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Touchscreen-enhanced visual learning in rats

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The efficiency of traditional levers and of modern touchscreen technology for training rats on a computerized visual discrimination was studied in a series of observations. When compared with a lever-based discrimination procedure, the use of touchscreens supported the faster development of signal tracking behavior and acquisition of a two-stimulus simultaneous visual discrimination. It did not affect the final level of accuracy. Factors related to spatial proximity of the responses with the stimuli, sign-tracking, and increased ease of touchscreen motor responses were suggested as possible reasons for the touchscreen training advantage. This increased efficiency allows large numbers of animals to be tested quickly, a necessary requirement for studies involving genetic and physiological interventions.

Over the last decade or so, the use of computer-presented stimuli and touchscreens for the measurement of stimulus-controlled behavior has dramatically increased in psychology laboratories, especially in the testing of pigeons (e.g., Blough, 1986; Cook, 1992), primates (e.g., Bhatt & Wright, 1992), and humans (e.g., Huguenin, 2000). Computer-controlled testing chambers are highly attractive because of their flexibility in stimulus creation and presentation and their increased precision in measuring behavior (Allan, 1992; Blough, 1986; Morrison & Brown, 1990; Pisacreta & Rilling, 1987). The increased use of touchscreens has also been driven by the implicit assumption that these techniques more readily promote learning in comparison with the use of traditional pecking keys or response levers. For instance, the touchscreen permits the animal to respond directly toward the stimulus, rather than by pressing a lever that is spatially separated from the stimulus. As a consequence, learning and responding by animals in general may benefit from increased salience of the stimulus-reinforcer relations produced by this type of directed action (e.g., Burns & Domjan, 2000; Hearst & Jenkins, 1974; Killeen, 2003; Leslie, Boakes, Linaza, & Ridgers, 1979; Purdy, Roberts, & Garcia, 1999; Reilly & Grutzmacher, 2002).

Unfortunately, there has been little empirical evidence to support this "touchscreen superiority" assumption. At best, personal experiences and observations with touchscreen-based testing have been indirectly compared with the use of more traditional response devices. Given this situation, the present paper has three goals. First, we report empirical data collected from rats that directly support the touchscreen superiority assumption. Second, we describe in detail the touchscreen-based visual testing apparatus used in testing the rats. Third, we offer some theoretical speculations on the origins of the increased effectiveness of touchscreen-based responding.

Although the development and dissemination of touchscreen technology for behaviorally testing pigeons and primates has proceeded rapidly, the adaptation of this technology for testing rats has lagged behind, with only a handful of reports published since it was first suggested (Bussey, Muir, & Robbins, 1994). For instance, Markham, Butt, and Dougher (1996) and Bussey, Muir, Everitt, and Robbins (1997) reported that touchscreen technology can be used to teach rats a variety of simple visual discriminations, but they conducted no direct comparison with more traditional lever-based approaches. Our procedural comparison of traditional levers and touchscreen technology grew out of our efforts to create a highly automated situation for rapidly training visual discriminations in rats. In our specific case, we were interested in using rats to test for gene-mediated neural potentiation of learning. Because this type of work requires one to test a large number of animals in a large number of control conditions, we needed an easy-to-learn and standardized testing procedure. As we developed our research program, we first employed traditional levers in our training protocols, but we then switched to touchscreens because of their assumed greater potential. Because the protocols were almost identical except for the change in the response technologies, this allowed us to make an empirical comparison of how they each affected response training and discrimination learning in the rats.

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The training protocols for the lever and touchscreen conditions consisted of three phases: (1) an initial phase during which the rats learned to press a lever for a milk reward; (2) a discrimination training phase during which the rats learned to track a large white circle between the left and right sides of the computer screen used for all stimulus presentations; and (3) the learning of a simultaneous visual discrimination using horizontal and vertical striped stimuli. Here we report that the use of touchscreens supported the faster development of stimulus-controlled tracking behavior and acquisition of the simultaneous visual discrimination. It did not affect the final level of choice accuracy, which was the same for both response conditions. These data thus provide support for the previously assumed advantages of using touchscreen-based technology for testing animals. Because of this advantage, and to encourage researchers to adopt this technology in testing animals, we have included additional details about the construction of the apparatus.

METHOD

Animals

Forty-four 100- to 125-g Long-Evans rats (Charles River) were tested. They were maintained on moderate food deprivation (8 g of rat chow per day), with water available ad lib throughout the experiment. The experiments were approved by the Children's Hospital, Boston IACUC committee.

Apparatus

Twelve operant chambers were used in these experiments. Each chamber was enclosed within a 76-cm box (FIC units, Plas Labs, East Lansing, MI). Each of these boxes was equipped with an overhead fluorescent light and speaker (ENV-223A, MED Associates, St. Albans, VT) located on the rear panel. A ventilation fan provided masking white noise from the adjacent boxes. A computer located outside of the test box was used to control and record experimental events. Each of the touchscreen-equipped chambers was constructed from a clear plastic rat cage (46 × 20 × 24 cm). A touchscreen (IRFP-10.4, originally purchased from Carroll Touch, but now marketed by Elo TouchSystems; see below) was centered on one of the long sides of the cage and placed directly in front of a 14-in. computer monitor set for SVGA mode. A liquid feeder (ENV-110 and ENV-201A, MED Associates) was mounted in the center of the wall opposite the computer screen. In addition, a lever (ENV-110, MED Associates) could be mounted underneath either the touchscreen or the feeder (see training procedure). The lever-equipped testing chambers were identical to the chambers described above, except that levers located on the right and left sides of each chamber, separated by 13.75 cm, replaced the touchscreen for recording the animal's discriminative responses.

Figure 1 shows a picture of one of the touchscreen-equipped chambers. The touchscreen was mounted on a 31 × 28.6 cm frame of .2-cm thick aluminum. A 24 × 17.2 cm rectangular cutout was removed from the middle of this frame, and the touchscreen was attached using the holes provided on the plastic mounting of the touchscreen. To make space for a lever at the bottom of the frame, a 7 × 1.9 cm area was removed from the center of the bottom (not visible). Two hinges were mounted on the bottom of the frame (National N146-159 V518) and attached to

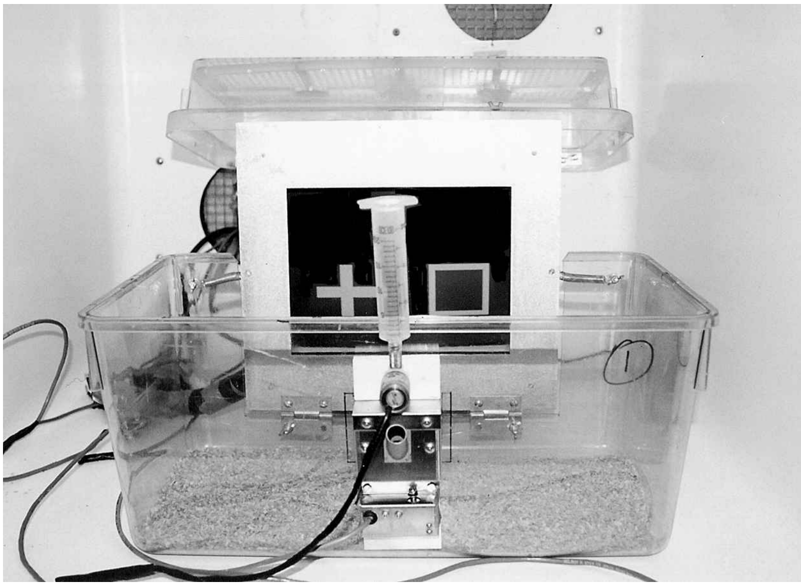

Figure 1. The touchscreen testing chamber used to test the rats in the touchscreen condition.

the front of the chamber. The hinges provided flexibility so that the panel gave slightly when the animal made contact with the touchscreen. To return the touchscreen to its normal position, springs were attached to each side of the frame (Handyman Springs SP-9604) and then attached to the chamber 14 cm from the bottom of the frame. The front wall of the chamber was modified to allow the touchscreen to be flush with the outside wall. A ventilated plastic cover (not shown) was placed over the top of the chamber to prevent the animal from leaving it.

The infrared touchscreen used here is now available from Elo TouchSystems at a cost of $230, http://www.elotouch.com). Device drivers for Windows, DOS, Unix, and OS/2 operating systems are available. Further technical specifications concerning mechanical and electrical details can be found at http://www.elotouch.com/products/cttec/ctspec.asp. A technical drawing is also available at http://www.elotouch.com/pdfs/drawings/ms500277.pdf. The cable connecting the touchscreen to the computer is a standard DB9 serial connection. This cable carries serial data and also supplies 12-V power for the touchscreen itself. The company sells a serial interface card ($90) for connecting the touchscreen to the computer. To save the latter cost, we simply used the serial port standard on most PCs, stripped out the two wires (pins 9 and 5) that supplied the touchscreen's power, and connected them directly to an inexpensive 12-V power supply purchased from Radio Shack. Either way, the user must provide this power, whether by going directly to the touchscreen or through the power connection located on the Elo serial interface card.

Procedures

Initial shaping. Initial shaping consisted of placing each rat in a chamber, with three levers located underneath the feeder on the back wall away from the computer monitor. The rats were tested in 1.5-h sessions until they had responded to the levers more than 60 times over two consecutive sessions. All responses were rewarded with a 1-sec buzzer and 0.1-sec release of 2% lowfat milk from the feeder. During these initial sessions, free food was given once every 5 min, to encourage responding. Following this, the number of levers on the back wall was reduced to one. The rats were tested until they made 600 or more total responses over three sessions. At this point, the single lever was moved to the front wall, opposite the feeder, and the rats were tested until they had performed 100 total responses over two sessions. The rats in the lever procedure then received an additional period of shaping on a partial reinforcement schedule. Over about nine sessions, they were reinforced with milk on a gradually increasing fixed ratio (FR) schedule. This continued until they performed more than 200 responses for two sessions on an FR-3 schedule. During this training, every response was secondarily reinforced with a buzzer. Through experience, we had found that this additional training helped the transition to the next phase for the lever-trained rats. This was not our experience with the touchscreen condition, however, so it was dropped in the interests of efficiency.

Stimulus control training: Touchscreen. The next stage was used to generate stimulus-directed responding to a visual display presented on the computer screen. The first stage involved pseudo-randomly presenting a 7.3-cm white circle on either the left or the right side of the display, with no more than 3 consecutive presentations on one side and counterbalanced over blocks of 20 presentations. Each trial consisted of the circle's being presented for 600 sec or until a response occurred. A response to any portion of the touchscreen while the circle was on was rewarded. Free food was also given every 5 min, to encourage responding. Each session lasted for 120 presentations or 1 h. This initial training continued until the rats made 80 touchscreen responses, at which point all responses were required to be directed at the side with the circle. Responses directed toward the blank side of the screen now resulted in a 3-sec timeout, during which the circle and overhead houselight were turned off, followed by representation of the circle for 30 sec or until a response was made. This type of training continued until the rats made 80 or more directed responses per session for two sessions. Next, the lever was replaced underneath the touchscreen, and the rats had to initiate each trial by pressing the lever for the opportunity to respond to the circle. Once the rats had completed 80 or more trials for two sessions, the start lever was moved to the back wall underneath the feeder, and the rats had to complete 80 or more trials per session for two sessions. Starting at this point, circle presentation was reduced to 8 sec and responses on the incorrect blank side terminated the trial, with the overhead houselight turned off for 15 sec and a large 23.5×10.1 cm solid rectangle flashed three times (1 sec on, 1 sec off) on the monitor. A correction procedure was now also employed, with every fourth incorrect response being followed by the representation of the particular trial. Sequences of four or more consecutive correct responses were reinforced with twice the food reward. This type of discrimination training continued until the rats' performance was over 75% correct for three sessions. Twenty-eight rats received this type of training.

Stimulus control training: Levers. Stimulus control training in these animals began with three levers presented on the front wall underneath the monitor. The levers were placed close together, with 1.3 cm separating them. Trials began with a press on the middle lever, at which point the white circle was presented on one side or the other. The circle was presented for 600 sec or until either the right or the left lever was pressed. Correct responses were reinforced with food, and incorrect responses received a 3-sec timeout. This continued until the rats completed 80 or more trials per session for three sessions. Next, the middle lever was moved to underneath the feeder on the back wall and the front response levers were moved outward to the right and left. They were now separated by 13.8 cm, and the rats were trained for three or more sessions, with more than 80 lever responses required per session. At this point, circle presentation was reduced to 8 sec, responses on the incorrect lever terminated the trial with the overhead houselight turned off for 15 sec and the large 23.5 × 10.1 cm solid rectangle flashed three times (1 sec on, 1 sec off) on the monitor, and a correction procedure was added. This type of discrimination training was conducted until the percentage of correct responses exceeded 70% for two sessions, at which point the correction procedure was discontinued, and training continued until the percentage of correct responses exceeded 75% for three sessions. Sixteen rats received this type of lever training.

Simultaneous visual discrimination training. Following this training, each group was then trained to discriminate vertical striped stimuli from horizontal striped stimuli. These stimuli each consisted of seven alternating white and black bars, each one 1.6 cm wide and 9.5 cm long. The vertical stimulus was always designated correct for both groups. Each trial began with a middle lever press, causing the vertical and horizontal stimuli to appear on the screen. The vertical and horizontal stimuli were randomly presented to the left and right on the screen over trials. Making contact with the vertical stimulus in the touchscreen group or pressing the lever underneath this stimulus in the lever group resulted in a milk reward (0.1-sec release of milk; four correct responses in a row caused this reward amount to double [0.2-sec release] until the next the error). An incorrect response to the horizontal stimulus caused the overhead houselight to be turned off for 15 sec while a large 23.5 × 10.1 cm solid rectangle flashed on the monitor three times. Each daily session consisted of 120 discrimination trials. A correction procedure was employed, with every fourth incorrect response causing a re-presentation of a trial for the touchscreen group, and every incorrect response causing a re-presentation for the lever group. Twenty-eight rats were trained on the touchscreen procedure, and 7 rats were trained on the lever procedure. Sessions were conducted 7 days a week.

RESULTS

Figure 2 shows the mean number of sessions needed by the touchscreen and lever groups for each phase of the experiment. There were no significant differences in how long it took the groups to learn to lever press prior to the stimulus control training [$t(42) = .02$]. During stimulus control training, we found that the use of a touchscreen saved a number of procedural steps during the training to track the circular signal. For example, we could eliminate the step required in the lever procedure where the rats were first trained on closely spaced levers, then on the wider standard separation. A t test comparing the number of sessions required for completion of the stimulus control phase revealed a significant savings for the touchscreen group ($M = 12.8$) in comparison with the lever group ($M = 17.3$ sessions) [$t(42) = 3.4$]. Final accuracy was not different between the two groups, both of which easily tracked the side with the circular signal (lever = 90%, touchscreen = 92%).

The learning of the simultaneous visual discrimination also benefited from the use of the touchscreen. Despite the fact that the rats were responding identically at the end

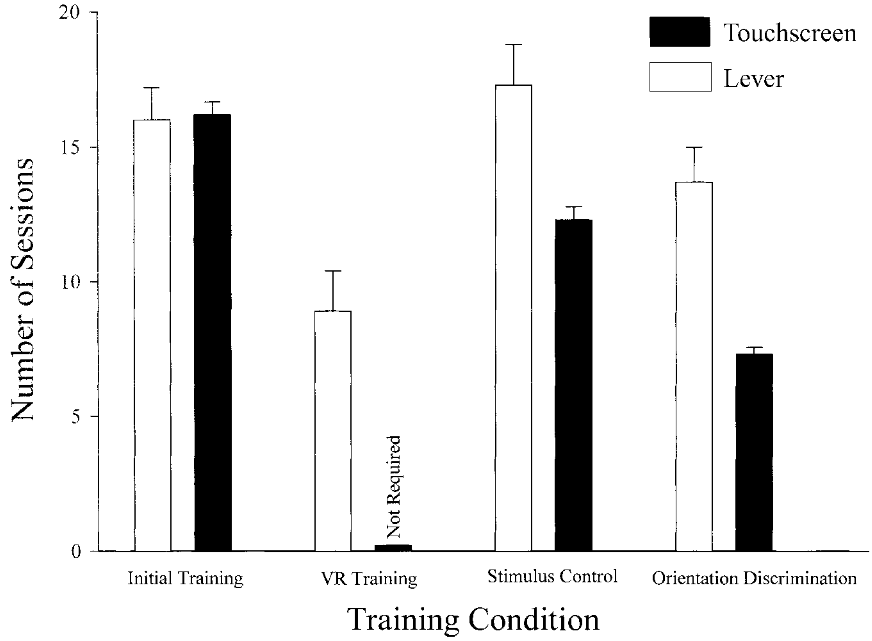

Figure 2. The number of sessions required for initial lever training, stimulus control training, and acquisition of the visual orientation discrimination. The average number of sessions (±*SEM*) required for the animals to reach criterion is shown for each condition.

of stimulus control training, the touchscreen group acquired the line orientation discrimination in about half the time for the lever group. A *t* test comparing the number of sessions required for completion of discrimination learning revealed a significant savings for the touchscreen group (M = 7.2 sessions) in comparison with the lever group (M = 13.7 sessions) [$t(33) = 6.1$]. Again, final accuracy was not different between the two groups [$t(33) = .05$], both of which learned to choose the vertical stimulus at high levels of accuracy (lever = 85%, touchscreen = 85%). Overall, the entire training protocol from start to finish averaged 53 sessions for the lever group and 34 sessions for the touchscreen group, a total savings of about 35%.

DISCUSSION

These results offer, to our knowledge, the first empirical support for the implicit assumption that touchscreen-based response technologies directly benefit discrimination learning in animals. This benefit of the touchscreen consisted primarily of savings during training, rather than improvement in the terminal level of accuracy in our tasks. Overall, the touchscreen conditions were generally more efficient in promoting each phase of acquiring the required discriminative behaviors. The best evidence of this touchscreen superiority comes from the last discrimination training phase, where rats tested with the touchscreen learned a vertical/horizontal discrimination in a little over half the time required by rats responding with levers.

Recall that our primary original objective was to develop an easy-to-learn automated visual discrimination for rats, not to compare these different response devices. As such, it is important to point out that our comparison between the touchscreen and lever conditions was not textbook perfect, because the procedures used in each phase were very similar, but not identical. Certain training steps were dropped in training the touchscreen response during the stimulus control phase, and there was a slight difference in the frequency of applying the correction procedure during discrimination training. Could these slight procedural differences, rather than the response device, have been responsible for the considerable savings observed in each phase? We think not. In some cases, we would argue that they represent the beneficial effect of the touchscreen training itself. For instance, during stimulus control training, we found through experience that we needed to have the levers first placed closely together, then separated, to promote the fastest learning in the rats trained with levers. The touchscreen group never required this additional training, as the rats adapted immediately to the wider display separation during this phase, allowing us to skip this training step.

Regarding our best evidence, the difference in learning the vertical/horizontal discrimination, it could be argued that the one small procedural difference between these conditions should have favored the lever condition. In this case, the lever group's correction procedure resulted in every trial's being repeated until the response was correct, whereas the touchscreen group only had every fourth trial repeated following an error. Since stricter correction procedures typically facilitate learning, it would seem better to attribute the faster acquisition observed in the touchscreen group to the difference in apparatus than to this slight procedural contrast. As a result, given our consistent empirical data and observations, especially from the discrimination training phase, our strong recommendation to researchers interested in facilitating response and discrimination learning in rats would be to purchase and implement a touchscreen procedure before making minor modifications to the frequency of their correction procedures.

Although it is difficult to specifically identify why the touchscreen supported faster acquisition, we suggest that the primary benefits stem potentially from the increased ease of making motor responses required by the touchscreen and the spatial proximity of the stimulus and response. Figure 3 shows a rat making a typical choice response in this task. The effort of this rearing and contact response seemed easier for the rats than the leverpress, and in our observations this type of touchscreen-directed responding always emerged from the rats with far less difficulty than did the initial leverpress. Because rearing and investigatory behaviors are more frequent behaviors in the animal's normal operant repertoire than lever pressing, obtaining control of these behaviors by the visual stimulus would naturally be easier. Further, because the animals make direct contact with the discriminative stimuli, this permits them to engage in more complete and extended observing responses to the stimuli while concurrently making their "choice" responses (Dinsmoor, 1985). The close connection between choice behavior and investigation of the stimulus may let the animals see the consequences of their actions more directly than when they are forced to respond even a small distance away from the stimulus, as is the case with levers. This type of stimulus–response contiguity has been found important in a wide variety of other discrimination settings (see, e.g., Stollnitz, 1965). Spatial

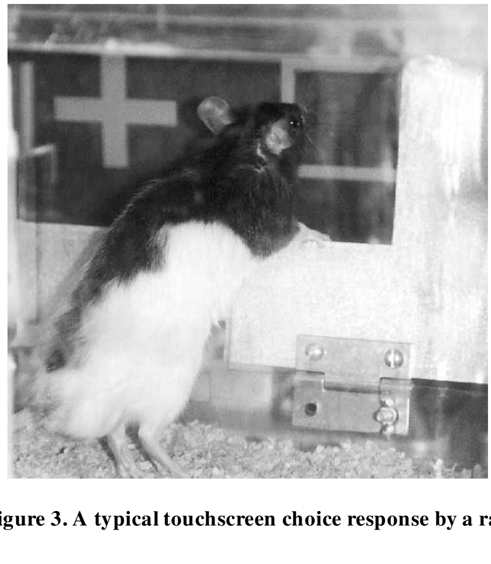

Figure 3. A typical touchscreen choice response by a rat.

contiguity is also known to influence the connection between stimuli (e.g., Rescorla & Cunningham, 1979). Another important and highly related contributor to the touchscreen superiority effect derives likely from an enhancement of sign-tracking behaviors (Hearst & Jenkins, 1974; Killeen, 2003). Rats have frequently been autoshaped to press levers (e.g., Smith, Borgen, Davis, & Pace, 1971), and the direct contact with the visual stimuli in the present task likely activated the same Pavlovian processes. Another factor that may also have contributed is related to the ease of the response. The physical effort of pressing the lever, though not large, was still greater than the mere contact required in the touchscreen conditions. It is likely that all these factors, including the opportunity for increased spatial proximity and "physical" contact with a positive signal for reward, strengthened the ease of making the tracking response. Numerous investigations of the neural and pharmacological mechanisms of lever-based autoshaping in rats have already been conducted, and one interesting direction for future work will be to examine whether the same mechanisms influence touchscreen-based directed action similarly.

Because of these factors, touchscreen technology might even be more valuable for the learning of difficult discriminations. For instance, over the course of these investigations, we have explored other visual stimuli besides the orientation stimuli described above; one of these involved a "cross" and the "outline of a square" (see computer screen in Figure 3). Despite several different attempts, we never successfully trained a handful of pilot rats to make this discrimination using the lever-based procedures. After implementing the touchscreen-based task, however, we found that the rats readily learned this simultaneous discrimination in about 8–10 sessions to a level of about 80% accuracy. Thus the increased efficiency of the computer-controlled touchscreen apparatus may have many potential advantages, especially in increasing the opportunities for testing visual discrimination learning in rats. Of course, this technology may not be perfect for every application. For instance, because of the minimal response effort involved, in some settings it might cause the rats to adopt a lax response criterion, responding too quickly or too frequently for a particular discrimination. In this case, a more resistive lever might cause the animals to be more meticulous or careful when responding. Clearly, such factors would need to be considered and examined for any situation; but we have been favorably impressed by how well it has worked in our application, and we recommend it as a general procedure.

Although rats are usually not considered to be highly visual creatures, the ability to examine visual discriminations in these animals easily using this technology should offer particular advantages in the testing of genetic and neural mechanisms of behavior. With the increased automation of testing provided by touchscreens and the increased sophistication of the visual stimuli that can be employed in such tests, it should now be possible to examine with more precision the relation between the brain and the mechanisms of discrimination behavior in rodents (e.g., Zhang et al., 2002).

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