

*EFFECTS OF SCHEDULES OF REINFORCEMENT ON POUCHED  
RATS' PERFORMANCE IN URBAN SEARCH-AND-RESCUE TRAINING*

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Standard operating procedures have been developed to train *Cricetomys* to locate humans in collapsed structures and return to the release point on command. The present study demonstrated that the schedule of reinforcement for target location influences the rats' performance. Rats required more time to locate targets when no reinforcement was arranged for target location but less time to return to the release point. These findings suggest that training conditions should be based on the priority assigned to target location and return in an operational scenario.

*Key words:* *Cricetomys ansorgei*, *Cricetomys gambianus*, detection animals, extinction, scent detection, schedules of reinforcement, urban search and rescue

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Urban search and rescue (USAR) involves finding, extricating, and medically treating people who have been trapped in collapsed structures. Locating people in rubble poses a major challenge because the paths leading to voids where survivors might be located are often dark, narrow, irregular, and unstable. Many rodents are highly adept at navigating spaces with these characteristics, and preliminary research with giant African pouched rats (*Cricetomys ansorgei*, previously referred to as *Cricetomys gambianus*) that work in a moderately complex search environment indicates that they can be

trained to locate people quickly and reliably and return to the point of release when a "return-to-start" signal is sent (La Londe et al., 2015). *Cricetomys* are nocturnal, burrowing rodents indigenous to sub-Saharan Africa with a highly developed sense of smell. They are used operationally to detect land mines (e.g., Edwards, Cox, Weetjens, Tewelde, & Poling, 2015) and human tuberculosis (e.g., Poling et al., 2011) and are sufficiently large and robust to carry a variety of sensors and equipment, such as cameras, beepers, and GPS receivers, that can aid in confirming the presence and identifying the location of victims in collapsed structures. In an initial investigation, La Londe et al. (2015) found that *Cricetomys* located humans in a simulated collapsed building on 83% of trials. These findings provide proof of principle with respect to the possibility of using pouched rats for USAR.

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The faster that living people trapped under rubble can be located, extricated, and treated, the greater the probability they will survive (Wong & Robinson, 2004). One potentially critical determinant of search speed with *Cricetomys* is the schedule of reinforcement that maintains the search behavior. In an evaluation of the influence of reinforcement schedules on response latency in a lever-pressing task, Stebbins and Lanson (1962) reported that response latency was lowest under variable reinforcement, intermediate under continuous reinforcement, and highest under extinction conditions. In training rats to find people and return to their release point, La Londe et al. (2015) used a variable-ratio 2 schedule of food reinforcement. Although this procedure was effective, there was no evaluation of performance under other schedules. In the present study, rats' search-and-return performance was evaluated under three different conditions: (a) no programmed consequences for target location (i.e., extinction), (b) a variable-ratio 2.5 reinforcement schedule for target location, and (c) a fixed-ratio (FR) 1 (continuous) reinforcement schedule for target location.

## METHOD

### *Subjects, Setting, and Apparatus*

Subjects were four male and five female *Cricetomys* from APOPO's breeding colony that were, on average, 14 months of age. All rats had been exposed to extensive training for search-and-rescue operations as described by La Londe et al. (2015), and five served as subjects in that study. All subjects were maintained in cages with free access to water. Weights were monitored on a weekly basis and maintained within 30 g of target weights (established according to previous performance and health records) by restricting daily access to food. Food restriction was sufficient to serve as an establishing operation for food delivery (described subsequently) as a positive reinforcer. Veterinary checks were conducted weekly, and ethical approval for the experiment was obtained from APOPO's Institutional Animal Care and Use Committee.

The study was conducted in a stable (10 m by 26 m) that was divided into 12 stalls separated by a central walkway. Debris, including bricks, boards, pipes, broken concrete, and broken appliances, was spread throughout the stable. The setting was identical to that described by La Londe et al. (2015). The reinforcer was a mixture of mashed banana, avocado, and ground rat chow squeezed directly into a rat's mouth with a 20-cc syringe. Before daily sessions, the rats were fitted with a harness with a pocket that contained a remotely activated beeper that was activated when food was available at the release point.

### *Procedure*

General aspects of the procedure were comparable to those described by La Londe et al. (2015). Rats were exposed to 10 trials each day. For each trial, the release point for rats and the location of the two human targets, who assumed seated positions within the rubble, were selected at random from lists. Target positions were not visible from the release point or central walkway. Twelve different people served as targets, with the persons selected for each trial chosen at random from those available on that day. The handler at the release point was equipped with a food syringe and a remote control that activated the rat's return-to-start beeper. A data collector was also stationed at the release point and was equipped with a data-collection sheet and two stopwatches. The target humans were equipped with food syringes and instructed to move into position silently and remain silent and motionless during each trial. On each trial, the data collector referenced the data sheet and told the human targets to deliver or withhold food when the rat arrived at the target according to the programmed schedule of reinforcement.

After the human targets were positioned and motionless, the trainer released the rat into the search area and called out for the start of the first timer. When the rat placed both front paws on one of the targets, that target called out to stop

the first timer and, if the trial was a reinforcement trial, delivered food. The target then called out for the start of the beeper and, after its initiation, the data collector started the second timer. When the rat reached the release point and placed both paws on the wall, the handler called out to stop the second timer and delivered food. The data collector then recorded the latency to the target and latency to the release point after initiation of the beeper. If the rat did not arrive at the target within 3 min or return to the release point after initiation of the beeper within 3 min, the data collector called for the handler to retrieve the rat and terminated the trial.

A second observer independently collected data on 18% of sessions. The mean absolute difference between the two observers was 0.71 s ( $SD = 0.47$ ) for search latency and 0.73 s ( $SD = 0.77$ ) for return latency, which indicates high agreement between observers. During 10% of sessions, selected at random, data on procedural integrity were collected using a checklist. These data revealed no deviations from standard operating procedures.

The three conditions, (a) no reinforcement (NR), (b) variable reinforcement (VR), and (c) continuous reinforcement (CR), were implemented in a sequence that was counterbalanced across subjects (i.e., each of the conditions was implemented first for three of the nine subjects). Each condition was implemented once for each subject and was in effect until that rat had been exposed to at least 10 sessions and data were deemed stable based on visual inspection. Table 1 shows the number of sessions per condition for each subject. Under the NR condition, the target never delivered food when the rat reached the target. Under the VR condition, the target delivered food when the rat reached the target on 4 of 10 randomly selected trials. Under the CR condition, the target delivered food each time the rat arrived at the target. Under all conditions, the trainer delivered food when the rat returned to the release point on every trial. Summary data obtained from each subject during the final four

Table 1  
Number of Sessions per Condition per Subject

Rat	NR	VR	CR
Chi Chi	14	10	11
Graca	11	11	10
Marcel	10	16	10
Ram	10	10	14
Ramires	10	12	10
Torres	10	10	10
Talos	12	10	10
Tam	10	11	10
VanP	10	10	10

sessions in each condition were used for data analysis (complete data set available in Supporting Information).

## RESULTS AND DISCUSSION

Figure 1 shows the mean latency to target (top) and mean latency to release point (bottom) for each rat and for the rats as a group under all conditions. In general, similar patterns are evident in the data for individual rats and for the rats as a group. Mean group latency for the final four sessions was 78.82 s ( $SD = 22.03$ ) under the NR condition, 65.51 s ( $SD = 11.80$ ) under the VR condition, and 63.79 s ( $SD = 13.86$ ) under the CR condition. With alpha set at 0.05, a repeated measures ANOVA was conducted to compare the obtained mean latencies across conditions. All assumptions for parametric tests were met for each outcome measure, with one exception. There was a statistically significant effect of reinforcement condition on latency to target,  $F(2, 8) = 6.80$ ,  $p = .007$ ,  $\eta^2$  (generalized eta squared, an omnibus measure of effect size) = 0.16. Post hoc Tukey contrasts revealed a statistically significant difference between NR and VR conditions ( $p = .009$ ) and between NR and CR conditions ( $p = .002$ ) but not between VR and CR conditions ( $p = 1$ ).

The mean group latency to return to the release point was 32.9 s ( $SD = 6.7$ ) under the NR condition, 47.8 s ( $SD = 10.9$ ) under the VR

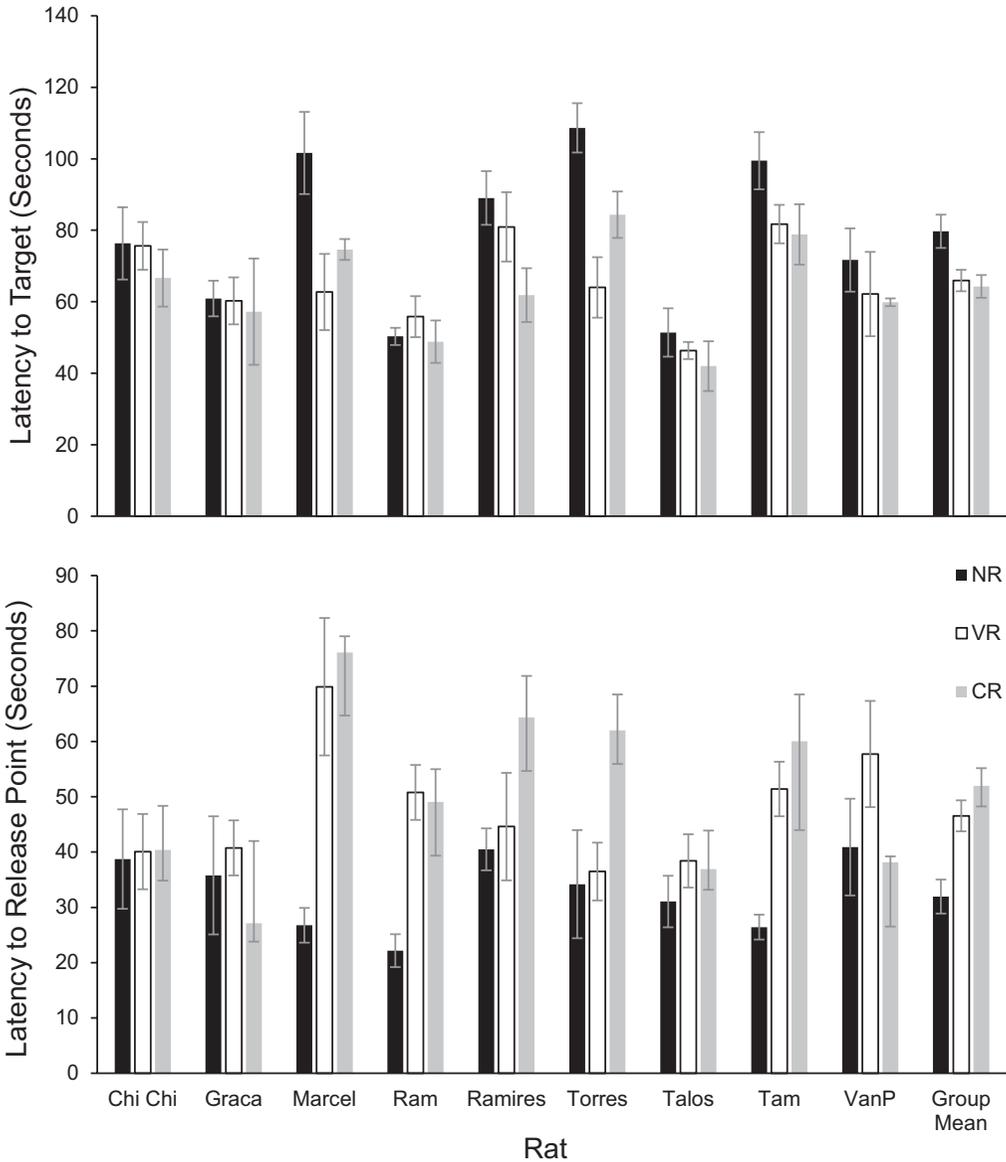


Figure 1. Mean ( $\pm$  SEM) latencies to contact targets (top) and return from targets to release points (bottom) during the final four sessions under no-reinforcement (NR), variable-ratio 2.5 (VR), and continuous-reinforcement (CR) conditions.

condition, and 50.5 s ( $SD = 16.0$ ) under the CR condition. There was a statistically significant effect of reinforcement condition on latency to return,  $F(2, 8) = 6.05$ ,  $p = .011$ ,  $\eta^2 = 0.32$ . Tukey contrasts revealed a statistically significant difference between NR and VR conditions ( $p = .019$ ) and between NR and CR conditions

( $p = .004$ ) but not between VR and CR conditions ( $p = 1$ ).

Total mean search time, or the sum of the mean latency to locate the target and to return to the release point, was 111.76 s ( $SD = 23.45$ ) under the NR condition, 113.30 s ( $SD = 16.36$ ) under the VR condition, and 114.25 s ( $SD = 27.02$ )

under the CR condition. Reinforcement condition did not significantly affect this measure,  $F(2, 8) = 0.08$ ,  $p = .921$ ,  $\eta^2 = 0.002$ .

The mean percentage of trials in which the target was located within 3 min was 89% ( $SD = 7.8\%$ ) under the NR condition, 97% ( $SD = 3.6\%$ ) under the VR condition, and 97% ( $SD = 3.8\%$ ) under the CR condition. There was a statistically significant effect of reinforcement condition on the percentage of trials in which the target was located within 3 min,  $F(2, 8) = 7.70$ ,  $p = .005$ ,  $\eta^2 = 0.35$ . Tukey contrasts revealed a statistically significant difference between NR and VR conditions ( $p < .001$ ) and between NR and CR conditions ( $p = .001$ ), but not between VR and CR conditions ( $p = 1$ ).

The mean percentage of trials in which the rats returned to the release point within 3 min of initiation of the return-to-start signal was 100% ( $SD = 0.7\%$ ) under the NR condition, 98% ( $SD = 4.7\%$ ) under the VR condition, and 98% ( $SD = 3.8\%$ ) under the CR condition. These data were not normally distributed because of a ceiling effect (Shapiro-Wilk  $W = 0.51$ ,  $p < .001$ ); therefore, they were analyzed using the Friedman test. Reinforcement condition did not significantly affect this measure,  $\chi^2(2) = 3.0$ ,  $p = .223$ .

The present findings demonstrate that the reinforcement schedule arranged by human targets affects some aspects of the performance of pouched rats being trained to find these targets and to return to their release point after hearing a signal. Specifically, rats found targets faster and located targets within 3 min on a higher percentage of trials when trainers arranged variable-ratio 2.5 or FR 1 schedules when compared to extinction. In contrast, rats returned to their release points fastest when trainers arranged extinction for finding targets, although they located significantly fewer targets within 3 min. It is likely that these findings are a product of the availability of food contingent on target location under VR and FR conditions.

Under the NR condition, food was available only at the release point. The schedule of reinforcement had no effect on their overall search time, indicating that the reductions in latency to the target obtained in the reinforcement conditions were offset by increases in latency to return to the release point. Had we tested a larger ratio for the VR condition, differences between CR and VR conditions may have been more pronounced. The value of 2.5 was selected because it was similar to, but slightly larger than, the value used in the previous evaluation.

Based on the present findings, USAR training protocols for *Cricetomys* should be adjusted according to the priorities of targeted operational scenarios. Reinforcement at the target cannot be arranged during operational search. However, if the expedient return of the animal after initiation of the return-to-start signal is the highest priority, as when the plan is to deploy the rats for a short time immediately before machinery is used to remove rubble, then a training protocol with no food reinforcement for successful location of targets should be employed before operational deployment, even though that procedure might slightly reduce the probability of targets being located. Although combined search and return times were not found to differ among the three conditions, rapid retrieval of the rat at initiation of the signal would be beneficial under these circumstances. If, on the other hand, timely arrival at the victim with maximum detection accuracy was the highest priority, as when the rats are used in a situation in which a live signal from the search camera can be obtained, then a training protocol with food reinforcement for location of targets would be better. It is, of course, essential to demonstrate that the present findings can be replicated under conditions in which the rats work for longer periods with fewer targets and to show that the effects of the training schedule are practically as well as statistically significant. The results of the present translational study are of value in suggesting that this is likely to be the case.

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