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Abstract

The increasing demand for highly automated and flexible tasks capable of assessing visual learning and memory in nonhuman animals has led to the exciting development of a wide array of prefabricated touchscreen-equipped systems. However, the high cost of these prefabricated systems has led many researchers to develop or modify their own preexisting equipment. We developed a freely downloadable App, the Touchscreeen Behavioral Evaluation System (TBES) for use in conjunction with an iPad (Apple, Cupertino, California) as an alternative to prefabricated touchscreen systems. TBES allows for stimulus presentation and data collection on an iPad. The touchscreen technology offered by the iPad is attractive to researchers due to its affordability, reliability, and resistance to false inputs. We highlight these, as well as the feasibility and procedural flexibility of TBES, in an effort to promote our system as a competitive alternative to those currently available.

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Need to train your rat? There is an App for that: A touchscreen behavioral evaluation system

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Chad M. Ruprecht · Kenneth J. Leising

Abstract The increasing demand for highly automated and flexible tasks capable of assessing visual learning and memory in nonhuman animals has led to the exciting development of a wide array of prefabricated touchscreen-equipped systems. However, the high cost of these prefabricated systems has led many researchers to develop or modify their own preexisting equipment. We developed a freely downloadable App, the Touchscreeen Behavioral Evaluation System (TBES) for use in conjunction with an iPad (Apple, Cupertino, California) as an alternative to prefabricated touchscreen systems. TBES allows for stimulus presentation and data collection on an iPad. The touchscreen technology offered by the iPad is attractive to researchers due to its affordability, reliability, and resistance to false inputs. We highlight these, as well as the feasibility and procedural flexibility of TBES, in an effort to promote our system as a competitive alternative to those currently available.

Q1

The advent of new technology often precedes major shifts in our understanding of ourselves and the world around us. This relationship, however, is not one of happenstance; technological advances allow researchers to improve the quality and quantity of their measurements. Once a technology's value is recognized, it is often adopted by related fields and used for novel purposes. The personal computer is a perfect example of this type of relationship. The personal computer has played a major role in psychology by providing a precise and flexible means for displaying stimuli and recording human and nonhuman animal behavior. As scientists continue to propose new questions regarding the structures of psychological experience, there continues to be a need for innovation of equipment and software designed to measure behavior. To this end, we introduce a software platform that supports the use of an iPad (Apple, Cupertino, California) for behavioral research. We briefly review the progression of equipment used in psychological research with nonhuman animals in order to emphasize the unique value of an iPad-equipped apparatus.

Small enclosed chambers were used in the 1930s to provide an environment for nonhuman animals to engage in repetitive behavior (e.g., leverpressing) unperturbed by the experimenter. The operant chambers were fitted with levers and cumulative recorders to quantify the acquisition and maintenance of learned behaviors (e.g., Nevin, 1967; Skinner, 1938, 1956). Paramount discoveries in psychology were made using a manipulandum (e.g., levers or chains for rats, peckable keylights for pigeons) and a recorder, and the fundamental operant setup remains an indispensable tool for behavioral and pharmacological studies that focus on stimulus control, motivational factors, and response timing. Unfortunately, recording other dimensions of responding, such as *where* responses were emitted, was limited by the number of manipulanda with which a chamber could be equipped.

Psychologists interested in measuring where a response occurred (i.e., spatial learning and memory) often chose more ecologically valid preparations than the operant chamber, such as open fields and mazes. However, comparative psychologists began using touchscreen-equipped operant chambers (TOCs) in the late 1980s to improve the accuracy and flexibility of stimulus presentation and response detection. In a TOC, stimuli can be presented across the entirety of a large display, and response detection is accurate across the same surface. As a result, TOCs have become a popular preparation for studying discrimination learning and spatial behavior (e.g., Leising, Garlick, & Blaisdell, 2011; Leising, Sawa, & Blaisdell, 2012; Leising, Wolf, & Ruprecht, 2013; Spetch, Cheng, & Mondoch, 1992).

The design of the modern TOC (e.g., Gibson, Wasserman, Frei, & Miller, 2004) calls for replacing one wall of a traditional operant chamber with a touchscreen-equipped monitor

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that serves two functions: (1) to display one or many computer-generated items or stimuli and (2) to record responses within a coordinate plane rather than in a binary fashion at a response manipulandum. Rats (Bussey, Muir, & Robbins, 1994; Cook, Geller, Zhang, & Gowda, 2004; Markham, Butt, & Dougher, 1996; Sahgel & Steckler, 1994), pigeons (Allan, 1992; Blough, 1986; Pisacreta & Rilling, 1987; Wright, Cook, Rivera, Sands, & Delius, 1988), and primates (Elsmore, Parkinson, & Mellgren, 1989) have been successfully trained to interact with a touchscreen. The most common touchscreen technology used with nonhuman animals is infrared. An infrared touchscreen operates by detecting a disruption in a matrix of photobeams. Together, the infrared touchscreen and accompanying video display enabled novel tasks to be presented, and moreover, held an advantage over traditional methods limited by the number of manipulanda available and the capacity of the slide projector displaying visual stimuli.

The modern TOC also has some advantages for the study of visual learning in rats. In a recent study, traditional response manipulanda (i.e., levers and lights) were compared with an infrared touchscreen-equipped display. Cook et al. (2004) reported faster development of goal-tracking behavior and acquisition of a visual discrimination task with two stimuli when rats viewed the stimuli and responded to a touchscreen, as compared with traditional lights and levers. Any technology capable of decreasing the time needed for an animal to learn a task is invaluable to researchers on many levels.

A custom-built or prefabricated TOC apparatus with infrared touchscreen technology for rats, however, is not an ideal solution for many researchers. First, they are expensive. A prefabricated touchscreen-equipped apparatus for rats ranges from ~$5,000 (Med Associates, Georgia, VT) to ~$10,000 (Lafayette Instruments, Lafayette, IN) per unit. The software is often sold separately as a package (e.g., Med Associates, ~$3,000) or as specific software modules needed for each procedure (e.g., autoshaping; Lafayette Instruments, ~$1100). These costs will likely prevent widespread adoption by psychologists, especially those at smaller institutions. Second, the accuracy of data recording within the TOC has encountered difficulties. The rat's whiskers or tail can break the infrared field, resulting in false positives. Some fairly elaborate but also intrusive (i.e., reducing the use of the entire screen) modifications have been developed to circumvent these problems. In sum, there is a need for a highly reliable and affordable touchscreen technology that is resistant to false positives, permits responding across the entirety of the search space, and can be adopted by those with limited budgets.

The iPad is quickly becoming a useful tool in institutional research settings as a wireless apparatus that offers a high degree of accuracy and customization (e.g., Geist, 2011; Leising et al., 2012). In terms of accessibility, the iPad is highly affordable (a 16-GB iPad-2 can be purchased for $399). In terms of feasibility, one distinct advantage of the iPad platform is the capacitive sensor grid used to detect responses. The capacitive sensor responds to changes in conductance, such as contact from a finger or paw, to record a response. This method eliminates the problem of whisker/tail beam breaks.

The purpose of the present analysis is threefold. First, we describe specifications of the hardware necessary for implementing an iPad into a traditional operant chamber. Q2 Second, we discuss the specifications of the software, Touchscreen Behavioral Evaluation System (TBES), available for free as an App in the iTunes™ store. Third, we report the successful shaping of a group of rats using our iPad hardware and software. The possibilities of a more seamless and automated comparative analysis between nonhumans and humans is much improved by use of the iPad and its ability to present analogous tasks to various species.

Method

Subjects

The subjects were 4 female and 3 male Long-Evans strain rats bred in the TCU vivarium from parents obtained from Harlan Laboratories (Indianapolis, IN). Subjects were pair-housed in translucent plastic tubs with a substrate of wood shavings in a vivarium maintained on a 12:12-h light:dark 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 subject reached 80 %–85 % of its free-feeding weight. All animals were handled daily for 30 s for a week prior to the initiation of the study.

Hardware

Operant chamber

All tests occurred within a standard operant chamber measuring 30 × 25 × 20 cm (l × w × h) housed within a sound- and light-attenuating environmental isolation chest (Med Associates). The walls and ceiling of the chamber were composed of clear Plexiglas, and the floor was constructed of stainless steel rods measuring 0.5 cm in diameter, spaced 1.5 cm center-to-center. The chamber was equipped with a dipper, located on the rear wall of the chamber opposite the iPad mount, capable of delivering sucrose solution (18 % v/v). When in the raised position, a small well (0.05 cc) at the end of the dipper arm protruded up into the drinking niche. Breaks to an infrared beam positioned over the dipper measured entries into the drinking niche. Ventilation fans in each enclosure and a white-noise generator on a shelf outside of the enclosure provided a constant 74-dB(A) background noise.

iPad and mount

A 16-GB iPad 2 (model A1395) was used in the experiment. Figure 1 shows the iPad mount.

The mount for the iPad was constructed of three pieces of black poster board. The individual pieces of poster board were held together by four sets of nuts, bolts, and washers located in each of the four corners of the mount. A rectangular recess of 0.96 cm was made in the front face of the poster board (i.e., first two pieces of poster board). Holes were drilled for ventilation every 2.34 cm in the poster board recess. The four sets of nuts and bolts were used to attach the iPad mount to the operant chamber.

In order to allow for rat access to the iPad when mounted outside the box, the modular panels on the back wall of a standard Med Associates operant chamber were removed. To keep the edges of the iPad and mount recess protected, three large removable panels (12.38 cm tall × 7.9 cm wide) were positioned above the mount, and three smaller panels (4.13 cm tall × 7.9 cm wide) were fixed 2.54 cm from the base of the chamber.

Software

TBES

iPad TBES application We refer to TBES as a system because it requires, at a minimum, an iPad and two freely downloadable software components: (1) the TBES App, available in the Mac App Store (Apple, Cupertino, California), and (2) a server program written in a programming language able to use TCP/IP sockets to communicate with the TBES App. For the latter component, we wrote an application in Microsoft Visual Basic 6 (VB6; Redmond, WA), VB6 TBES server, which is software used by many behavioral research labs. The VB6 TBES server is described below. The TBES App is written in Apple Xcode 4 for iOS 5.0 or later. Apple iOS 5 is available for the original iPad, iPad 2, and iPad 3. The App uses TCP/IP sockets to exchange data packets with the host PC. The host PC is programmed to simultaneously run the Med-Associates operant chamber(s) and communicate with the iPad(s). Upon startup, the iPad immediately seeks to establish a connection on a user-defined port number. The port number is customizable, allowing experimenters to utilize open ports within their system and enabling communication with multiple iPads.

The iPad screen is divided into two rows of three equal sections (see Fig. 1) and is numbered from top-left to bottom-right, allowing for the use of six stimulus/response locations. The TBES App is written to receive a series of stimulus IDs in the same order as the response locations. Seven stimuli are preprogrammed into the App (see Fig. 2) and assigned numeric IDs. These stimuli were chosen so researchers could investigate discrimination learning of brightness (light vs. dark) and patterns (sinusoidal patterns and images).[1] If the TBES App receives a value for one of the six sections, the stimulus identified by that value is placed in that section. If no value is given, a black square is presented, allowing for data collection within that section. During a trial, stimuli are presented in the assigned screen locations. All six locations display black squares during the time between trials, or the intertrial interval (ITI). When a subject makes contact, nose or paw, with one of the six locations, the iPad returns the Section ID to the host PC. The TBES App detects a response based on a “mouse down” event, which represents initial contact with the iPad display. The TBES server then determines whether the response was correct or incorrect.

Visual basic TBES server The TBES server application is available as a freely downloadable executable with all of the components needed to run the program on Windows XP and Windows 7 included in the setup file (.exe). The host computer must also have Microsoft Excel installed. The server application includes the following training programs: magazine training, autoshaping, successive discrimination, and simultaneous discrimination. During *magazine* training, a signal to raise the dipper is delivered every 60 s, and the dipper waits for a signal from the infrared detector to initiate a 5-s access period before lowering the dipper (see Table 1 for customization). No visual stimuli are presented. During *autoshaping*, a 5.7-cm training stimulus is displayed in position 2 (see Fig. 1) for 15 s, followed by a reward delivery command. A press to the training stimulus will also issue a reward delivery command (see Table 1 for customization). During the *successive discrimination* procedure, the set of six 5.7-cm images are divided into two categories. In one category (S+), a press to the image results in reward delivery. Presses to images in the second category (S−) result in a 10-s timeout period with no stimuli. If no response is made to the S+ or S−, then the trial times out after 15 s. During the *simultaneous discrimination* procedure, the same six stimuli are designated as S+ and S− but are presented simultaneously on the screen in positions 1 and 3, randomized across trials. Trials end if a response to the S+ is made or after 120 s, whichever comes first. Responses to the S − are recorded but have no nominal effects.

The program requires that each subject should have his or her own parameters file, which allows customization of program details (see Table 1). Lastly, the ability to control Med Associates Hardware requires Med Associates Control of Hardware from other Programming Languages software ($1,000 at time of submission) or the ability to control the hardware using custom code. The PC to iPad connection can

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[1] At present, these images cannot be replaced, but we expect to release an updated version of the TBES App (V3.0) that will allow users to add an infinite number of images via a Dropbox® account on the iPad.

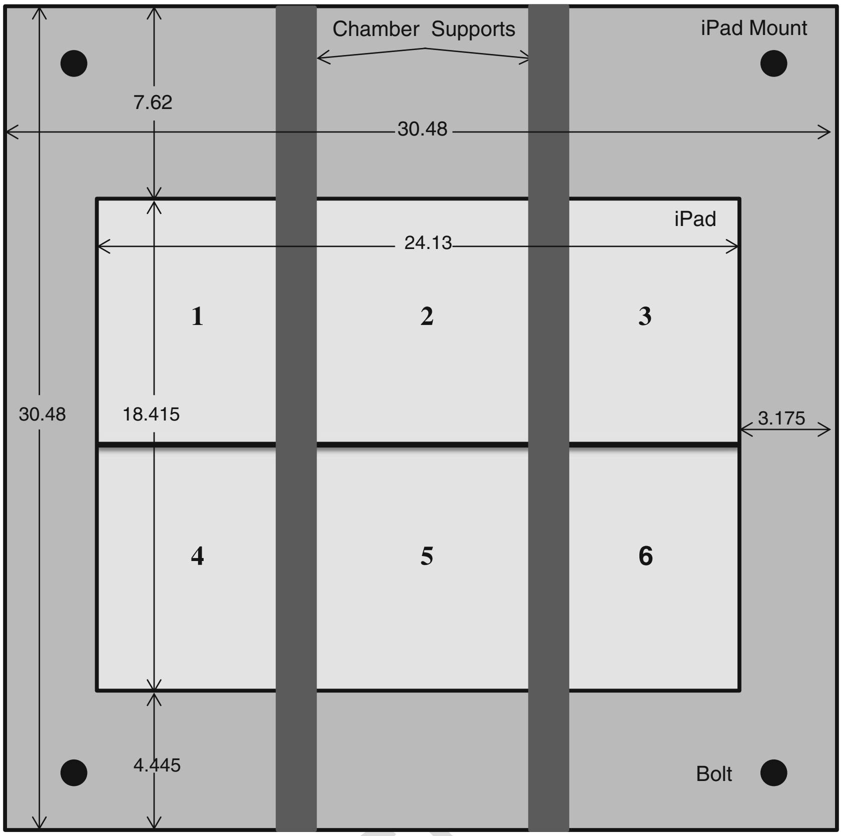

Fig. 1 A schematic of the iPad (light gray) and mounting apparatus (dark gray). The larger bold numbers represent the six distinct response/stimulus locations present on the iPad. The smaller numbers represent dimensions (in centimeters). Both the iPad and the vertical mount for the iPad are located behind chamber supports (darkest gray)

also be accomplished via a remote desktop program, such as RDP (Mochasoft Aps, Blokhus, Denmark), which can be downloaded from the Mac App Store (Apple, Cupertino, California). We have collected data with the TBES App, as well as a remote desktop program.[2]

Procedure

Feasibility

The feasibility of using an iPad apparatus with TBES (App and server) was tested in a number of ways: We tested (1) the latency from a tap on the iPad to sucrose dipper activation, controlled by the Med-PC hardware, (2) the sensitivity of the iPad by recording the number (out of 100) of taps registered, (3) whether a press (with paw) or a poke (with nose) from rats and mice were capable of meeting the iPad's capacitive sensor criterion necessary for a response, (4) whether the iPad screen needed a protective covering, (5) data collection and customization. Finally, we measured the battery life of the iPad during a typical day of use (9:30 a.m. to 5:30 p.m.)

Phase 1

In Phase 1, subjects were trained to drink sucrose from the feeding niche in the presence of the iPad. The iPad was placed inside the operant box at a 54° angle in relation to the grid floor of the chamber (side opposite the dipper; see Fig. 3). All six of the screen response locations were filled with the black square, creating a uniform dark surface. The training stimulus was not presented during phase 1, but 30 sucrose presentations were delivered on a fixed-interval schedule of 60 s. When sucrose was delivered, the dipper arm elevated and waited to lower until 3 s after the subject interrupted the infrared beam located inside the feeding niche.

An interruption of the infrared beam by the subject was required before the arm lowered and another ITI was initiated.

The houselight remained off while the dipper was elevated but co-terminated with the onset of the ITI following sucrose. Rats were required to access the sucrose on 90 % of trials (27/30) before advancing to phase 2.

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[2] We selected RDP after experience with many others because it offers many features and settings that are customizable. The features of RDP most essential to the researcher can be seen in Appendix 1. The RDP program replaces the iPad display with that of the host PC. All stimuli and responses made on the iPad are controlled by the host PC. This eliminates the need for the TBES to display stimuli and detect responses.

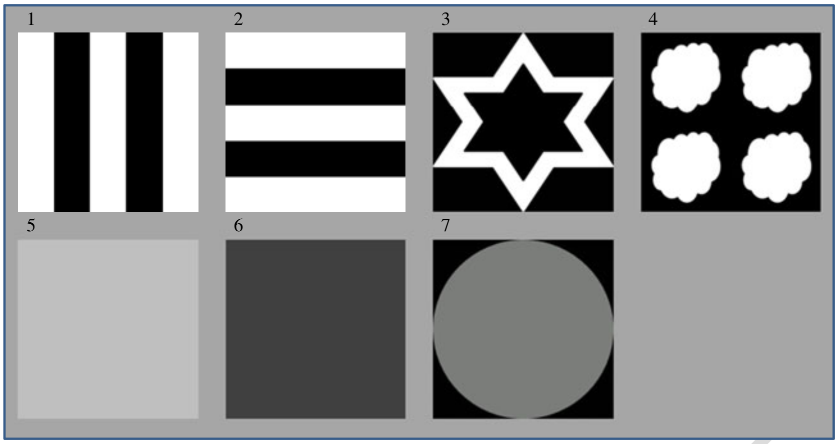

Fig. 2 The seven preprogrammed images that come with the TBES App. Image 7 is the stimulus used throughout the training procedure

Phase 2

The iPad remained in the slanted position. The slanted positioning of the iPad made use of the rats' natural tendency to rear and facilitated interaction with the display (see Fig. 3). Subjects received an autoshaping procedure, which consisted of 30 forward-paired trials of a 15-s stimulus followed immediately by 3-s access to the unconditioned stimulus (US), sucrose (e.g., Brown & Jenkins, 1968). The 5.7-cm light gray circle served as the training stimulus (see Fig. 2, Image 7). The training stimulus was positioned in the top-middle of the display. While the delivery of the US was not contingent on a response from the subject, a press (paw or nose) to the training stimulus terminated the stimulus presentation and activated US/reward delivery. Subjects were required to make at least one correct press to the training stimulus before manual shaping was implemented.

During manual shaping, the experimenter was able to activate reward delivery via a variety of keys on the host PC. The goal of shaping is to systematically reinforce approximations of a target behavior, which, in this case, was contacting the training stimulus on the iPad screen. A variety of commonly used commands are preprogrammed (assigned to keys) in the TBES server to facilitate the shaping process (see Appendix 2).

Table 1 The customizable components of a subject's parameter file

Customizable Component	Value (Integer)	Default Value	Parameter Description
Number of trials	unlimited	30	A session will terminate after all trials are completed (if more than one trial type, an equal number of each will be randomly presented)
Session duration	minutes	30	A session will terminate after the duration (irrespective of trials completed)
Dipper waits for head detection	0 or 1	1	If = 0, dipper lowers following the dipper duration
			If = 1, dipper lowers following a head detection and subsequent dipper duration
Stimulus duration	seconds	15	The duration a stimulus is presented
Dipper activation in response to stimulus press	0 or 1	1	If = 0, dipper not activated by a response to stimulus
			If = 1, dipper activated by a response to stimulus
Dipper activation in response to end of stimulus	0 or 1	1	If = 0, dipper not activated by end of stimulus presentation (animal must make response to activate dipper)
			If = 1, dipper is activated by end of stimulus presentation (animal not required to make response to activate dipper)
Dipper duration	seconds	5	Duration of dipper activation
Response or correct intertrial interval (ITI)	seconds	20	Duration of ITI after correct response
No response or correct ITI	seconds	80	Duration of ITI after no response or incorrect response
Fixed interval	milliseconds	1,000	The duration a stimulus must be present before a response will be reinforced

Fig. 3 A rat exploring the iPad screen in the slanted position during magazine training

After subjects pressed the stimulus on five consecutive trials on two separate occasions, or 10 consecutive presses, during the same session they were placed on a continuous reinforcement (CRF) operant schedule. During the CRF operant sessions, the duration of the stimulus was still 15 s, but the reward was delivered only if the training stimulus was pressed. Trials without a press terminated with the illumination of the houselight and a 20-s ITI, which separated all trials. The houselight remained off during the trial. Subjects were required to correctly respond on 90 % (27/30 trials) of trials to advance to phase 3.

Phase 3

The procedural details of phase 3 are identical to those of phase 2, with the exception that the iPad was mounted in the upright position behind the back supports of the operant chamber (see Fig. 4). Phase 3 consisted of sessions of manual shaping until five consecutive trials with a press occurred during the same session on two separate occasions, or 10 consecutive presses. Subjects were then advanced to a CRF schedule of reinforcement. Training continued until subjects responded correctly on 90 % (27/30 trials) of trials.

Results

Feasibility results

Latency

The TBES App was modified to generate a response signal every 1 s. The VB TBES server program included used a function to count an interval in milliseconds (1-ms resolution). When the server program received the response signal from the TBES App, the duration between signals was recorded. Deviations from 1,000 ms would be the result of the network signal. We compared these intervals with another set recorded on the basis of a timer hardcoded into the server program (i.e., no network). The timers were used to generate 100 recorded intervals per method. Both methods returned latencies of less than 5 ms. The variability of the wireless App was minimal (M = 3 ms, SD = 4 ms); however, the hardwired system produced no recorded variability.

Reliability

The RDP and TBES Apps both registered 100 % of human presses (100 out of 100), indicating high sensitivity and reliability. During interactions with the iPad, the paw and nose from a rat and mouse were found to successfully register on the iPad's capacitive display.

Screen protection

The use of two separate screen protectors was terminated, since they encouraged scratching and gnawing at the screen within 1–2 sessions. During subsequent use with an unprotected iPad

Fig. 4 The image on the left shows a rat engaged in a paw press, whereas the image on the right shows a rat engaged in a nose press at the iPad

screen (~60 sessions; see Leising et al., 2013), no damage occurred.

Data collection

Data collection from 50 presses across 10 sessions was without error. The VB6 TBES server program collected and stored the data of interest in two Microsoft Excel files. During the session, the trial-by-trial data were stored in a file titled by the subject's identifier and the session number, with sufficient detail to determine the time, location, and category of the response (i.e., correct or incorrect). At the end of a session, summary statistics from the session were stored in an Excel file that included summary data from other animals in the same experiment.

Battery life

We estimate that the iPad can be used for conducting research with TBES for up to 20 h before requiring charging. The iPad uses approximately 5 % (different programs utilize slightly different amounts of charge) of its overall charge for every 1 h of running time.

Shaping

Phase 1

Figure 5 displays the number of sessions to complete each phase of training. During phase 1, 6 of the 7 rats met the drinking criterion (27/30 trials drinking sucrose) after one session and advanced to phase 2. One rat repeated a session of phase 1 before advancing to phase 2.

Phase 2

During autoshaping with the iPad in the slanted position, all rats accessed the dipper following the appearance of the training stimulus. After drinking sucrose, the rats actively explored the chamber and the iPad. By the end of the of the second 30-trial session, 6 of the 7 rats (86 %) had already made one press or poke to the stimulus. After a mean of 1.71 (*SEM* = 0.29) autoshaping sessions, all rats had pressed the stimulus and were advanced to manual shaping.

After only a few manual shaping trials (e.g., 5–10), all rats began to check the dipper after making contact with any part of the iPad screen. After approximately 15–20 trials (number of trials varied from rat to rat), most rats were consistently making contact with the training stimulus in the form of paw presses (no nose pokes had emerged). After a mean of 1.89 (*SEM* = 0.26) manual shaping sessions, each rat was placed on a CRF operant schedule for the remainder of the 30 trials. It was during this phase that one of the rats developed a nose press strategy. Figure 4 shows an example of a press and poke response, respectively. It is difficult to say why nose poking became the dominant method of responding in one rat. It is possible that nose poking was incidentally reinforced during shaping or, perhaps, was an easier method of responding for that particular rat during the CRF schedule. The rats required only one session of CRF to achieve the final criterion of 90 % of trials with a correct response, (27/30).

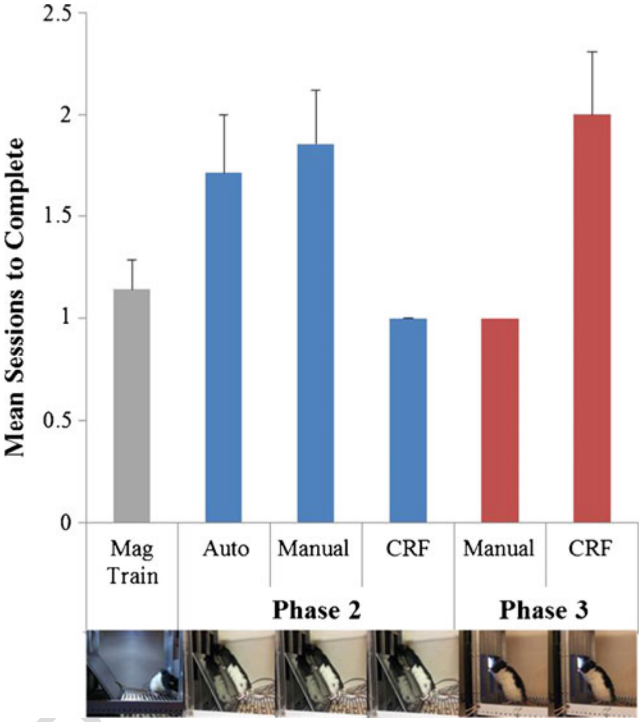

Fig. 5 Mean sessions in each phase of training. The light gray bar represents Phase 1. The images below the figure indicate the position of the iPad during each phase of training. Error bars represent standard errors of the means

Phase 3

After demonstrating reliable responding to the training stimulus with the iPad in the slanted position, rats were trained with the iPad in the vertical mount. All rats required only one session of manual shaping to achieve reliable responding to the vertically mounted iPad.

After manual shaping, the rats were reliably responding and reached the final criterion of 90 % of trials with a correct response to the stimulus with a mean of 2 (*SEM* = 0.31) sessions. The same rat from phase 2 who developed a poke press strategy with the iPad in the slanted position continued to utilize this strategy for the remainder of phase 3.

Discussion

The purpose of the present set of experimental tests was to evaluate whether the proposed iPad-equipped system (TBES) was a feasible and flexible alternative to the touchscreen technology currently available for behavioral and neuroscience research. The results of the feasibility tests showed that TBES is a sensitive, reliable, and flexible platform for recording responses by rats (both nose and paw). Rats trained with this system acquired the basic task of reliably responding to the training stimulus with the vertically mounted iPad within a mean of eight sessions (*SD* = 0.82).

TBES can easily be constructed to work in conjunction with existing operant chambers and is cost effective, when compared with prefabricated TOC systems. At the bare minimum, the basic hardware, software, and additional software packages needed to embark on even a simple shaping task with a prefabricated touchscreen system cost at least $8,000. Our proposed iPad equipped apparatus includes the following: a TBES server program (freely downloadable), a TBES App (freely downloadable), an iPad ($399 at time of submission), and either the Med Associates Control of Hardware from other Programming Languages software ($1,000 at time of submission) or the ability to control the hardware from another programming language. The TBES App and TBES server program are also open source, giving immediate access to the developed program or the freedom to modify for individual purposes. The provided programs (manual shaping, autoshaping, successive discrimination, and simultaneous discrimination) allow researchers to easily replicate and directly compare results.

Major changes, such as to the stimulus layout, would require knowledge of XCode and Visual Basic. However, choosing between the various training procedures requires no programming knowledge but, rather, requires a click to the desired procedure from a drop-down menu at the start-up of the program. We also included a simple method for altering the 10 most commonly changed visual discrimination learning parameters. These changes require simply replacing the default values of cells within a Microsoft Excel file.

The tests described here demonstrate that TBES is more than just a cost-effective alternative to the current touchscreen technology but, furthermore, provides a glimpse of the potential for asking new questions about the mind and behavior of nonhuman animals. Lastly, the results demonstrate how TBES is well suited for conducting hands-on classroom demonstrations or laboratories associated with psychology courses. Rats could quickly be trained to interact with an iPad within 2-weeks of a semester-long course. Just as the personal computer was adopted by researchers in fields unrelated to its initial development, it is our hope that the iPad and related technologies can be utilized by researchers interested in both human and nonhuman behavior.

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Appendix 1

Table 2 Identification and description of remote desktop settings

Setting and Display Options	Value	Description of Options
PC keyboard type	US	
Screen size	800 × 600 pixels	
16-bit color mode	On or Off	
Mouse at finger	On or Off	On = ipad responds to the first touch it senses Off = ipad waits for the response to come off screen before responding
Show warnings	On or Off	Off = memory usage warnings not displayed
Show circle at click	On or Off	Off = ipad does not show green circle around response point
View mode only	On or Off	Display only or record responses on the remote computer
Motions	On or Off	Multifinger motions disabled
Wireless keyboard	On or Off	Bluetooth keyboard option

Note. Settings and display options important for use with the remote desktop App (RDP). Whether or not the wireless keyboard option is activated depends on system availability. Screen size is in pixels.

Appendix 2

Table 3 Identification and description of shaping keys for TBES

Key "F"	Key "R"	Key "U"	Key "D"	Key "H"	Key "L"	Key "I"	Key "P"
Freezes stimulus on screen	Resumes regular trials	Elevates dipper (up)	Lowers dipper (down)	Reinforce trial as if correct response	Lengthens stimulus interval	Operant: response required	Pavlovian: response not required

Note. The shaping keys included in the TBES package. Top row of the table displays the key available for use while the bottom row indicates the outcome of a keypress.

References

Allan, R. W. (1992). Technologies to reliably transduce the topographical details of pigeons' pecks. *Behavior Research Methods, Instruments, and Computers, 24,* 150–156.

Q3 Badelt, S. W., & Blaisdell, A. P. (2008). Capacitive sensors for detecting proximity and response. *Behavior Research Methods, 40,* 613–621.

Blough, D. S. (1986). Odd-item search by pigeons: Method, instrumentation, and uses. *Behavior Research Methods, Instruments, and Computers, 18,* 413–419.

Brown, P. L., & Jenkins, H. M. (1968). Auto-shaping of the pigeon's keypeck. *Journal of the Experimental Analysis of Behavior, 11,* 1–8.

Bussey, T. J., Muir, J. L., & Robbins, T. W. (1994). A novel automated touchscreen procedure for assessing learning in the rat using computer graphic stimuli. *Neuroscience Research Communications, 15,* 103–110.

Q4 Cheng, K. (1988). Some psychophysics of the pigeon's use of landmarks. *Journal of Comparative Physiology, 162,* 815–826.

Q5 Clarke, R. L., Smith, R. F., & Justesen, D. R. (1985). An infrared device for detecting locomotor activity. *Behavior Research Methods, Instruments & Computers, 17,* 519–525.

Cook, R. G., Geller, A. I., Zhang, G. R., & Gowda, R. (2004). Touchscreen-enhanced visual learning in rats. *Behavioral Research Methods, Instruments, and Computers, 36,* 101–106.

Elsmore, T. F., Parkinson, J. K., & Mellgren, R. L. (1989). Video touchscreen stimulus response surface for use with primates. *Bulletin of the Psychonomic Society, 27*(1), 60–63.

Q6 Emmerton, J. (2001). Pigeons' discrimination of color proportion in computer generated visual displays. *Animal Learning and Behavior, 29*(1), 21–35.

Geist, E. (2011). The game changer: Using iPads in college teacher education classes. *College Student Journal, 45,* 758–768.

Gibson, B. M., Wasserman, E. A., Frei, L., & Miller, K. (2004). Recent advances in operant conditioning technology: A versatile and affordable computerized touchscreen system. *Behavior Research Methods, Instruments, & Computers, 36,* 355–362.

Q7 Kendall, S. B. (1983). Tests for mediated transfer in pigeons. *Psychological Record, 33,* 245–256.

Leising, K. J., Garlick, D., & Blaisdell, A. P. (2011). Overshadowing by proximity with pigeons in an automated open-field and touch screen. *Journal of Experimental Psychology: Animal Behavior, 37*(4), 488–494.

Q8 Leising, K. J., Garlick, D., Parenteau, M., & Blaisdell, A. P. (2009). Behavioral research in pigeons with ARENA: An automated remote environmental navigation apparatus. *Behaviuoral Processes, 81,* 105–113.

Leising, K. J., Sawa, K., & Blaisdell, A. P. (2012). Factors that influence negative summation in a spatial-search task with pigeons. *Behavioral Processes, 90*(3), 357–363.

Leising, K. J., Wolf, J. E., & Ruprecht, C. M. (2013). Visual Discrimination Learning With an iPad-Equipped Apparatus. *Behavioral Processes, 93,* 140–147.

Markham, M. R., Butt, A. E., & Dougher, M. J. (1996). A computer touch-screen apparatus for training visual discriminations in rats. *Journal of the Experimental Analysis of Behavior, 65,* 173–182.

Morris, R. G. M. (1984). Developments of a water-maze procedure for studying spatial-learning in the rat. *Neuroscience Methods, 11,* 47–60. Q9

Nevin, J. A. (1967). Effects of reinforcement scheduling on simultaneous discrimination performance. *Journal of the Experimental Analysis of Behavior, 10*(3), 251–260.

Noldus, L. P. J. J., Spink, A. J., & Tegelenbosch, R. A. J. (2001). EthoVision: A versatile video tracking system for automation of behavioral experiments. *Behavior Research Methods, Instruments, and Computers, 33*(3), 398–414. Q10

Perkins, D., Lydersen, T., & Chairez, H. (1976). Fixed-ratio discrimination: Comparison of spatial and nonspatial choice procedures. *Perceptual and Motor Skills, 43*(2), 587–593. Q11

Pisacreta, R., & Rilling, M. (1987). Infrared touch technology as a response detector in animal research. *Behavior Research Methods, Instruments, and Computers, 19,* 389–396.

Reynolds, G. S., & Limpo, A. J. (1969). Attention and generalization during a conditional discrimination. *Journal of the Experimental Analysis of Behavior, 12*(6), 911–916. Q12

Sahgel, A., & Steckler, T. (1994). Touch Windows and operant behavior in rats. *Journal of Neuroscience Methods, 55*(1), 59–64.

Skinner, B. F. (1938). *The behavior of organisms*. New York: Appleton-Century-Crofts.

Skinner, B. F. (1956). A case history in scientific method. *American Psychologist, 11,* 221–233.

Spetch, M. L., Cheng, K., & Mondoch, M. V. (1992). Landmark use by pigeons in a touch-screen spatial search task. *Animal Learning and Behavior, 20*(3), 281–292.

Walsh, R. N., & Cummins, R. A. (1976). The open-field test: A critical review. *Psychological Bulletin, 83,* 482–504. Q13

Wright, A. A., Cook, R. G., Rivera, J. J., Sands, S. F., & Delius, J. D. (1988). Concept learning by pigeons: Matching-to-sample with trial-unique video picture stimuli. *Animal Learning and Behavior, 16,* 436–444.

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