. Because of the order in subtracting, positive

values indicate greater persistence in the presence of the signal of pellets plus milk, a value of zero indicates no difference in persistence, and negative values indicate greater persistence in the presence of the signal of pellets alone.

The second row of panels in Figure 1 show these log relative resistance to change values for the response rates that are plotted in the top row. Only for Rat A4 is there any evidence of an upward trend in the points. The trend for Rat A2 is downward; the points for Rats A1 and A3 appear to vary unsystematically around a value close to zero. Two indexes summarize these impressions. The first is the mean of these log relative resistance to change values, which indicates the average extent of divergence. The second is the slope of the best fitting line, which indicates the extent to which the response-rate plots continue to diverge as extinction progresses. The line was fit to only the first 10 points because, as discussed above, responding later in extinction sometimes became quite variable. The numerical values of these indexes, given in the second row of panels, again show little evidence of differential persistence.

The extinction sessions that followed the other exploratory conditions (except for the last ones that arranged long blackouts between components) produced results similar to those shown in the top half of Figure 1; that is, no clear differential persistence. This was true for the rats in Squads A and B. The last five columns of Tables 1 and 2 give the values of the two indexes of the single-session differential persistence.

In contrast, the log relative resistance to change values for extinction after training with the 120-s blackout between components (Condition 5b), shown in the bottom row of Figure 1, yielded positive values of both indexes for all 4 rats (but least for Rat A3). Such values indicate that responding was more persistent in the presence of the signal of pellets plus milk than in the presence of the signal of pellets alone. The values of the indexes were also positive for the rats in Squad B following training with the long (120 s and 240 s) blackouts (see the data in the last five columns of Table 2 for Conditions 4b and 4c).

Because of the encouraging results from the single extinction session following train-

ing with long blackouts between components, we carried out extinction for three consecutive sessions following these training conditions, the results of which are shown in Figure 2 for Squad A (top set of four) and Squad B (bottom set of four). In every case, regardless of whether the schedules were assigned to two levers (Squad A) or one (Squad B), responding was more persistent, relative to its baseline level, in the presence of the signal of pellets plus milk than in the presence of the signal of pellets alone. (Quantitative support for this conclusion will be presented below.)

For most of the rats, the response-rate plots for the two discriminative stimuli crossed, so that the discriminative stimulus that engendered the lower response rate during baseline came to engender the higher response rate at some point during extinction. This crossover, however, appears to be at least partly due to an artificially reduced rate of lever pressing during baseline in the presence of the signal of pellets plus milk. The response rates during the control component arranged for Squad A (i.e., the signal of pellets plus milk but without milk deliveries) were mostly higher than the response rates during the same stimulus when milk deliveries actually occurred (compare the triangles with the open circles for the baselines in Figure 2, top). If the response rate during the control component is taken as the appropriate estimate of baseline performance during the signal of pellets plus milk (i.e., as the learned adjustment to the VT schedule of milk delivery superimposed on the VI schedule of pellets), then the evidence of such response-rate reversals is much weaker. Regardless of which baseline measure is used, however, response rates consistently declined more slowly relative to their baseline levels in the presence of the signal of pellets plus milk than in the presence of the signal of pellets only.

The rats in Squad C did not experience any of the earlier, exploratory training conditions. Instead, their first baseline training condition was similar to the next-to-last condition for the rats in Squad B, a condition that was effective in generating differential resistance to extinction in favor of the milk-correlated stimulus. We suspected that the critical factors for obtaining differential persistence were the use of the larger (0.04 ml)
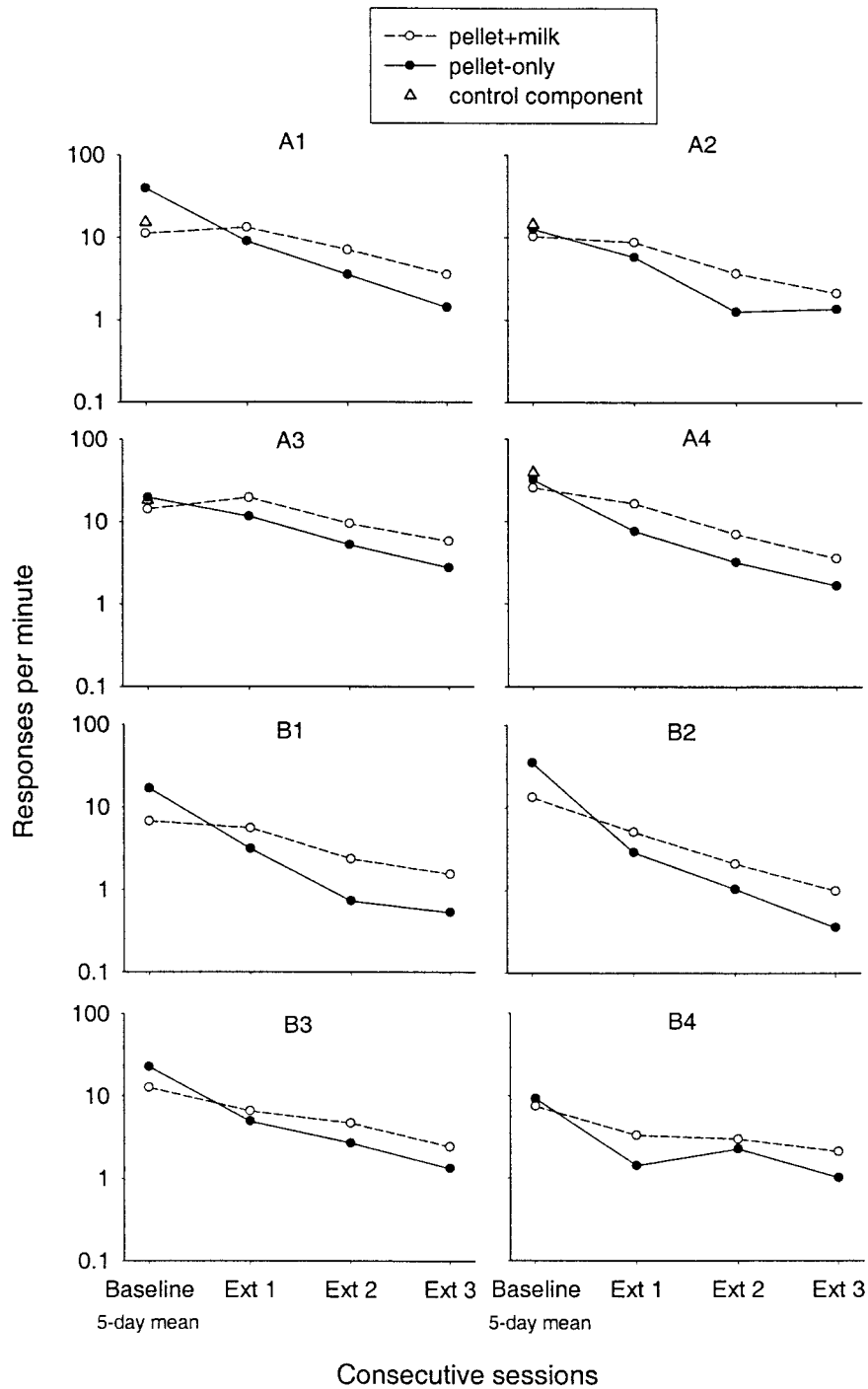
Fig. 2. Across-session extinction plots for the 4 rats in Squad A (top set) and the 4 rats in Squad B (bottom set) following training in which a 120-s blackout (Squad A, Condition 5b) or 240-s blackout (Squad B, Condition 4c) was inserted between the two components of the multiple schedule of reinforcement (i.e., VI 100 s [pellets] vs. VI 100 s [pellets] + VT 30 s [0.04 ml milk]). Each plot shows the average response rate per session in the presence of one of the discriminative stimuli at the end of baseline training (mean over last five sessions) and over three consecutive sessions of extinction. Open circles show response rates during the signal of pellets (VI) plus milk (VT); filled points

Table 3

Indexes of differential persistence from the first session of extinction for Squad C following training with a 120-s blackout (Condition 1) and a 240-s blackout (Condition 2). Two indexes of relative resistance are presented for each rat. The top value is log relative resistance to change; the bottom value is the slope of the best fit line over the first 10 points (see text for details).

Training condition	Blackout duration	Rat			
		1	2	3	4
1	120 s	0.036	0.288	0.441	−0.044
		0.097	0.089	0.125	−0.039
2	240 s	0.235	0.259	0.169	0.155
		0.028	0.100	0.097	0.002

dipper size and, especially, the imposition of a fairly long (120-s) blackout between the two discriminative stimuli. Thus, the initial training condition for the rats in Squad C included those components (plus a more concentrated milk solution than was used for the other rats). Results indicating differential persistence from this first training condition for Squad C would provide evidence that the extensive training history of the other squads was not an important contributing factor to the results we had obtained with the other squads.

For 3 of the 4 rats in Squad C, response rate during the first of the three extinction sessions following training with the 120-s blackout declined more slowly in the presence of the signal of pellets plus milk than in the presence of the signal of pellets (single-session indexes are given in Table 3). For the 4th rat (C4), response rates declined at a similar rate in the presence of the two discriminative stimuli (see the indexes for this rat in Table 3). A similar pattern is apparent in the plots of response rate over baseline and the three extinction sessions (Figure 3). Thus, again, there is good agreement in the trends between the within-session extinction plots and the extinction plots over sessions.

For Rats C1, C2, and C3, the baseline response rates during the control component (signal of pellets plus milk but without milk deliveries) were lower than the response rates in the presence of the signal of pellets alone (Figure 3). Such differential responding was not so apparent in the data from Squad A (Figure 2, top). This difference may have been due to the more extensive training with the blackouts that the rats in Squad C received. In any case, it may be significant that the rat whose extinction functions showed no differential persistence (Rat C4) is the same rat whose baseline response rates showed no evidence of differential responding between the control component and the pellet-only stimulus. Such a pattern is consistent with the possibility for Rat C4 of little control by the blinking versus the steady status of the lights.

In the hope of sharpening stimulus control, especially for Rat C4, we gave the rats in Squad C nine additional sessions of baseline training but with a longer (240-s) blackout. The results from the subsequent sessions of extinction were similar to those already shown in Figure 3. The only notable difference was some additional separation in responding for Rat C4 indicating differential persistence in favor of the signal of pellets plus milk. The persistence indexes for the

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show response rates during the pellet-only (VI) stimulus. The open triangles (top set) are the mean response rates during the control components (signal of pellets plus milk but with no milk delivery). Each panel shows data for 1 of the 8 rats. For 4 rats (A1, A3, B1, and B3) the blinking light signaled pellets (VI) plus milk (VT); for the other 4 rats (A2, A4, B2, and B4) the steady lights signaled pellets (VI) plus milk (VT). For each pair of rats the other stimulus signaled pellets (VI) alone. Moreover, for the 4 rats in Squad A, the components were differentiated also by location, left (blinking) versus right (steady). Thus, the plots for the blinking lights show response rates on the left lever; the response rates for the steady lights show response rates on the right lever. For the 4 rats in Squad B the blinking versus steady lights appeared above the left lever, and only the left lever was operative.
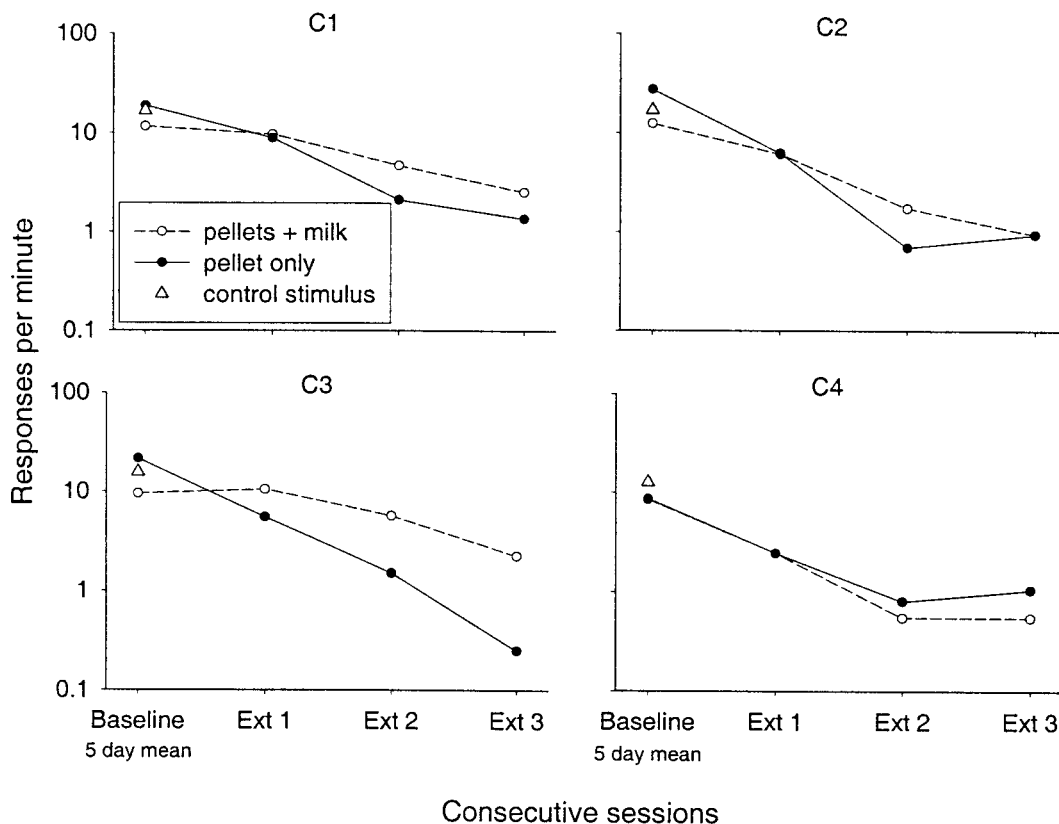
Fig. 3.   Across-session extinction plots for the 4 rats in Squad C following training in which a 120-s blackout was inserted between the two components of the multiple schedule of reinforcement (i.e., VI 100 s [pellets] vs. VI 100 s [pellets] + VT 30 s [0.04 ml milk]). Each plot shows the average response rate per session in the presence of one of the discriminative stimuli at the end of baseline training (mean over last five sessions) and over three consecutive sessions of extinction. Open circles show response rates during the signal of pellets (VI) plus milk (VT); filled points show response rates during the pellet-only (VI) stimulus. The open triangles are the mean response rates during the control components (signal of pellets plus milk but with no milk delivery). Each panel shows data for 1 of the 4 rats. For 2 rats (C1 and C3) the blinking light signaled pellets (VI) plus milk (VT); for the other 2 rats (C2 and C4) the steady lights signaled pellets (VI) plus milk (VT). For each pair of rats the other stimulus signaled pellets (VI) alone.

first extinction session following this training condition are given in Table 3.

If the across-session extinction plots are reasonably linear (with logarithmic y axis), a convenient index of differential persistence (Nevin, 1992; Nevin & Grace, 2000) consists, first, of calculating the slopes of the extinction functions like those in Figures 2 and 3. (Note that the y axis for these plots is scaled logarithmically, so the response rates are converted to their logarithms for determining the slopes.) The steeper the slope, the less persistent responding is. Next, the ratio of the two slopes is calculated. And, finally, the logarithm of that ratio is determined. For our data, we determined the slopes based on a least squares fit. We calculated the ratios by

putting the slope for the pellets-only signal in the numerator and the slope for the pellets-plus-milk signal in the denominator. Thus, logarithms of these ratios that are greater than zero indicate greater persistence in favor of the signal of pellets plus milk; logarithms below zero indicate greater persistence in favor of the signal of pellets only. Table 4 shows these logarithms of slope ratios for the last condition for the rats in Squad A and for the last two conditions for the rats in Squads B and C. For the rats in Squads A and C, the logarithms are also shown for calculations in which the baseline response rates were derived from the control component. In all but one comparison (Rat C4, 120-s blackout), the slope-ratio logarithms are positive in value

Table 4

Across-session indexes of relative resistance to extinction for each rat under the training conditions that arranged either a 120-s or a 240-s blackout between components. This index is calculated by first determining the slope of the across-session extinction plot for each of the two discriminative stimuli (by least squares fits to the logarithms of the response rates)—that is, for the plots such as shown in Figures 2 and 3. Then a ratio of these slopes is formed (slope for signal of pellets alone/slope for signal of pellets + milk). The third and fourth columns show the logarithm of this ratio. Positive values indicate that lever pressing was more resistant to extinction in the presence of the signal of pellets (VI) plus milk (VT). Negative values indicate that lever pressing was more resistant to extinction in the presence of the signal of pellets (VI) only. Baseline values were means over the last five baseline sessions. For the numbers in the third column, the baseline response rate for the signal of pellets plus milk were taken from components in which milk could have been (and usually was) delivered. For the numbers in the fourth column, the baseline response rates for the signal of pellets plus milk were taken from the control components (intervals during which the signal of pellets plus milk was present but during which no milk deliveries could occur).

Rat	Blackout duration during training (s)	Slope ratio using baseline with milk delivery	Slope ratio using baseline with control component
A1	120	0.43	0.34
A2	120	0.17	0.10
A3	120	0.29	0.21
A4	120	0.16	0.08
B1	120	0.47	
B2	120	0.13	
B3	120	0.57	
B4	120	0.03	
B1	240	0.35	
B2	240	0.23	
B3	240	0.24	
B4	240	0.20	
C1	120	0.22	0.15
C2	120	0.15	0.11
C3	120	0.47	0.37
C4	120	−0.13	−0.19
C1	240	0.49	0.38
C2	240	0.28	0.22
C3	240	0.32	0.18
C4	240	0.18	0.11

(Table 4). This was true regardless of whether the baseline response rates for the signal of pellets plus milk were estimated from the control component or from the stimulus during which milk was presented.

Obtained Rates of Pellet and Milk Deliveries

Because of the way the VI and VT schedules were arranged (a constant probability of reinforcement assignment at the end of each consecutive 3-s unit during the discriminative stimuli), sampling variability could have produced rates of reinforcement that were quite different from the scheduled rates. It would be particularly troublesome if the rate of pellets had turned out to be higher in the presence of the signal of pellets plus milk than in the presence of the signal of pellets only. It would then be hard to determine whether the greater persistence in the presence of the signal of pellets plus milk was due to the presentations of milk or to the inadvertently higher rate of pellets. Table 5 lists the obtained rates of pellet and milk deliveries for the baseline conditions that included blackouts between components. There were no systematic differences in the rate of reinforcement between the two discriminative stimuli. The small difference that did emerge (13 of the 20 comparisons) favored the signal of pellets only.

An odd result is the high rate of pellets for the rats in Squad C, especially in the presence of the signal of pellets alone. These rates were higher than the intended programmed rates of pellet reinforcement. We suspect that some aspect of the hardware or software changed in the intervening year from the end of the conditions for Squads A and B until the start of the conditions for Squad C so that the same probability settings generated different obtained frequencies. For example, a newer version of the commercial software was installed during this period.

DISCUSSION

Previous research has demonstrated that persistence of a response in the presence of a discriminative stimulus can be enhanced with response-independent reinforcers that are the same as the dependent reinforcers for that response (Nevin, 1992; Nevin & Grace, 2000). It is now apparent that persistence can be enhanced with response-independent reinforcers that are different from the ones maintaining that response. Response-independent milk deliveries during training enhanced the resistance to extinction of pellet-reinforced lever pressing. This is consistent with the interpretation that any reinforcer deliveries that occur in the presence of a stimulus enhance the value of that stimulus, and

Table 5

Obtained rates of pellets and milk deliveries for each rat during the training conditions that included a blackout between components (means over the last five sessions of each condition). In the presence of either discriminative stimulus, food pellets were obtained by lever pressing on a VI 100-s schedule, which should have resulted in an average maximum of 36 pellets per hour. In the presence of the signal of pellets plus milk, a VT 30-s schedule also provided milk deliveries (i.e., the average rate of milk deliveries should have been about 120 per hour). For Rats A1, A3, B1, B3, C1, and C3 the blinking lights signaled the pellets plus milk. For the other rats, the steady lights did so.

Rat	Blackout duration during training (s)	Pellets per hour during pellet-only stimulus	Pellets per hour during pellet + milk stimulus	Milk per hour from VT
A1	120	37	37	128
A2	120	37	27	116
A3	120	31	30	131
A4	120	30	31	131
B1	120	36	34	119
B2	120	39	35	123
B3	120	37	38	118
B4	120	35	34	125
B1	240	32	28	124
B2	240	31	40	120
B3	240	39	37	130
B4	240	36	31	127
C1	120	50	29	124
C2	120	47	39	129
C3	120	40	34	128
C4	120	47	33	151
C1	240	39	45	121
C2	240	40	44	116
C3	240	38	33	121
C4	240	41	49	123

therefore the persistence of the response that occurs in the presence of that stimulus (Grace & Nevin, 1997; Nevin & Grace, 2000).

Pellets and milk are, of course, types of food. As such, their effectiveness as reinforcers is likely to be sensitive to the same kinds of establishing operations (e.g., food deprivation). Thus, although pellets and milk are not the same, they might share a number of functional similarities (i.e., they might be members of a common motivational class, or they might function as partial substitutes; Bickel, Green, & Vuchinich, 1995; Hursh, 1984). Perhaps the results of our study would have been different if the dependent and independent food deliveries had come from different motivational classes.

Our failure to demonstrate differential persistence following the initial, exploratory training conditions may be instructive. In general terms, a failure to demonstrate differential persistence is ambiguous. Such failure might indicate that the variable of interest—the response-independent milk deliveries in

our case—is ineffective. But it could also indicate that the training or testing procedures are not favorable for demonstrating a differential effect because of factors unrelated to the variable of interest. The latter possibility turned out to be true for our work. It took a fairly lengthy sequence of exploratory procedures to arrive at an effective set. But once identified, those procedures proved to be capable of generating differential persistence in favor of the signal of pellets plus milk.

We suspect that our initial failures were due to insufficient size of the milk deliveries and, especially, to poor stimulus control by the status of the lights. We also suspected that imposing the 120-s (or 240-s) blackouts between components encouraged stimulus control and, hence, engendered differential resistance to extinction. This interpretation of the effect of the blackout is speculative, however, because we have no direct measure of stimulus control before and after the introduction of the blackout.

In research on persistence carried out with

pigeons, the development of good control by the discriminative stimuli can usually be taken for granted. Pigeons are thought to be highly "visual" animals. The discriminative stimuli are typically different bright colors projected on the response key. Pigeons are likely predisposed to observe such stimuli, and stimulus control develops rapidly. Rats, in contrast, are thought not to be highly visual animals. They have a relatively large proportion of their cortex devoted to the olfactory modality (as opposed to the visual modality), suggesting a relatively higher dependence on olfaction in exploring their environment (Feldhamer, Drickamer, Vessey, & Merritt, 1999). In our experimental chambers, the relevant visual stimuli were not located on the lever but rather 2.5 cm above it. The rats probably were not predisposed to attend to (i.e., observe) the lights, so special circumstances might have been needed to encourage the prerequisite observing behavior (cf. Dinsmoor, 1983, 1995). This might be the role of the fairly long blackouts.

The effect of response-independent reinforcers on the persistence of behavior in the presence of a discriminative stimulus (and on the value of that stimulus) may have important applied implications (Mace, 1994; Mace et al., 1990; Nevin, 1996). Consider an application to the training of dogs. An important goal of search-and-rescue training, for example, is to have the searching behavior persist in the face of distraction, low-frequency reinforcement, fatigue, and so forth. Because persistence is a priority, it might be advantageous for the handler to provide frequent reinforcers without worrying that every delivery be dependent upon on-task behavior. As long as the reinforcers occur in the presence of the discriminative stimulus for the dog's searching response—perhaps a vest worn by the dog while on duty—it should be possible to present many of the reinforcers independently of any particular response and still enhance the value of that stimulus and, hence, the persistence of the designated response.

The question would still remain as to whether all the reinforcers need be the same type. Could the searching response of a search-and-rescue dog be maintained by dependent food reinforcers and the persistence of that response enhanced by response-independently throwing a ball for the dog to chase? Or, in another applied example, could a teacher maintain a student's on-task behavior by presenting response-dependent gold stars but enhance persistence of that behavior with response-independent verbal praise? Our results move only a small distance toward answering these kinds of questions, but they suggest the answer might be "yes."

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