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A COMPUTER TOUCH-SCREEN APPARATUS FOR TRAINING VISUAL DISCRIMINATIONS IN RATS

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We describe an operant conditioning apparatus that uses computerized touch-screen technology and is designed for the versatile and highly controlled testing of rats in a potentially wide variety of behavioral paradigms. Although computer-controlled touch-screen systems have been developed for use with pigeons, monkeys, and humans, analogous technologies and methods have not yet been developed for rats. The development of a touch-screen system for rats could enhance the efficiency of behavioral research with rats, and may offer a unique tool for studying animal learning. In the first test of the utility of the apparatus, 3 Sprague-Dawley rats learned to activate the touch screen only after the touch-screen panel was made slightly movable. These animals then learned to discriminate visual stimuli presented on the computer monitor, but only after the food magazine and pellet dispenser were moved to the rear of the chamber opposite the stimulus display and response window. In a test of the utility of the modified apparatus, 6 Long-Evans rats learned to activate the touch screen and learned one of three different simple discriminations using computer-generated, visually presented stimuli. A basic method for training rats to activate the computer touch screen and for visual discrimination training is described. Results show that rats learned to activate the touch screen and discriminate visual stimuli presented on a computer monitor. Potential applications and advantages of the touch-screen-equipped rat operant conditioning chamber are discussed.

Key words: visual discrimination, computer images, touch screen, rats

The purpose of this report is to describe our application of computer touch-screen technology to the study of operant conditioning in rats. Although computer controlled touch-screen systems have been used to study the behavior of pigeons (Blough, 1986; Spetch, Cheng, & Mondloch, 1992), monkeys (e.g., Bhatt & Wright, 1992; Murray, Gaffan, & Mishkin, 1993), and humans (e.g., Lynch & Green, 1991), to date no published reports have described analogous technologies and methods for use with rats.

Many advantages are provided by computerized touch-screen systems that are not afforded by more conventional operant conditioning equipment. For example, using computerized systems, visual stimuli can be located continuously across the screen, rather than only in fixed locations. Also, by using touch-screen technology, the precise temporal and spatial location of responses can be recorded. Enhanced flexibility of stimulus presentation and increased precision of response registration allowed by computerized touch-screen technology have been recently demonstrated in behavioral research studying spatial memory in pigeons (Spetch et al., 1992).

Another important advantage offered by computer technology is that a virtually unlimited number of visual stimuli can be generated and presented on the video monitor (Morrison & Brown, 1990). The ability to present a large number of training stimuli has been credited by Wright, Cook, Rivera, Sands, and Delius (1988) as a determining factor in demonstrating generalized matching-to-sample performances in pigeons. When only a few different stimuli were used, pigeons performed poorly with novel stimuli in a matching-to-sample task, but with an expanded stimulus set, pigeons clearly showed evidence of concept learning in this computerized operant task (Wright et al., 1988). Finally, the development of a touch-screen conditioning system for rats would allow

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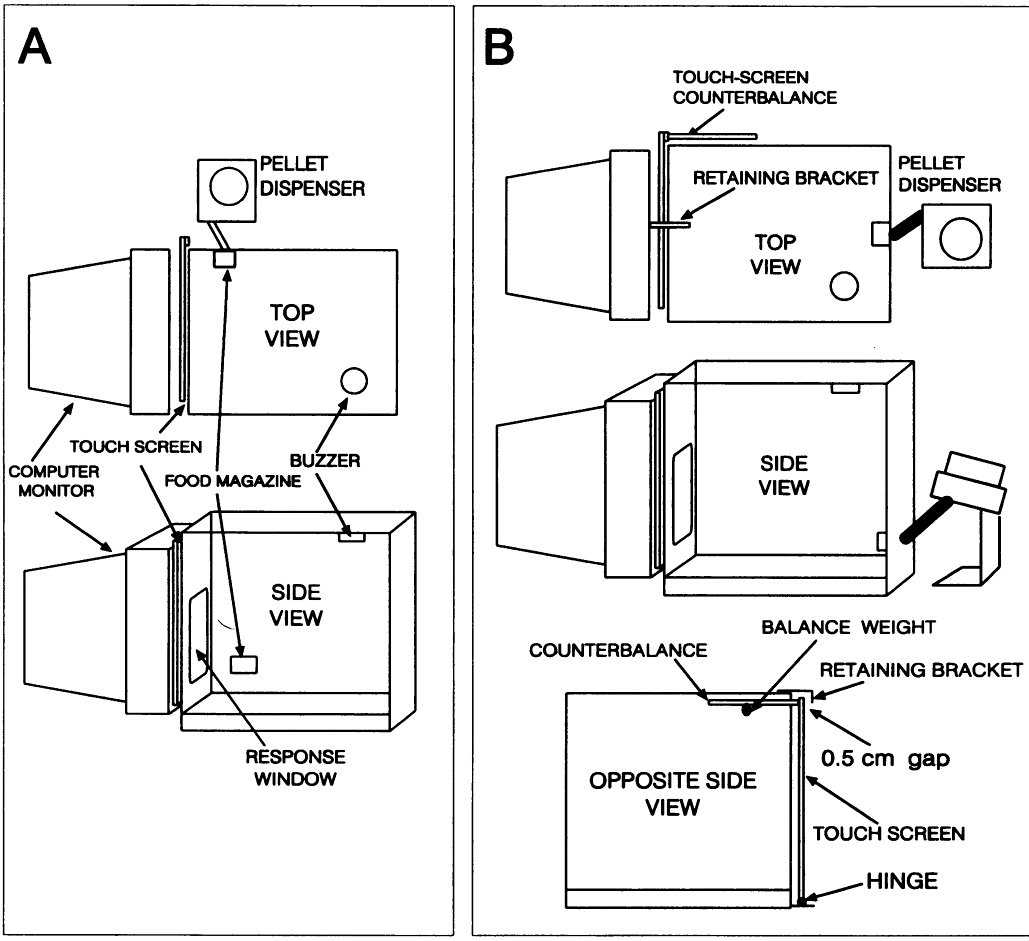

Fig. 1. Panel A: initial design of the touch-screen chamber used in Experiment 1. Panel B: design of the touch-screen chamber after modifications made during Experiment 1. This design was used throughout Experiment 2.

cross-species comparisons of performance in identical tasks. Currently, rats are excluded from direct comparison with other species (e.g., pigeons, monkeys, humans) that have been tested in touch-screen paradigms.

We modified a conventional operant conditioning chamber by fitting it with a computer monitor for presenting stimuli and a resistive membrane touch-sensitive screen for detecting responses. The apparatus and procedures described here were refined and developed through the course of considerable pilot research. During initial tests of the utility of the apparatus, we were unable to train rats to activate the touch screen and discriminate visual stimuli. These failures revealed the necessity of some unique modifications to the apparatus. Specifically, making the touch-screen panel slightly movable, rather than firmly fixed, greatly facilitated training animals to activate the touch screen. Second, rats successfully discriminated visual stimuli only when the food magazine was moved from a position near the stimulus display to the back wall of the chamber, opposite the stimulus display. After making these modifications, we conducted a second experiment to confirm the utility of the modified apparatus for training rats to discriminate visual stimuli.

DESIGN OF THE TOUCH-SCREEN CHAMBER

The touch-screen chamber (see Figure 1A) was built by modifying a standard operant conditioning chamber. The chamber measured 30.5 cm by 24 cm by 27 cm. The left and right walls and chamber ceiling were Plexiglas (6 mm thick). The left wall was hinged to provide access to the chamber. The front and rear walls were stainless steel, and the floor was constructed of steel rods (5 mm diameter) spaced horizontally 1.5 cm apart. A rectangular response window (16 cm by 12.5 cm), located 2 cm from the floor, was cut into the front panel of the chamber, replacing the original response lever and visual stimuli.

An Edmark Touchwindow® resistive membrane touch screen (cost: $335.00) was mounted behind the front panel, filling the response window. A force of 0.2 N was necessary to activate the touch screen. Initially, the touch screen was firmly attached to the chamber. During Experiment 1, the touch screen was hinged to allow some movement (see Figure 1B). The touch screen was hinged at its base and counterbalanced at the top so that it rested against the response window and so that pressure (greater than 0.05 N) against the touch screen would cause it to deflect outward (i.e., away from the chamber) 0.5 cm at the top. The touch screen was covered with a sheet of transparent Mylar (2 mil) to protect the it from damage caused by animals' scratching. An amber monochrome monitor (30 cm) was placed directly behind the touch screen. A piezo buzzer (20 kHz) was mounted on the ceiling of the chamber 3 cm from the hinged Plexiglas wall and 2.5 cm from the rear wall. A food magazine (6.5 cm by 3.5 cm by 3 cm) was initially mounted on the right wall 1 cm above the grid floor and 3 cm from the front wall. During Experiment 1, the food magazine was moved to the rear chamber wall, 1 cm above the grid floor and centered on the rear wall (see Figure 1B). Noyes food pellets (45 mg) were delivered by an automated Gerbrands pellet dispenser located outside the chamber.

The touch-screen chamber and computer monitor were housed inside a custom-constructed sound- and light-attenuating enclosure (1.25 m by 0.45 m by 0.45 m). This enclosure was constructed of particle board (1.9 cm thick) and had one wall hinged at the bottom to allow access to the touch-screen chamber. The interior of the enclosure was lined with polystyrene insulation (2.5 cm thick) to provide sound attenuation. A small fan mounted on the side of the enclosure provided ventilation and masking noise.

An IBM®-compatible computer equipped with a monochrome graphics adapter presented stimuli on the monitor, controlled stimulus and food presentation in the chamber, and recorded data. The computer was located outside the sound-attenuating enclosure and controlled pellet dispenser and piezo buzzer operation inside the chamber using a custom-constructed control interface (Markham, 1993).

EXPERIMENT 1: INITIAL TEST OF THE TOUCH-SCREEN CHAMBER

Subjects and Apparatus

Subjects were 3 albino Sprague-Dawley rats housed individually in hanging cages under a 12:12 hr light/dark cycle with free access to water. Animals were food deprived for 24 hr before the first session, and were thereafter maintained at 90% of their free-feeding weights. Animals were approximately 120 days old and weighed about 250 g at the beginning of the experiment. One touch-screen conditioning chamber (described above) was used in this experiment.

Procedure and Results

Experimental sessions were conducted daily. Sessions were 45 min in duration. Each session began when the animal was placed in the chamber. The chambers were cleaned using a damp sponge at the end of each day.

Phase 1: Screen-press shaping. Each animal was placed in a chamber with the entire response window illuminated amber by the computer monitor. The experimenter controlled delivery of food pellets during these sessions. Successive approximations to screen presses (pressing with enough force to activate the touch screen) resulted in the delivery of one food pellet. Cumulative screen presses are shown in Figure 2. After 16 sessions without any increase in the rate of screen presses, we modified the apparatus to make the touch-screen panel movable (see Figure 1B). Following this modification, all animals rapidly acquired the screen-press response (see Figure 2).

Phase 2: Training simultaneous visual discrim-

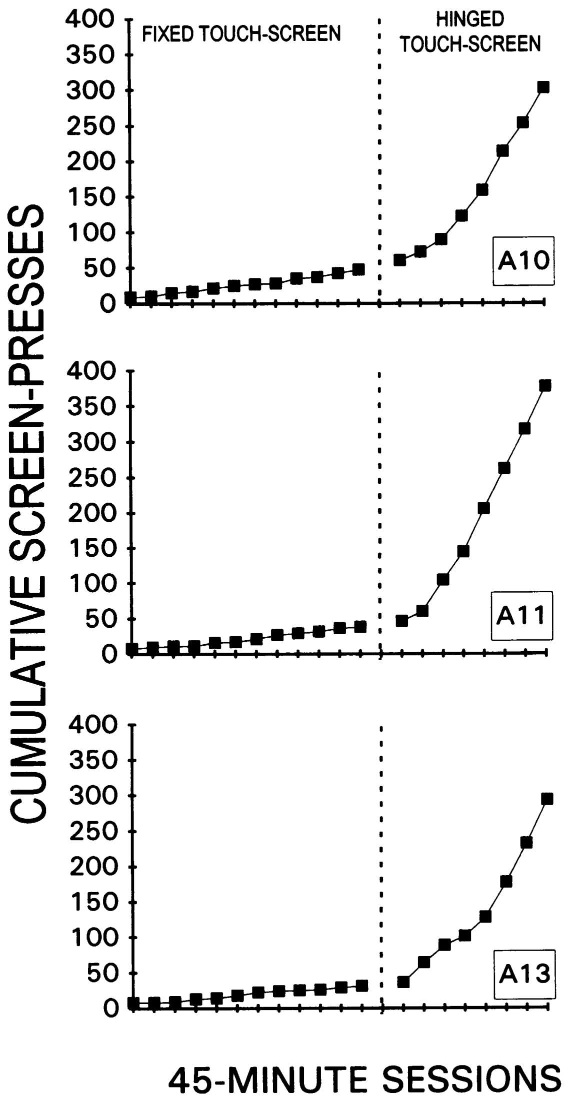

Fig. 2. Cumulative screen presses over successive sessions for all animals in Phase 1 of Experiment 1. The vertical dashed lines indicate when the touch screen was hinged.

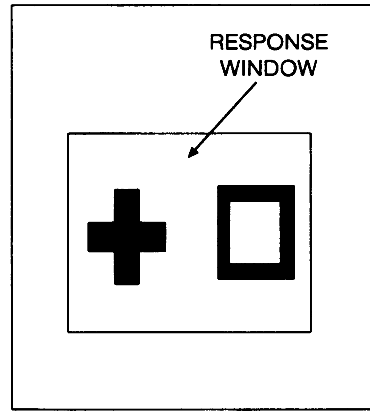

Fig. 3. Sample stimulus display from Phase 2, Experiment 1. All animals were presented with the same two visual stimuli shown here.

inations. After shaping the screen-press response, animals were trained to respond differentially to two visual stimuli. Stimuli were two geometric figures (11 cm high by 8 cm wide) equal in lighted screen area and presented on the computer monitor (see Figure 3).

On each trial the two stimuli were presented at the left and right sides of the response window. Stimuli were pseudorandomly assigned to the left and right screen positions on each trial. The screen cleared after the animal pressed either stimulus. Presses on the correct stimulus resulted in the delivery of a food pellet. Presses on the incorrect stimulus resulted in a 500-ms tone. When animals pressed the incorrect stimulus, the trial was repeated until the animal responded correctly. The intertrial interval (ITI) was 3 s for all trials. Each session consisted of 80 trials. Repeated presentations of trials following incorrect responses were not counted toward the 80-trial session limit.

Data from Phase 2 are shown in Figure 4. After nine sessions, all animals were still responding at chance (50% or below) accuracy. In light of reports by Dean (1981) and Green, Powers, and Banks (1980), whose assessments of rats' visual acuity indicated that rats should be at least 20 cm from visual stimuli to achieve accurate visual discrimination, we reasoned that increasing the animals' distance from the video screen at the beginning of trials might improve performance. Accordingly, after Session 9, the chamber was modified by moving the food magazine and pellet dispenser so that pellets were delivered at the center of the rear chamber wall (see Figure 1B). This change was made so that the animal would be at the rear of the chamber when each new trial was presented. The performance of Animal A10 rapidly improved after the food magazine was moved, but did not improve beyond 70% accuracy after 14 sessions. After Session 9, the performance of Animal A11 improved to slightly better than

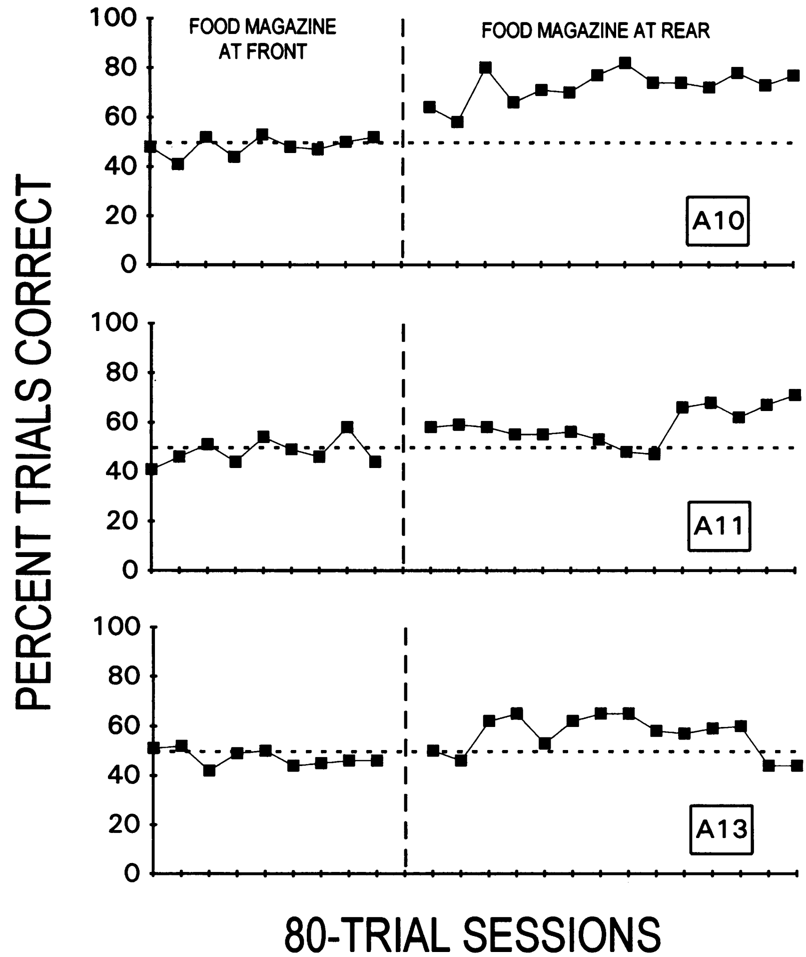

Fig. 4. Percentage of correct responses over successive 80-trial sessions for each animal in Phase 2 of Experiment 1. Horizontal dashed lines indicate 50% accuracy (chance performance). Vertical dashed lines indicate when the food magazine was moved to the rear of the chamber.

chance performance, and improved to approximately 65% only during the last five sessions. Animal A13 responded at chance accuracy during Sessions 10 and 11 then responded at or near 60% accuracy for the remainder of the experiment.

The results of this procedure indicate that the rats did discriminate visual stimuli using an operant conditioning chamber equipped with a touch screen. However, the terminal performance of Animals A11 and A13 was relatively poor and inconsistent. Several factors, including the protracted shaping procedure, changes in the apparatus during the procedure, and the fact that albino rats' visual acuity is worse than that of pigmented rats (e.g., Birch & Jacobs, 1979), may have contributed to these results. We therefore conducted an additional test to assess the utility of the modified touch-screen chamber.

EXPERIMENT 2: TEST OF THE MODIFIED TOUCH-SCREEN CHAMBER

Subjects and Apparatus

Subjects were 6 Long-Evans hooded rats housed and maintained as described in Experiment 1. Four touch-screen chambers, described and modified as described above (see Figure 1B), were used.

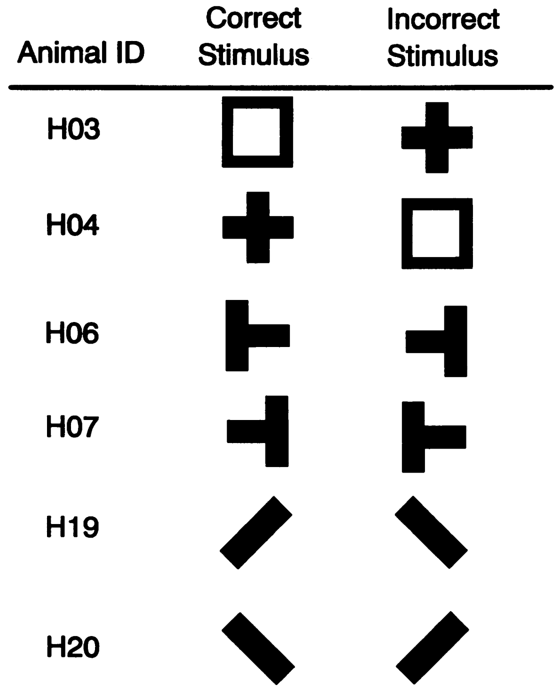

Fig. 5. Stimuli used in Phase 5, Experiment 2.

Procedure

Experimental sessions 45 to 90 min in duration were conducted daily. Sessions began when the animal was placed in the chamber. All trials in this experiment did not end until the animal made a response.

Phase 1: Magazine training and screen-press training. During magazine and screen-press training, each animal was placed in a chamber with the entire response window illuminated amber by the computer monitor. Food pellets were delivered on a variable-time (VT) 45- to 60-s schedule (i.e., one food pellet was delivered every 45 s to 60 s) for a period of 45 min. During these sessions, a pellet was delivered if the rat pressed the touchscreen with enough force to activate the touch screen. After an animal had activated the touch screen eight times during a session or after 30 pellets had been delivered according to the VT schedule, food pellets were delivered only when the animal activated the touch screen. Phase 1 continued until the animal made 30 screen-press responses in one session.

Phase 2: Screen-press training. Phase 2 proceeded as Phase 1. except that food pellets were delivered only when the animal activated the touch screen. Responses during the 10-s ITI had no programmed consequences. Phase 2 continued for two sessions or until the animal made 30 screen-press responses in one session. Animals that completed two sessions without making 30 responses in either session were returned to Phase 1.

Phases 3 and 4: Split-screen training. Phases 3 and 4 trained the animal to press a lighted rectangle that filled the left or right half of the response window. The side of the window that was illuminated was pseudorandomly determined for each trial. Presses on the lighted half of the response window ended the trial and resulted in the delivery of a food pellet followed by a 10-s ITI. During Phase 3, screen presses on the unlighted half of the screen had no effect. During Phase 4, presses on the unlighted half of the screen ended the trial and resulted in a 500-ms tone. Phase 3 continued until the animal pressed the lighted half of the screen 20 times in one session. Phase 4 continued until the animal pressed the lighted half of the screen on 20 consecutive trials without pressing the unlighted half of the screen.

Phase 5: Concurrent visual discrimination training. Animals were then trained to respond differentially to two visual stimuli. Stimuli were three pairs of geometric figures (11 cm high by 8 cm wide) presented on the computer monitor (see Figure 5). Stimuli in each pair were equal in lighted area. Two animals were trained to discriminate each pair of stimuli (see Figure 5).

Trials began with the simultaneous presentation of two stimuli at the left and right sides of the response window. Assignment of stimuli to the left and right positions was pseudorandomly determined. The screen cleared after the animal pressed either stimulus. Presses on the correct stimulus resulted in the delivery of a food pellet. Presses on the incorrect stimulus resulted in a 500-ms tone and the trial was repeated. The ITI was 3 s for all trials. Each session consisted of 80 trials. Repeated presentations of trials following incorrect responses were not counted toward the 80-trial limit for each session.

Phase 5 continued until animals reached a criterion of two consecutive sessions at or

Table 1

Progression of each animal through Phases 1 through 4 of Experiment 2. Numbers indicate the experimental phase the animal experienced during the session. Numbers in parentheses indicate the number of screen presses emitted in Phase 1 and Phase 2 sessions.

Animal	Session 1	2	3	4	5	6	7	8	9
H03	1 (2)	1 (7)	1 (49)	2 (9)	2 (84)	3	4		
H04	1 (5)	1 (62)	2 (51)	3	4	4	4	4	
H06	1 (3)	1 (2)	2 (3)	2 (0)	1 (32)	2 (81)	3	4	4
H07	1 (6)	1 (38)	2 (52)	3	4				
H19	1 (33)	2 (9)	2 (2)	1 (48)	2 (46)	3	4	4	
H20	1 (49)	2 (20)	2 (70)	3	4	4	4	4	

above 90% accuracy. Phase 5 testing was further constrained by the requirement that testing occurred for at least 10 sessions but no more than 25 sessions.

Results

Phases 1 through 4. During screen-press training, 2 animals (H04 and H19) pressed the touch screen with both their snouts and forepaws, and all other animals used only their snouts to activate the touch screen. All animals completed Phases 1 through 4 within nine sessions. Table 1 shows the progress of each animal through the first four experimental phases. Only H06 and H19 required a return from Phase 2 to Phase 1.

Phase 5. Percentage of trials correct for each animal in each session was calculated by considering only the first presentation of each trial (repeated trials resulting from the correction procedure were not considered in this measure). Individual-subject data for all 6 animals are shown in Figure 6. H04, H19, and H20 met the criterion of two consecutive sessions at or above 90% accuracy in 11, 6, and 8 sessions, respectively. H03, H06, and H07 did not meet the performance criterion during the experiment. However, these animals did reach levels of accuracy above 80% during the experiment. All animals acquired and maintained visual discriminations at levels of accuracy not lower than 80%.

Figure 7 presents the within-session performance for each animal during the last session of the experiment. Overall, the within-session performance of all animals was consistent during the final session. However, the performance of H03, H04, H06, and H20 improved slightly during the session.

GENERAL DISCUSSION

In this report we describe the construction and use of a computerized touch-screen-equipped operant conditioning chamber designed specifically for use with rats. Two experiments were conducted to assess the utility of this apparatus in training rats to discriminate computer-generated visual stimuli. In Experiment 1, an initial failure to shape screen presses was solved by hinging the touch screen. An initial failure to train visual discriminations was solved by moving the food magazine to the rear of the chamber. After making these changes in Experiment 1, rats learned to activate the touch screen and discriminated computer-presented visual stimuli, although at only moderate levels of accuracy.

In Experiment 2, using the modified apparatus, we trained rats to activate the computer touch screen and discriminate visual stimuli. With the touch screen hinged to allow some movement, free-operant acquisition procedures were effective in training rats to activate the touch screen. Thus, a movable response mechanism, analogous to the typical operant response lever, appears to facilitate the development of responding using the touch-screen device. The facilitative role of response-produced feedback in operant conditioning is well documented (Mackintosh, 1974) and appeared to influence operant responding in the current situation.

Following training of screen presses in Experiment 2, animals were trained to discriminate computer-generated, visually presented stimuli. Observations made during discrimination training showed that rats pressed the

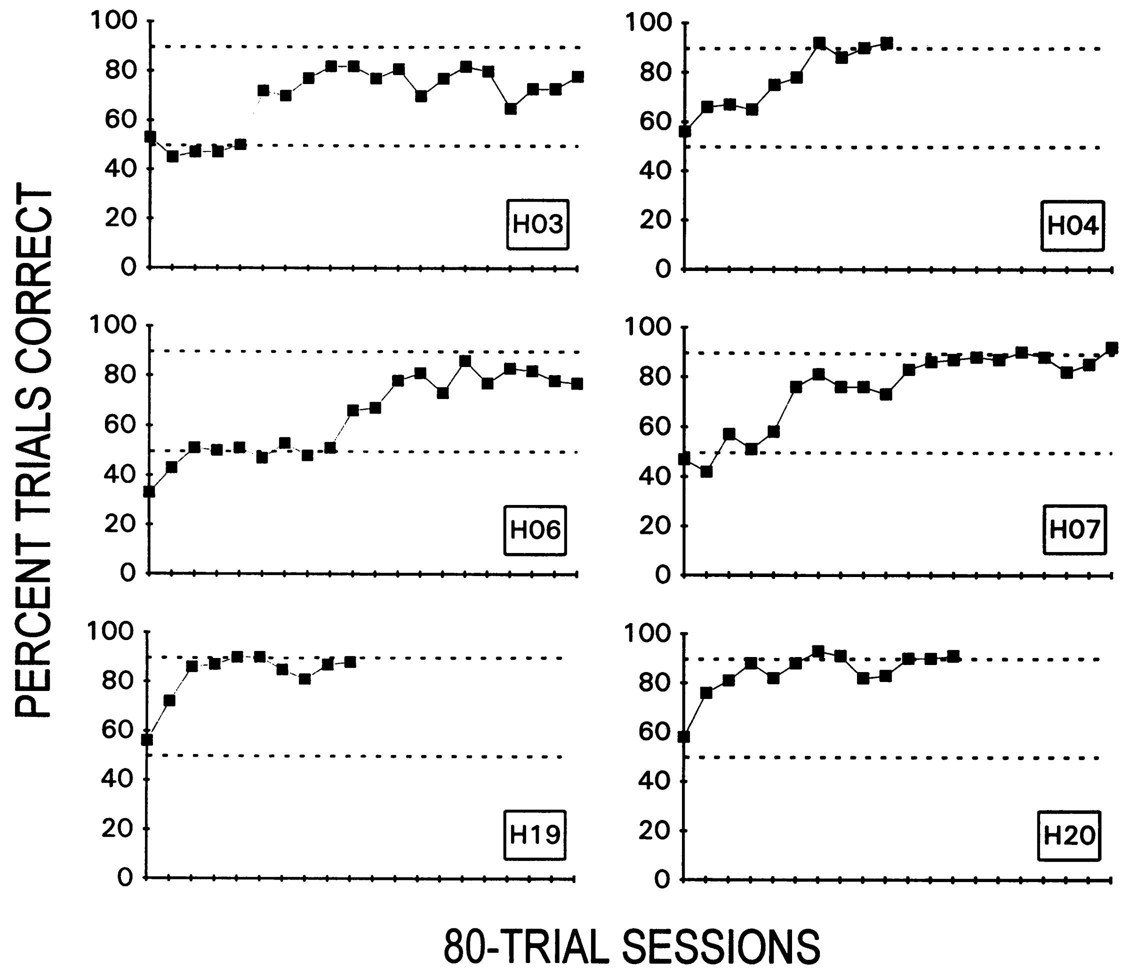

Fig. 6. Percentage of correct responses over successive 80-trial sessions for each animal in Phase 5 of Experiment 2. Horizontal dashed lines indicate 50% accuracy (chance performance) and 90% accuracy (performance criterion for Phase 5).

stimuli with their snouts. Furthermore, accurate visual discrimination performance was obtained in all animals; performance levels exceeded 80% correct in all animals, regardless of which of three specific stimulus pairs were presented. These results demonstrate the utility of the touch-screen system in studying operant conditioning in rats and indicate that rats discriminated among several computer-generated visual stimuli presented on a computer monitor.

Although animals discriminated the stimuli in each stimulus pair, certain pairs appeared to be more readily discriminable than others. In particular, animals presented with the stimulus pair consisting of opposing, diagonally oriented rectangles (see Figure 3; H19 and H20) acquired the visual discrimination more quickly than did the animals presented with other more visually complex stimuli (see Figure 3; H03, H04, H06, and H07). Differential ease of discriminability, therefore, should be considered when using different computer-generated visual stimuli in discrimination paradigms. This distinction may be of practical value in future studies in which a research goal might be to manipulate task difficulty (i.e., ease of discriminability) without directly manipulating other task parameters.

The potential range of behavioral research paradigms that the touch-screen system might support is substantial. Based on results from

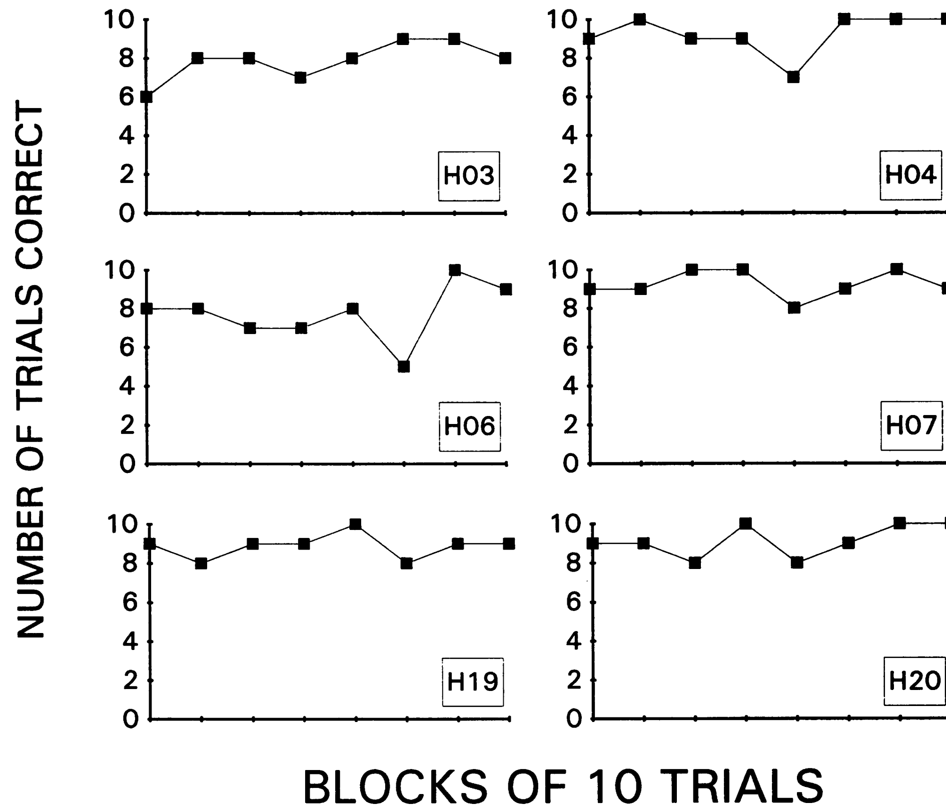

Fig. 7. Within-session performance for all animals during the final session of Experiment 2. These graphs show number of trials correct over successive blocks of 10 trials during the final experimental session.

the current study of visual discrimination learning, we suggest that the touch-screen system described here might provide a versatile and efficient means of exploring learning in rats. Many operant conditioning paradigms (e.g., discrimination reversal, conditional discrimination, delayed nonmatching to position, transverse patterning discrimination, and negative patterning) could be adapted for use in the touch-screen system. For example, the apparatus described here may be of considerable utility in automation of the delayed nonmatching-to-sample paradigm, which is recognized as an important behavioral measure in experimental models of anterograde amnesia in humans, monkeys, and rats (Aggleton, Shaw, & Gaffan, 1992). The ability to demonstrate nonmatching to sample or other concept learning often depends on the presentation of a large number of nonrecurring exemplars; this dependency has been observed in pigeons (Wright et al., 1988), monkeys (Wright, Santiago, Urcuioli, & Sands, 1984), humans (Homa, Sterling, & Treple, 1981), and rats (Aggleton, 1985). Testing rats in an image-based nonmatching-to-sample paradigm offers certain practical advantages over the use of conventional, object-based nonmatching-to-sample paradigms (e.g., Aggleton, 1985). A practically unlimited number of different stimuli can be generated and presented using the touch-screen system, and the potential rate of stimulus presentation is far greater than in the conventional apparatus.

In addition, based on data from experiments using pigeons (Blough, 1986; Pisacreta & Rilling, 1987; Spetch et al., 1992), it may be possible to automate certain paradigms used for testing spatial learning in rats (e.g., Morris water maze). By developing touch-screen paradigms for rats that are analogous to those currently used to study human, primate, and avian behavior, cross-species comparisons using nearly identical tasks would be possible.

The potential contributions of the touchscreen system to the study of animal behavior and to the discipline of behavioral neuroscience are considerable and warrant further experimentation. Further research, of course, will likely lead to improvements in the apparatus and methodology described here.

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