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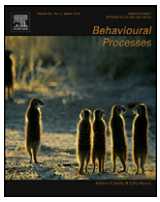

Highlights

Behavioural Processes xxx (2012) xxx–xxx

Visual discrimination learning with an iPad-equipped apparatus

Kenneth J. Leising*, Joshua E. Wolf, Chad M. Ruprecht

► We examined visual discrimination learning in rats interacting with an iPad. ► Differential reinforcement of other behavior and differential outcomes were used to train a successive discrimination. ► Discrimination performance in underperforming rats improved during training with a simultaneous discrimination. ► These results suggest the iPad is an attractive alternative to costly touchscreen packages.

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Visual discrimination learning with an iPad-equipped apparatus

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ABSTRACT

Visual discrimination tasks are commonly used to assess visual learning and memory in non-human animals. The current experiments explored the suitability of an iPad (Apple, Cupertino, California), as a low-cost alternative touchscreen for visual discrimination tasks. In Experiment 1, rats were trained with patterned black-and-white stimuli in a successive non-match to sample procedure. Rats successfully interacted with the iPad but failed to learn to withhold responding on trials in which the sample matched the comparison. Experiment 2 used the same patterned stimuli, but the procedure was simplified to a successive discrimination procedure and we explored the use of procedures known to facilitate discrimination learning. Rats that received training with differential outcomes and a differential reinforcement of other behavior schedule successfully acquired the task. In Experiment 3, the same rats were tested in a simultaneous discrimination task and we explored the use of a correction and non-correction method during acquisition. Rats that failed to learn the discrimination in the previous experiment, improved while trained with the correction method. These experiments support the use of the iPad in visual discrimination tasks and inform future studies investigating learning and memory within a touchscreen-equipped (iPad or other) apparatus.

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1. Introduction

In the past decade, touchscreen technology has dramatically changed the way we interact with our environment. From bank ATMs to cell phones, touchscreens improve the flexibility and ease with which we can display information and record behavior. These benefits have not been overlooked by behavioral scientists. Touchscreen displays have been used with pigeons (e.g., Allan, 1992; Blough, 1986; Pisacreta and Rilling, 1987; Wright et al., 1988), rats (e.g., Bussey et al., 1994; Cook et al., 2004; Markham et al., 1996; Sahgal and Steckler, 1994), non-human primates (e.g., Bhatt and Wright, 1992; Elsmore et al., 1989), and humans (e.g., Huguenin, 2000). Furthermore, touchscreens have been used to study the effects of neural lesions and pharmacological agents on behavior (e.g., Bussey et al., 1997a, 1997b, 1998, 2001; Parkinson et al., 1999, 2002). Though many factors have contributed to the popularity of touchscreens in research, most researchers are attracted by the ease with which visual stimuli can be created and displayed, and the flexibility to detect responses across the entire display.

Recognizing the constraints imposed by the display equipment used in research in the 1980s, Dr. Anthony Wright became one of the pioneers in developing methods for the use of touchscreen technology in research. Wright et al. (1988) suggested that the use of small numbers of exemplars in most previous reports on match-to-sample performance (a consequence of the 12-slide projectors used by most researchers at the time) encouraged item-specific, rather than relational (i.e., concept) learning. Wright et al. used a novel, horizontally mounted touchscreen-equipped display to present 152 trial-unique stimuli to a group of pigeons during match-to-sample training. When compared to a group trained with only 2 stimuli, the results revealed concept learning only in the group trained with a large number of exemplars. This experiment highlighted the benefits associated with incorporating new technology into research and demonstrated how extending the levels of an independent variable can result in qualitative differences in learning (see Wright, 2010 for a review). Wright and colleagues have also been interested in procedural changes that accelerate the development of concept learning. Wright and Delius (1994) required pigeons to dig through different colored and textured sand in match and oddity tasks and found a 100-fold acceleration in learning relative to more traditional methods. More recently, Schmidtke et al. (2010) describe how differential outcomes can accelerate the expansion of concept learning to produce better transfer to novel items in a same/different task. The present experiments are inspired by Wright and colleagues use of new technology

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and manipulation of experimental parameters to better understand the nature of learning and memory. We explored the suitability of training rats in a novel iPad-equipped apparatus and explored conditions which may facilitate discrimination learning.

The use of touchscreens in research was extended to rats by Bussey et al. (1994) and Markham et al. (1996). Much of the subsequent research has investigated discrimination learning by varying object luminance (Minini and Jeffery, 2006), shape (e.g., Bussey et al., 1994, 2001, 2008; Markham et al., 1996; Minini and Jeffery, 2006; Simpson and Gaffan, 1999), or pattern (e.g., Cook et al., 2004; Prusky et al., 2002). However, a subset of the research has focused on determining methods suitable for a touchscreen environment. For example, Markham et al. (1996) reported better acquisition in rats interacting with a touchscreen when the site of reward delivery was at the opposite wall of the chamber from the touchscreen, rather than adjacent to it. Recently, Bussey et al. (2008) found that learning rate could be improved through the use of larger stimuli, longer inter-trial intervals (ITIs), and more trials per session. Lastly, Cook et al. (2004) directly compared the benefits of touchscreen technology with traditional lever press equipment. Rats were trained in a simultaneous visual discrimination task with either traditional stimulus and response equipment (e.g., lights and levers) or a touchscreen-equipped display. Rats responding to the touchscreen learned the discrimination faster than rats responding on traditional levers.

Researchers have demonstrated visual discrimination learning in rats interacting with infrared (Bussey et al., 1994, 2001, 2008; Cook et al., 2004) and pressure sensitive (Markham et al., 1996; Minini and Jeffery, 2006) touchscreens. Although both touchscreens are suitable for use with rats, the motivation to develop an alternative to the currently available infrared touchscreen systems is their cost. Assuming one already has a operant chamber for rats (e.g., test chamber, reward delivery mechanism, etc.), an additional touchscreen package will cost $5000 (Med Associates, Georgia, VT) to $10,000 (Lafayette Instruments, Lafayette, IN) and does not include the software (e.g., $3000, Med Associates) or any additional software packages (e.g., autoshaping, $1100, Lafayette Instruments). One alternative to these systems is to design a custom touchscreen chamber (see Cook et al., 2004). However, variations in the type of touchscreen purchased and the placement of the touchscreen in an operant chamber can influence affect learning outcomes (e.g., Markham et al., 1996). With the goal of providing a flexible, low cost alternative touchscreen system, we have recently validated the use of an iPad 2 (Apple, Cupertino, California) with rats (Wolf et al., submitted for publication).[1]

The iPad provides a high-resolution display, and a capacitive touchscreen that offers drift-free stable performance. Although infrared touchscreen technology has improved and the issue of drift has been largely eliminated, the lingering issue with infrared touchscreens is that the panel frame, which houses the LEDs and phototransistors, always protrudes slightly above the screen. This becomes a problem when a rat's whiskers or other object triggers a response in lieu of a true touch. Additionally, obstructions (e.g., feces) on the thick panel frame can block the infrared sensors rendering them non-functional until the obstruction is removed. Capacitive touchscreens detect responses through changes in current as a result of direct contact with the screen and automatically recalibrate when an obstruction is present. Lastly, the iPad is wireless-enabling it to be mounted in any position and easily repositioned within an operant box or open field (e.g., on the wall or embedded in the floor). Visual Basic 6 software (Microsoft, Redmond, WA) also allows you to display and record from multiple iPads concurrently, using the same PC. Multiple iPads could be used to create a 4-walled iPad environment, or control iPads in separate locations in an open field. In sum, the use of an iPad is relatively inexpensive and the technology is reliable, durable, and enables wireless flexibility.

The current research explores the suitability of three visual discrimination procedures for use in an iPad-equipped apparatus (see Fig. 1a). Discrimination learning has long played an important role in investigations of perception and memory and remains popular among those interested in cognition and physiology (Dudchenko, 2004). Among the tasks used by researchers, successive and simultaneous discrimination procedures are most commonly used to evaluate visual learning and memory in rodents. Despite varying cognitive demands, each task requires that a subject discriminate between objects (presented successively or simultaneously) and associate the identified object with reward or non-reward. The experimental setup utilizes an iPad, operant chamber, a remote desktop program, and Visual Basic 6 software. Experiments 1–3 evaluated the iPad as a suitable device for use with rats and explored conditions which may facilitate learning. Experiment 1 tested rats in a successive match-to-sample task with patterned black-and-white images as stimuli. The same stimuli were then used in successive and simultaneous discrimination tasks in Experiments 2 and 3, respectively. Together, these experiments suggest the iPad is an attractive alternative to costly prepackaged touchscreen systems.

2. Experiment 1

In one of the first studies of memory in non-humans, Hunter (1913) evaluated delayed choice in rats, raccoons, and dogs. The animals were confined to a chamber in view of three separate choice boxes. Over one of the choice boxes a light was shown for a brief period of time. Once extinguished, the animal was freed from the chamber to select a choice box. The delay between the presentation of the light and release was then manipulated to determine the duration of working memory. In subsequent years, the use of successive presentations of stimuli in a match-to-sample format allowed a more thorough investigation into the nature of working memory. Subjects in a match-to-sample task are presented with one stimulus (sample), which is followed after some delay by a second stimulus (comparison). The subject is then required to detect whether the comparison matches the sample stimulus. Selection of the match or non-match comparison may be correct depending on the procedure selected by the experimenter. This type of procedure can be used to study the acquisition, content, and retrieval of the memory for the sample.

The purpose of the present experiment was to evaluate the use of a successive non-match to sample task with rats interacting with an iPad. Rats were presented with a sample followed by a brief delay and a second, comparison stimulus. If the comparison stimulus matched the sample, then the correct response was to withhold touching the comparison until the stimulus timed out. If the comparison did not match the sample, then touches to the comparison stimulus were rewarded. We used four circular black-and-white patterned images as stimuli (see Fig. 1b). Previous research has shown rats can solve visual discriminations based on pattern alone (e.g., Cook et al., 2004; Lashley, 1938; Prusky et al., 2002); however, rats have been shown to rely primarily on unidimensional (e.g., size or brightness) differences in stimuli (Minini and Jeffery, 2006). Thus, we expected that the relative similarity between our stimuli would result in slow learning in the task.

2.1. Method

2.1.1. Subjects

Three female experimentally naïve Long–Evans rats (*Rattus norvegicus*) obtained from the TCU Breeding Colony served as

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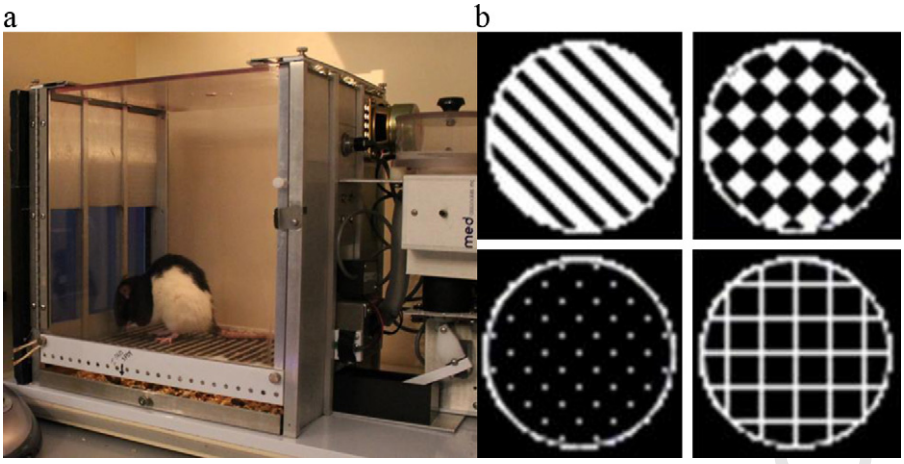

Fig. 1. (a) A picture of the iPad-equipped operant box. Stimuli were displayed on the wall opposite of a sucrose delivery system. (b) All four stimuli were used in Experiment 1. The two stimuli on the top row were used in Experiments 2 and 3.

subjects. Females were pair-housed in translucent plastic tubs with a substrate of wood shavings in a vivarium maintained on a 12-h dark/12-h light cycle. All experimental manipulations were conducted during the light portion of the cycle. A progressive food restriction schedule was imposed over the week prior to the beginning of the experiment, until each rat received 15 g of food each day. All animals were handled daily for 30 s during the week prior to the initiation of the study.

2.1.2. Apparatus

A test chamber measuring 30.5 cm × 24.1 cm × 29.2 cm (length × width × height) was housed in a sound- and light-attenuating environmental isolation chest (Med Associates, Georgia, VT). The side walls and ceiling of the chamber were constructed of clear Plexiglas. The front and rear walls were constructed of aluminum panels. The floor was constructed of stainless-steel rods measuring 0.5 cm in diameter, spaced 1.5 cm center-to-center. The enclosure was dimly illuminated by a 28-V, 100-mA shielded incandescent house light mounted on the top of the rear wall of the chamber, 2 cm below the ceiling. One wall of the chamber was equipped with a dipper that could deliver a sucrose solution (16%). When in the raised position, a small well (0.05 cc) at the end of the dipper arm protruded up into the feeding niche. An infrared photo-detector was positioned across the entrance to the feeding niche. When a rat placed its nose into the feeding niche to lick the sucrose solution (i.e., a nose poke), the photo beam was disrupted. The duration of sucrose access did not begin until the computer detected an interruption of the photo beam. A ventilation fan in the enclosure and a white-noise generator on a shelf outside of the enclosure provided a constant 74-dB (A-Scale) background noise.

On the wall opposite of the hopper (30.5 cm), an iPad was mounted flush against the rear of the test chamber (see Fig. 1a). The iPad features a 24.63 cm (diagonal) LED-back lit glossy widescreen display with multi-touch sensitivity. Although the iPad recognizes three different types of touches – taps, moves and gestures, only the tap function was utilized in the current experiments. The program code treated every touch as a tap by detecting and recording only touch-down (i.e., screen contact) events. For one day in pretraining, the iPad was turned off and positioned in a landscape orientation and placed at a 54° angle inside the test chamber. This procedure encouraged the rats to approach and contact (e.g., rear and lean on) the screen. On all subsequent days, the iPad was positioned in the same orientation but mounted at a 90° angle at the rear of the test chamber.

The display of stimuli on the iPad, data collection, and hardware activation (houselight, dipper, and fan) were controlled by an adjacent PC. The PC to iPad connection was accomplished via a remote desktop program RDP (Mochasoft Aps, Blokhus, Denmark) downloaded from the App Store (Apple, Cupertino, California; but see also Wolf et al. for a recently developed Mac application). The programs for all of the experiments were written in Microsoft Visual Basic 6.0, which used a dynamic link-library (dll), purchased as part of the Control of Med Input/Output from Other Languages Med Associates Product (SOF-732-3), to control Med-Associates hardware.

2.2. Procedure

2.2.1. Stimuli

A 6.2 cm light gray circle served as the pretraining stimulus. During training, the stimuli were 4.7 cm circles filled with a black-and-white checker, a white on black background grid, a scattered white dot on black background, and a diagonal-striped pattern (see Fig. 1b). The training stimulus was positioned at the midpoint of the iPad, which coincided with the midpoint of the rear wall of the test chamber. The stimuli were displayed at 12.2 cm from the chamber floor.

2.2.2. Pretraining

The rats were initially trained to drink from the dipper with the iPad located in the test chamber. Sucrose was delivered for 3-s on a variable-time (VT) 60-s schedule. After rats were drinking reliably, the iPad was moved to the rear of the chamber and mounted at a 90° angle. Over the next 1–5 Days, rats were exposed to a combination of autoshaping and manual shaping. Autoshaping consisted of a 32-trial session with presentations of an 8-s pretaining stimulus followed by 3-s access to sucrose and then an 80-s inter-trial interval (ITI).

2.2.3. Successive nonmatch-to-sample training

On sessions 1–35, each discrimination training session consisted of 40 trials (20 match and 20 non-match trials). The onset of the sample stimulus was always marked by darkening of the houselight. The sample stimulus was always presented for 5 s, but the duration of the comparison stimulus was gradually reduced from 60 to 10 s across sessions. Trial termination following a touch to a comparison stimulus was constrained by a fixed-interval (FI) 1 s schedule of reinforcement. This was used initially to ensure the comparison stimulus would be viewed for a fixed amount before a response terminated the trial. The FI schedule was increased

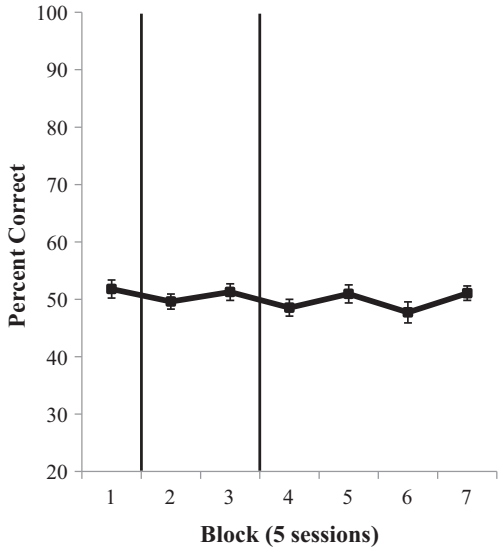

Fig. 2. Data are from the last 35 sessions of training during Experiment 1. In Block 1, the delays were 0, 50, and 100 ms. This was increased to 0, 50, 100, 200, and 250 ms during Blocks 2–3, and then increased again to 250, 500, and 750 ms in Blocks 4–7. Error bars represent standard error of the mean.

gradually from 1 to 4 s across sessions to allow a direct comparison of responding during a fixed amount of time on match and non-match trials. The delay between stimuli was also manipulated across sessions. The delay was initially chosen pseudo randomly from among 0, 50, and 100 ms. This was subsequently increased to 0, 50, 100, 200, and 250 ms; and increased again to 250, 500, and 750 ms. For all rats, a touch to a non-match comparison after the FI resulted in 3-s access to sucrose. A touch to a matching comparison after the FI terminated the trial and initiated a 16-s timeout period. A 4-s fixed-time ITI separated all trials. The houselight was off throughout the duration of a trial, but remained on during the ITI and timeout periods.

On Days 36–47, sessions consisted of 50 trials with 25 match and 25 non-match trials. A trial terminated after 10-s of the comparison stimulus or the first response following the FI-4, whichever came first. A variable-interval 500 ms (250, 500, and 750 ms) delay separated the sample and comparison stimulus. All other details were the same as described above.

2.3. Results

Fig. 2 displays data from 35 sessions of training. A percent correct for each session was calculated by dividing the number of correct responses on non-match (i.e., a touch) and match (i.e., no touch) trials by the total number of trials. As indicated by Fig. 2, there was little change across sessions and no evidence for a preference to respond on non-match trials. A statistical analysis was conducted on Days 36–47, which represented a period of consistent session parameters. A *t*-test against chance (50%) confirmed no subject demonstrated a preference to respond on non-match trials across the last 12 sessions of training, $ts(11) < 1$, $ps > .05$. Other measures, including a discrimination ratio (DR) calculated using responses collected within the FI-4 s period after the onset of the comparison stimulus also indicated no difference, $ts(11) < 1$, $ps > .05$. Lastly, we compared the DR during the different delay intervals (250, 500, and 750 ms) but found no preference to respond on non-match trials at any delay, $ts(11) < 1$, $ps > .05$.

All rats failed to show successive nonmatch-to-sample performance after many sessions of training. Rats may have failed to learn the correct response as a result of poor discriminability between stimuli, memory interference, or a combination. Previous research has shown that rats rely mostly on unidimensional (e.g., size or brightness) differences in the lower hemifield during simultaneous discrimination procedures (Lashley, 1938; Minini and Jeffery, 2006; Sutherland, 1961). Discrimination of patterned images can be learned but typically proceeds slowly. For example, Minini and Jeffery (2006) reported slow learning and low asymptotic performance while training rats using a touchscreen to discriminate shape. In their procedure (Experiment 3), the luminance and position of two visual stimuli were controlled for but aspect ratio, a basic property of shape, was the cue for the S+. After 40 sessions of 128 trials per session (5120 trials), mean asymptotic performance was only 64%. In their results, however, rats showed some evidence of learning in the first 10 sessions of training (1280 trials). We terminated the current experiment after the last 35 sessions (1500 trials) indicated no evidence of learning.

In addition to poor discriminability, retroactive interference as a result of short ITIs and repeated stimuli likely contributed to poor performance in this task (c.f., Frank and Wasserman, 2005; Kelly et al., 1999). For example, the rewarded comparison stimulus on one trial (i.e., a non-match trial) could become a non-rewarded comparison stimulus (i.e., a match trial) on the very next trial. Long-duration ITIs and session-unique, highly discriminable stimuli would likely facilitate acquisition of the non-match to sample task. Subsequent studies may also include a trial initiation response, which has been shown to facilitate acquisition of visual discriminations (Bussey et al., 2008), as well as further manipulate the delay between stimuli (e.g., Bussey et al., 2008; Pontecorvo, 1983; Pontecorvo et al., 1996).

3. Experiment 2

Experiment 1 showed rats can be quickly trained to interact with an iPad-equipped apparatus but fail to learn the correct response in a successive non-match to sample task. In Experiment 2, we trained four naïve rats in a successive discrimination task using two of the four cues from Experiment 1. Stimuli were designated as either S+ or S– and presented on separate trials. A target response on trials with the S+ was reinforced, whereas, a response on trials with a S– either terminated a trial with no reinforcement and a time-out. The aims of Experiment 2 were to demonstrate visual discrimination performance in an iPad-equipped apparatus with patterned stimuli, and to evaluate manipulations known to facilitate learning in tasks where generalization or response confusion may occur (e.g., Delamater et al., 2010; Lieberman et al., 1979, 1985; Urcuioli and Kasprow, 1988; Williams, 1999).

In a typical successive discrimination procedure, all trials end with the termination of the target stimulus and an empty interval (i.e., an ITI). Consequently, on S+ trials with no response and S– trials with a response or not, the subject receives the same end-of-trial events. The similarity in trial outcomes likely attenuates discrimination performance. In order to facilitate discrimination performance in our task, a response to the S+ was rewarded with sucrose and, for some rats a response to the S– was not rewarded and followed immediately by a flashing light of the same duration as the sucrose (c.f., Cook et al., 2004). Any facilitated learning effect would resemble the differential outcomes effect (DOE) found in instrumental (see Overmier and Linwick, 2001) and Pavlovian procedures (e.g., Delamater et al., 2010). In discriminations involving two S+ stimuli (e.g., a low and high pitched tone) and two responses (e.g., left and right lever), responding appropriately to each stimulus is enhanced if the correct responses are associated with different outcomes (i.e., O1 and O2). One theory explaining the DOE involves an "acquired distinctiveness" which develops between cues followed by different events (see Hall, 1991, for a review). In addition

to acting as a unique outcome, the flashing light served to mark an incorrect response, thereby enhancing the salience of that response and discrimination learning (e.g., Lieberman et al., 1979, 1985; Urcuioli and Kasprow, 1988; Williams, 1999).

Another procedure that has been used to enhance discrimination performance is a differential reinforcement of other behavior (DRO) schedule. A DRO schedule was used successfully by Kelly et al. (1999) to train pigeons to discriminate visual stimuli in a successive discrimination task. In their procedure, if a no-go test stimulus occurred, pigeons were reinforced for withholding pecking for 5 s. If a peck did occur, the DRO timer was reset to 5 s. In the last phase our experiment, we implemented a DRO schedule. Rats were required to withhold touching the S− for 4-s before the trial would terminate. Differential outcomes, marking procedures, and DRO schedules have all been shown to facilitate learning in discrimination tasks. We explored whether these procedural manipulations could be effective in an iPad-equipped apparatus.

3.1. Method

3.1.1. Subjects

Four experimentally naïve Long–Evans rats (*R. norvegicus*) obtained from the TCU Breeding Colony served as subjects. Two male and female rats were randomly assigned to two groups, with the constraint that one male and female was in each group. All other details are the same as in Experiment 1.

3.1.2. Apparatus

The apparatus was the same as that used in Experiment 1. However, during a session the house light could be flashed by turning the light on and off every 25 s.

3.2. Procedure

3.2.1. Stimulus displays

The stimuli were the diagonal-striped pattern and black-and-white checkered images used in Experiment 1 (Fig. 1b, top row). The two stimuli were assigned as S+ and S−, counterbalanced across subjects. All other details are identical to that of Experiment 1.

3.2.2. Pretraining

Pretraining occurred in the same manner as described in Section 2.

3.2.3. Phase 1: discrimination training (Days 1–6)

Each discrimination training session consisted of 56 trials (28 S+ and 28 S−). A trial terminated after a touch to the stimulus or 20 s, whichever came first. The duration of the stimulus presentation was reduced from 20 to 10 s across sessions. A fixed-interval 1-s schedule (FI-1) determined whether a touch terminated a trial. The FI ensured the stimulus would be displayed for a minimum duration before a response would terminate the trial. The FI schedule was increased gradually from 1 to 4 s across sessions. For all rats, a touch to the S+ after the FI resulted in 3-s access to sucrose. For rats in the control group, a touch to the S− after the FI terminated the trial and initiated a 16 s timeout period, whereas, rats in another group were given a 3-s flashing light followed by a 16 s timeout period. All trials, correct or incorrect, were followed by a 4-s fixed-time ITI. The houselight was off during all trials, but remained on during the ITI and timeout periods.

3.2.4. Phase 2: fixed-interval discrimination training (Days 7–12)

The number of trials was increased to 100 (50 S+, 50 S−) and a fixed-interval 4-s schedule determined whether a response terminated a trial.

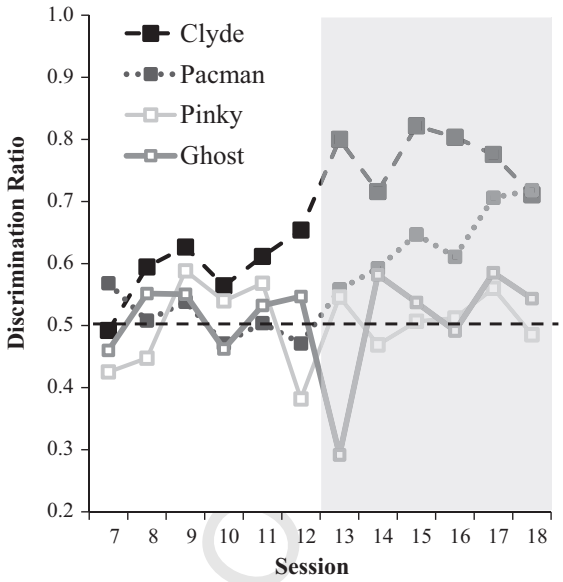

Fig. 3. Data from the first 4-s of S+ and S− trials in Experiment 2 were used to calculate discrimination ratios for each rat. The left-hand side of the figure displays performance during Phase 2 (sessions 7–12) and the right-hand side (light gray shading) indicates performance with the DRO schedule during Phase 3. The dotted-line patterns represent animals that received a flashing light after an incorrect response. The dotted line at .50 represents no difference between responding on S+ versus S− trials.

3.2.5. Phase 3: differential reinforcement of other behavior training (Days 13–18)

A differential reinforcement of other behavior (DRO) schedule was introduced. On this schedule, an S− trial would not terminate until 4-s elapsed with no response to the stimulus. Reinforced trials remained unchanged from Phase 2.

3.3. Results and discussion

Percent correct was calculated for all sessions in Phase 1 ($M = 50.08$, SD = .72). Clearly, mean performance during Phase 1 indicated no preference for responding on S+ trials. In Phase 2, the number of trials increased and the FI-4 was introduced. During the FI-4, responding was uninterrupted by reward or trial termination allowing a direct comparison between S+ and S− trials. A discrimination ratio was calculated as in Experiment 1, such that a preference for the S+ was indicated by values greater than .5. Fig. 3 displays the discrimination ratio for all rats during Phases 2 and 3. A *t*-test against chance (.50) compared responding across all six sessions of Phase 2 and revealed a significant preference for the S+ in one rat in the group receiving the flashing light, $t(5) = 3.90$, $p < .05$. In Phase 3, the DRO procedure was implemented. The same analysis conducted on the six sessions from Phase 3 revealed that both rats responded in the group receiving the flashing light responded more on S+ trials than S−, $ts(5) > 5.33$, $ps < .01$, whereas no rats in the control group showed this preference, $ts(5) < 1$, $ps > .05$.

These results suggest that rats can be trained to discriminate between highly similar patterned stimuli within an iPad-equipped apparatus. Evidence for successful visual discrimination was present only for the rats that received the flashing light and DRO procedures. It is beyond the scope of these data to determine whether the flashing light enhanced the salience of an incorrect response through marking or enhanced the discriminability of the S+ and S− via a differential outcomes effect. Certainly, there is support in the literature for facilitated learning as a result of both manipulations. The two rats without the differential outcome failed to learn the task. Though, the small number of subjects per group

suggests caution when interpreting these results. In Experiment 3, another common task for evaluating visual learning, a simultaneous visual discrimination, was used to determine whether (1) rats that learned the successive discrimination would perform well on the first trial of a simultaneous discrimination procedure, and (2) rats that had not learned the task in Experiment 2 would acquire a simultaneous discrimination with the same stimuli.

4. Experiment 3

In Experiment 3, the two stimuli from the last experiment were presented simultaneously in positions on the left and right sides of the display. The assignment of stimulus to S+ and S− from Experiment 2 was maintained. As before, responses to the S+ were reinforced, whereas responses to the S− were non-reinforced. Acquisition of the task was evaluated by comparing responses to the S+ and S− during the first 4-s (FI) of each trial. The simultaneous discrimination task allowed subjects more of an opportunity to compare the features of the S+ and S−, which should benefit those rats that failed to learn the discrimination in Experiment 2.

We expected to observe fairly rapid learning in all rats during training with the simultaneous discrimination procedure. Bussey et al. (2008) trained naïve rats in a simultaneous discrimination with similar parameters (e.g., trials per session, ITI duration, and image size) and found evidence of learning within five sessions. In Experiment 3, we trained rats during the first three sessions with a correction method followed by another three days of training with a non-correction method. In discrimination learning paradigms, the use of a correction method permits the animal to continue to respond until a correct response is made. However, a non-correction method indicates that a trial will terminate (or the animal will be removed from the apparatus) after an incorrect response. In Experiment 3, we explored the use of a simultaneous discrimination procedure and correction method with rats interacting with an iPad display. We expected discrimination performance to develop quickly for all rats and no decrement in responding when the non-correction method was introduced.

4.1. Method

4.1.1. Subjects

The same four Long–Evans rats (*R. norvegicus*) from Experiment 2 served as subjects.

4.1.2. Apparatus

The apparatus was the same as that used in Experiments 1 and 2.

4.2. Procedure

4.2.1. Stimuli

The stimuli were the same as those used in Experiment 2, except the diameter of the pretraining stimulus was reduced from 6.2 to 5.0 cm and the training stimuli were reduced from 4.7 to 4.5 cm. This reduction allowed the circular stimuli to fit within the three columns inherent to the test chamber (see Fig. 1a). All of the positions were 13.3 cm from the chamber floor. The middle position was at the midpoint of the iPad and the chamber, and the left and right positions were 15 cm, center to center. The pretraining stimulus was displayed in each of three positions during pretraining but the training stimuli occupied only the left and right positions during simultaneous discrimination training.

4.2.2. Pretraining

Subjects were trained to touch the pretraining stimulus in the left, middle, and right positions on the iPad (see Wolf et al., submitted for publication, for details). After two days of training, rats were then trained with the pretraining stimulus at both the left and right positions, but the position associated with reinforcement was determined pseudo randomly so that it occurred equally often at both sides. Training continued for two days or until any side bias was eliminated.

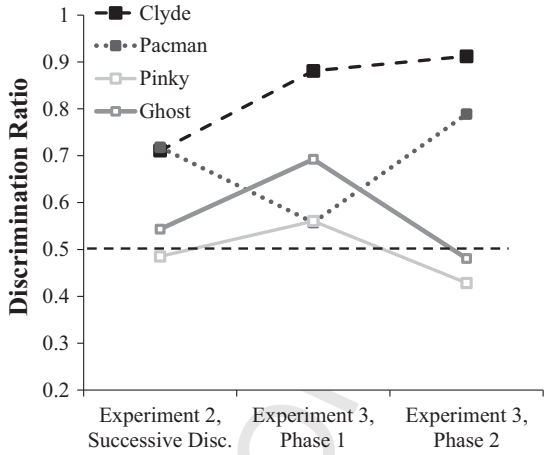

Fig. 4. Data from the first 4-s of trials in Experiments 2 and 3 were used to calculate discrimination ratios for each rat. Data from the last session of Experiment 2, as well as the last session Phase 1 (Day 3 with correction method) and Phase 2 (Day 9 with non-correction method) of Experiment 3 for all rats. The dotted lines represent animals that received a flashing light after an incorrect response in Experiment 2. The dotted line at .50 represents chance performance.

4.2.3. Phase 1: correction simultaneous discrimination training (Days 1–3)

Each training session consisted of 50 trials. The first trial of every session was a probe trial, in which the trial duration was 60-s and there was no opportunity for reinforcement. On the remaining trials, a trial terminated with a touch to the S+ after the FI-4 schedule or 180 s elapsed from trial onset, whichever came first. Responses to the S− were recorded but had no nominal effects. A 4-s fixed-time ITI separated all trials. The houselight was off during all trials, but remained on during the ITI period.

4.2.4. Phase 2: non-correction simultaneous discrimination training (Days 4–9)

Training was similar to that of Phase 1, with the exception that a response to the S− after the FI-4 terminated the trial with a flashing light, non-reinforcement, and a 16-s timeout for all rats. A programming error resulted in the first trial terminating with a response to the S− for all rats. The data from these trials were discarded from the analysis.

4.3. Results

4.3.1. Phase 1 (Days 1–3)

During the probe trial on the first trial of Day 1, a preference to respond to the S+ was observed for 2 of the 4 rats (binomial tests, $ps < .05$). The two rats that performed above chance were the same rats that demonstrated discrimination learning in Experiment 2. This same result was found if we conduct the analysis on responding during the first 4 s (i.e., the FI-4 s period) across all of the trials on Day 1 (binomial tests, $ps < .05$). Fig. 4 displays performance from the last session of Experiment 2, as well as the last sessions of Phase 1 and 2 of Experiment 3. We find evidence of learning in all rats when the analysis was conducted on data from Days 2–3, such that all rats are responding more to the S+ ($M = 179.75$, SD = 190.42) than

S− (*M* = 65.25, SD = 35.11) during the first 4 s of the trials (binomial tests, *ps* < .05).

4.3.2. Phase 2 (Days 4–9)

Given the duration of Phase 1 (3 Days), it would be informative to evaluate performance on Days 5–6 of Phase 2. Performance during the first 4 s of trials revealed that 2 of the 4 rats that were responding above chance on Days 2–3 of Phase 1, responded below chance on Days 5–6 (binomial tests, *ps* > .05). The two rats that performed below chance on Days 5–6 were the same rats that showed no evidence of learning in Experiment 2. As indicated by Fig. 4, performance in these rats did not improve after an additional 3 training sessions (Day 9) with the non-correction method.

Successful performance by rats in Experiment 2 (successive discrimination) led to a preference to respond to the S+ on the very first trial of a simultaneous discrimination in Experiment 3, despite novel positions for the S+ and S−. Interestingly, the two rats that failed to learn in Experiment 2 provided evidence of learning with a correction method during the simultaneous discrimination task. Performance decreased, however, across six subsequent training sessions with the non-correction method. The debate over the benefits of correction versus non-correction methods has a long history in learning, dating back to at least Kalish (1946) and continuing in recent research (e.g., Metcalfe et al., 2009). On the one hand, a correction method allows for each trial to terminate in reinforcement; on the other hand, it also allows for the incorrect response to be followed closely in time by reinforcement thereby creating response chains (Sutherland and Mackintosh, 1971). Our results suggest that rats do benefit from the opportunity to correct their mistakes early in training. The correction procedure allows an incorrect response to the S− to be quickly compared to a correct response to the S+, whereas, a rat with a non-correction method must endure the duration of the ITI before another opportunity to view the S+ and emit a response. Rats already responding correctly to a successive discrimination did not benefit from the opportunity to quickly correct mistakes. Though in need of subsequent validation, these results suggest the use of a correction method early in discrimination training.

One potential concern with our procedure is that a non-rewarded response on a trial could simply become a cue for a rat to respond to the other stimulus. For this reason, our analysis was confined to responses during the FI-4 s portion of the trial. During this time, responses to both the S+ and the S− were non-rewarded and thus cued switching should result in chance performance. Another concern is that the left and right positions occupied by the S+ and S− were separated by 15 cm and an empty middle panel (see Fig. 1a). This distance prevented simultaneous comparison of both stimuli from close distances. This factor likely contributed to the failures of the two rats to learn during non-correction training. In future studies, the stimuli could be placed in adjacent panels, reducing the distance from 15 to 7.5 cm. In our experimental setup, the left, center, and right panels are a consequence of the Med-Associates test chamber being used. A custom-built chamber could have the benefit of a uniform surface but may then lack the flexibility of using modular Med-Associates components (e.g., levers, lights, speakers, etc.).

5. General discussion

The present series of experiments evaluated whether rats could interact with an iPad and discriminate visual stimuli presented on the iPad display. Experiment 1 found that rats will quickly learn to interact with an iPad but fail to learn in a successive non-match to sample task with patterned stimuli. In Experiment 2, two of four rats responded more to a visual stimulus associated with reward than a stimulus associated with a time-out and flashing light in a successive discrimination task. One rat learned with only the flashing light (differential outcome), but both rats improved dramatically with a DRO schedule. In Experiment 3, all four rats were trained in a simultaneous discrimination task. The two rats that learned the discrimination in the second experiment performed well on the very first trial with the S+ and the S− displayed simultaneously in novel locations. Subsequent training with a correction method resulted in a preference for responding to the S+ for all rats. After switching to a non-correction method, performance decreased for two rats. These findings suggest the iPad can be a useful tool in behavioral investigations of visual learning and memory, but also indicate more research is needed to identify the optimal conditions for acquisition of discriminations (e.g., Bussey et al., 2008).

The continued use of touchscreen procedures is encouraged by successful demonstration of simultaneous discrimination and reversals (e.g., Bussey et al., 1997a; Chudasama et al., 2001; Morton et al., 2006); visuospatial conditional discrimination and reversal (e.g., Bussey et al., 1997a; Chudasama et al., 2001; Janisewicz and Baxter, 2003); configural discrimination tasks (Bussey et al., 1998); nonspatial nonmatch-to-sample (e.g., Bussey et al., 1994); and autoshaping (e.g., Dalley et al., 2005; Bussey et al., 1997a; Parkinson et al., 1999, 2002) in rats and mice using a touchscreen. These types of tasks previously required fabrication of a custom apparatus or costly touchscreen packages, but the current experiments demonstrate that the iPad presents a relatively simple alternative, utilizing equipment that many behavioral scientists are using or have access to. One additional benefit of the iPad over infrared touchscreens includes the opportunity for multi-touch detection. This feature could be used to require cooperation or competition between rats working on the same display or in observational learning paradigms.

A synergistic relationship exists between new technologies and scientific inquiry. Better technology allows the scientist to accumulate more evidence regarding existing questions but also expands the potential for new questions. The result of this relationship can be seen within the research career of Dr. Anthony Wright. Wright and colleagues pioneered the use of touchscreen technology for pigeons (Wright et al., 1988) and primates (Bhatt and Wright, 1992); concluding that touchscreen-equipped monitors could enhance stimulus control and flexibility, while maintaining precise response detection. In subsequent studies, Wright and colleagues used touchscreens to conduct comparative investigations of concept learning, memory effects in serial list learning, and working memory capacity. The present experiments corroborate Dr. Anthony Wright's legacy of incorporating new technology and examining the influence of experimental parameters in the study of learning and memory.

Uncited references

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Brigman et al. (2005), Chudasama and Robbins (2003), Izquierdo et al. (1993), Kimble and Kimble (1970), Lashley (1930) and Steckler and Sahgal (1995).

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