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Use of a Touchscreen-mediated Testing System with Mandrill Monkeys

Katherine A. Leighty and Margaret A. Maloney
Disney's Animal Programs and Environmental Initiatives, U.S.A.

Christopher W. Kuhar
Cleveland Metroparks Zoo, U.S.A.

Rebecca S. Phillips, Jonathan M. Wild,
Monica S. Chaplin, and Tamara L. Bettinger
Disney's Animal Programs and Environmental Initiatives, U.S.A.

Relatively little is known of the cognitive and perceptual abilities of mandrill monkeys (*Mandrillus sphinx*). Here, we document how seven adult mandrills were trained to effectively use a touchscreen-mediated testing system. Upon mastering use of this device, subjects were presented with two automated discrimination tasks; one requiring discrimination of the target from an array of distracters using color, the second requiring discrimination by shape. Examination of individual differences in both training and testing performance provided evidence that position in the social hierarchy and circumstances of the testing environment impacted learning. Further, examination of error production revealed that errors were not distributed randomly, with subjects being attracted to a biologically relevant color and a shape that was featurally similar to the target.

Mandrills (*Mandrillus sphinx)*, the largest of the cercopithicine monkeys, reside across large home ranges in the dense rainforests of western Central Africa (Jouventin, 1975; Rowe, 1996; Rowell, 1972; Sleeper, 1997). They live in large matrilineal groups with peripheral males entering the group during breeding season (Abernethy, White, & Wickings, 2002). Perhaps due to the dense habitat in which they live, their shy demeanor, and/or the size of their home range, mandrills have proven to be difficult to study in the wild (Campbell, Fuentes, MacKinnon, Panger, & Bearder, 2007; Rowell, 1972). Thus, much of what we know of these animals comes from studies conducted in captive settings including zoological parks and semi-free ranging research centers (Chang, Forthman, & Maple, 1999; Markowitz, Stevens, Mellen, & Barrow, 1981; Mellen, Littlewood, Barrow, & Stevens, 1981; Setchell & Dixson, 2001a,b; Setchell & Wickings, 2004, 2005; Yanofsky & Markowitz, 1978). While there have been relatively few investigations of their social behavior, even less is known about the cognitive and perceptual abilities of these animals.

Harlow and his colleagues were pioneers of early primate cognition research and examined an array of abilities across the taxa. They included

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mandrills from the Vilas Park Zoological Gardens and the Bronx Park Zoo as subjects in several of their studies. The focus of much of this work was on the impact of the duration of the delay period and presentation of distracters in memory tasks as well as performance on Harlow's famed patterned string tests in which the subject had to determine which of two or more strings was attached to a piece of food (Harlow, 1932; Harlow & Settlage, 1934; Harlow, Uehling, & Maslow, 1932; Maslow & Harlow, 1932; Yudin & Harlow, 1933). These researchers highlighted individual differences in performance rather than grouping individuals by species and discussed possible age and temperament effects when reporting their findings. For example, they stated that the poor performance of two mandrills was likely due to their "immaturity," and they believed that the inability of one mandrill to learn a task was a result of his "ill-tempered" nature (Harlow, Uehling, & Maslow, 1932; Maslow & Harlow, 1932). Although little detail beyond these subjective comments was provided, this work highlights the capacity of mandrills to learn complex cognitive tasks and emphasizes the need to examine findings at the level of the individual.

More recently, Markowitz and colleagues presented an adult male mandrill at the Washington Park Zoo with a simple reaction time task via a computerized game system (Markowitz et al., 1981; Yanofsky & Markowitz, 1978). The interactive system consisted of a console located inside the mandrill exhibit and an identical one mounted outside of the exhibit in the visitor viewing area. The mandrill would initiate a series of trials by pressing a plastic circle on his console. Visitors then had 15 seconds to press the circle on their console to join in; otherwise the computer would automatically make this response and become the challenger. Below the circle, one of three plastic squares would randomly illuminate and the objective was to see which player could press their lighted square the fastest. The mandrill's reaction times averaged below 500 ms, and he outperformed the human challengers in 57-68% of the games.

Computerized testing systems such as this were born of early technological advances in the study of animal learning such as the automated operant chamber ("Skinner box") (Heron & Skinner, 1939), lexigram keyboard (Rumbaugh, 1977), and joystick mediated testing system (Richardson, Washburn, Hopkins, Savage-Rumbaugh, & Rumbaugh, 1990). The successes of these approaches and continued technological innovations have made computerized testing systems a primary method of animal cognition research. Touchscreen displays are currently a popular mode of stimulus presentation and automated recording of subject responding. For example, these devices have been used across an array of primate species to address a number of cognitive abilities (squirrel monkeys (*Saimiri sciureus*) visual perception: Anderson, Kuwahata, Kuroshima, Leighty, & Fujita, 2005; chimpanzees (*Pan troglodytes*) navigational planning: Iversen & Matsuzawa, 2001; capuchin monkeys (*Cebus apella*), seriation tasks: McGonigle, Chalmers, & Dickinson, 2003; rhesus monkeys (*Macacca mullata*) face processing: Parr, Heintz, & Pradham, 2008; and gorillas (*Gorilla gorilla gorilla*) and orangutans (*Pongo abelii*) relational concept learning: Vonk, 2003). More recently, touchscreen displays have been used in cognitive research outside of the primate order, including work with dolphins (Delfour & Marten, 2005) and domestic dogs (Range, Aust, Steurer, & Huber, 2008).

Because touchscreen-mediated testing systems can be used by a variety of taxa, and because their computerized task presentation and data collection increases control across testing environments, they are likely to be a key methodology of future comparative cognition studies. It is for these reasons that we elected to train our collection of mandrill monkeys to utilize a touchscreen system to gain knowledge of the cognitive and perceptual abilities of this relatively under-investigated species. Here, we open this new line of inquiry by describing the process of training individual mandrills to use the touchscreen system with the aim that these accounts will benefit researchers wishing to utilize this technology with other naïve animals. Second, we documented the acquisition and error production of these individuals on two discrimination tasks to begin to illuminate how stimulus features (color and shape) impact the performance of these individuals. Following the work of Harlow and colleagues (Harlow, 1932; Harlow & Settlage, 1934; Harlow, Uehling, & Maslow, 1932; Maslow & Harlow, 1932; Yudin & Harlow, 1933) we highlight individual differences observed in the subjects and discuss them in relation to task performance.

Method

Subjects

Eight mandrills (3 males, 5 females; aged 6-19 years) housed at Disney's Animal Kingdom® served as subjects for this study (see Table 1). These animals were maintained as two troops that rotated each afternoon between an outside exhibit (926.07 m^2) and an inside holding area (114.83 m^2). Composition of these groups was variable over time due to changes in social organization, breeding recommendations, and transfers of animals to other facilities, but generally consisted of a larger social troop of 7 to 8 members and a smaller troop of 2 members. Testing sessions were conducted opportunistically while subjects were housed indoors. Subjects from the larger troop were typically separated, sometimes with 1 other animal, from the remainder of the troop during their sessions to allow them uninterrupted access to the touchscreen. When this occurred, their social troop was housed in an adjacent enclosure to which they had full visual and auditory access.

Table 1
Subject Information

Subject	Sex	Age[1]	Individual Characteristics[2]
S	M	19	Only male in the smaller troop
L	M	14	Most dominant male of the larger troop
W	M	6	Most subordinate male of the larger troop
D	F	17	A dominant female of the larger troop
P	F	16	A dominant female of the larger troop
J	F	14	Only female in the smaller troop
T	F	12	A subordinate female of the larger troop
N	F	12	A subordinate hand-reared female of the larger troop

[1]Age was calculated from the first day of testing.
[2]Dominance status determined based on priority of access to resources as well as observations of consistent displacements and submissions by the animal care staff.

Materials

All tasks were programmed in Microsoft Visual Basic and presented to the subjects on an Elo 17" IntelliTouch Entuitive surface wave touchscreen (model # ET-1726L-8SWF1) via a Hewlett-Packard Compaq dc5700 computer and later a Panasonic Toughbook CF-30. This testing equipment was set up on a heavy duty wheeled utility cart with the touchscreen monitor at one end facing the mandrill, and a computer monitor projecting the same image as the touchscreen facing the researcher on the opposite end. The cart was rolled up to the mesh for the testing sessions and the mandrills interacted with the touchscreen while seated on the floor of the enclosure (see Figure 1). None of the subjects had previously participated in cognitive research nor did they have any prior exposure to the touchscreen.

Figure 1. Image of subject interacting with the touchscreen testing system. Task depicted is training task #1. Image taken off-exhibit at Disney's Animal Kingdom®.

Initial touchscreen training

Initial training on use of the touchscreen progressed following the same general procedure for all subjects. This procedure was carried out as follows. The subject was first reinforced with small pieces of fruit for sitting in front of the monitor in order to habituate him or her to this novel item in their environment. Once the subject no longer avoided being in close proximity to or grabbed at the testing system, he or she was started on a series of three touchscreen training tasks. Each training session contained a maximum of 40 trials, typically lasted 5 to 10 minutes, and continued as long as the subject demonstrated interest in participating in the task. Effort was made by the experimenter to end each training session on a positive note. During this initial training, subjects were typically exposed to several sessions per day, as frequently as researchers' schedules allowed (typically 4 times per week). Determination of the rate of advancement through the training phases was made subjectively by the researcher; insuring that the animal was not having trouble physically selecting the stimuli and was attentive to the task.

In the first training task, the mandrill was shaped to touch a large blue square (24.76 x 24.76 cm) centered on the monitor (see Figure 2A). This process began by training the subjects to reach through the mesh of their enclosure and touch the monitor by placing grape halves or currants on the blue square stimulus. The verbal command of "touch" was then delivered by the researcher administering the task. The action of retrieving the food item from the screen often resulted in the subject's finger touching the blue square stimulus. This selection of the square resulted in a "correct" tone being produced by the computer and delivery of another small piece of fruit to the subject. When the subject would retrieve the mounted food item without touching the blue square, a reinforcer was still delivered during the first few training sessions. By the third or fourth session, the mounted food items were typically removed from the monitor as subjects had learned to associate touching the large blue square with receipt of food rewards. At this point, the interaction of the subject with the automated computer system controlled the progression of the sessions. For all remaining training and testing tasks, the subject was required to select the large blue square introduced in the first training task at the beginning of each trial to indicate their readiness to participate.

In order to begin refining the subject's touch to a smaller area, the blue target square in the second training task was reduced in size (13.97 x 13.97 cm) but still centered on the monitor (see Figure 2B). In the third and final phase of training, the dimensions of the blue square were again reduced (3.81 x 3.81 cm) and its position was randomized on the screen to train the subjects to make selections on all areas of the monitor (see Figure 2C).

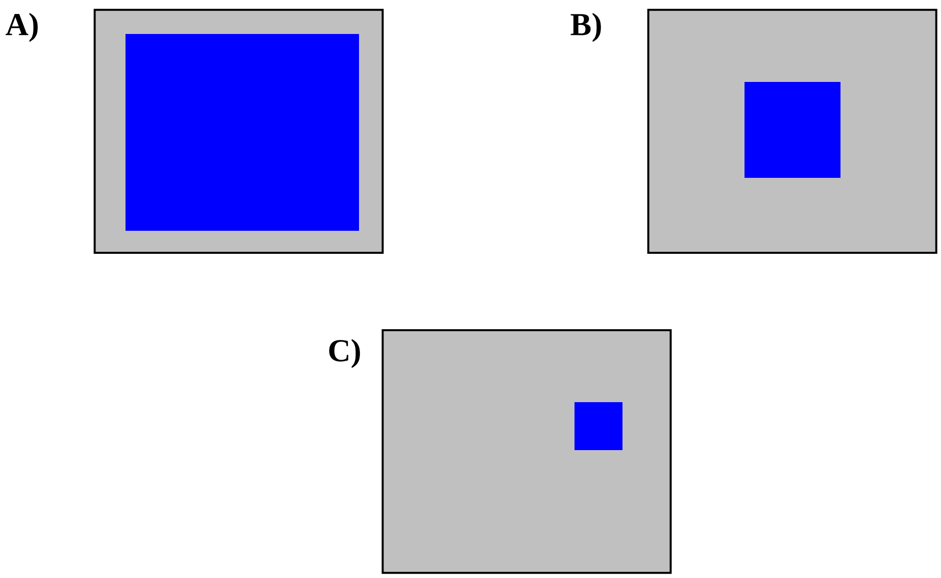

Figure 2. Depiction of the touchscreen training tasks: A) training task #1 in which the blue square measured 24.76 x 24.76 cm, this stimulus was also used on the initiation screen of each future task B) training task #2 in which the blue square measured 13.97 x 13.97 cm C) training task #3 in which the blue square measured 3.81 x 3.81 cm.

Discrimination tasks

Seven of the eight subjects mastered the three touchscreen training tasks and were then administered two discrimination tasks; a color discrimination task followed by a shape discrimination task. These tasks were presented at a maximum of one session per day per subject, typically 4 days per week. In the color discrimination task, subjects were required to select the blue square (3.81 x 3.81 cm) from an array of three distracter squares of the same size (all colored red, yellow, or green) (see Figure 3A). All colors were set to 100% saturation and brightness. The position of all squares on the screen was randomized with the restriction that no squares were overlapping or had their boundaries touching. When the blue square was selected the screen cleared, the "correct" tone was produced, and the food reinforcer was delivered. When a distracter square was selected (i.e., a non-blue square), the task would disappear from the screen, no tone was produced, and the subject entered a 5000 ms time-out period before continuing to the next trial. Touches made outside of the square stimuli did not impact the trial outcome. Testing sessions consisted of 21 trials, with a 2500 ms inter-trial interval. Criterion performance on this task was defined as correct responding on 17 or more trials within a session (>80%) across five consecutive sessions. The shape discrimination task was carried out with the same contingencies as the color discrimination task except that the subjects were required to select the blue target square (3.81 x 3.81 cm) from an array of three blue non-square distracter stimuli (all three being circles, triangles, or diamonds) (see Figure 3B).

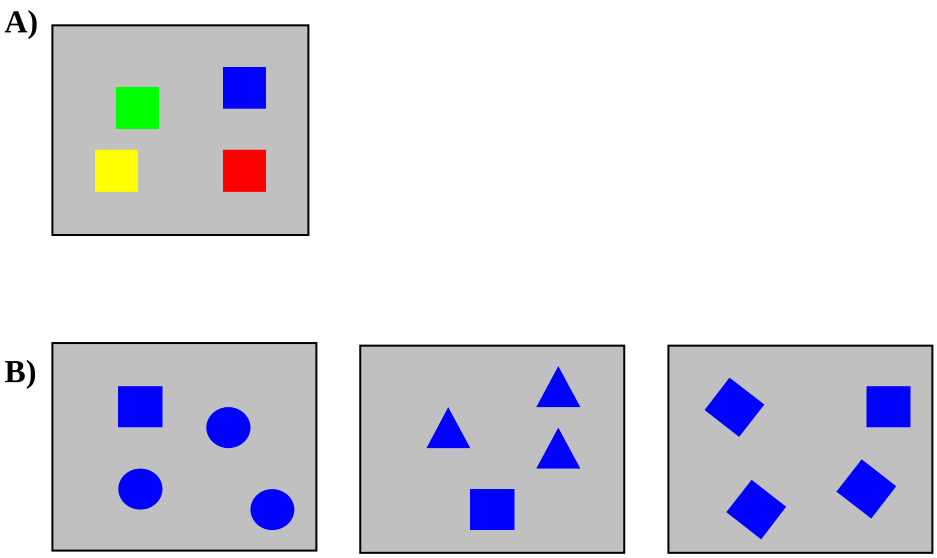

Figure 3. Depiction of discrimination tasks: A) color discrimination task in which the blue square was presented with red, green, and yellow distracter squares B) shape discrimination task in which the blue square was presented with circle, triangle, and diamond distracter stimuli.

Data collection and analysis

For both the color and shape discrimination procedures, we documented task acquisition as a function of the percentage of "correct" responses made per session and the number of sessions needed to attain criterion performance on the task. An error that was initially present in the data collection code of the color discrimination task invalidated the data from the first three subjects that were administered the task (J, L, and S). Data on task performance and rate of acquisition were systematically collected from the remaining four subjects for this task, and for all seven subjects for the shape discrimination task. To determine if distracter color or shape had a significant impact on subjects' responding or whether they distributed their errors randomly across distracters, errors made in the first five sessions (i.e., task novice) and the last five sessions (i.e., task mastery) of each task were analyzed using the G-test of goodness-of-fit. Finally, a Z-test for proportions was utilized to investigate potential sex effects in error distribution. Statistical analyses were conducted using SPSS version 15.0 (Chicago, Illinois) and PopTools version 2.7.5, with alpha set at 0.05.

Results

Initial touchscreen training

Qualitative accounts of individual performance and progression through the training tasks are presented in Table 2. Seven of eight mandrills advanced through the three training tasks and learned to reliably make selections on the touchscreen. Mandrill "N" never learned to associate touches of the target stimuli with food reinforcement and after multiple attempts to grab and destroy the testing equipment, the decision was made to halt training with this subject.

Table 2

Individual accounts of touchscreen acquisition process

S	Subject never avoided the testing cart but initially looked away from the screen frequently to monitor the experimenter and lost interest in the task quickly. Focus was regained by using a more valued food reward (peanuts) for a brief period. Subject would initially swipe at the screen with the whole hand and would leave his hand on the screen at the end of trials. The experimenter shaped the subject to remove his hand between trials and the swiping technique was refined to a touch across the first several sessions without intervention.
L	Subject was the first of all subjects to be presented with the testing cart and required an extended period of shaping before he would sit in front of the monitor. He learned to touch the screen with his fingers in the first three sessions. While he initially demonstrated a startle response to the "correct" tone, he quickly habituated and learned to associate the tone and food reinforcer. The subject generally exhibited interest in the tasks but often left the testing station or looked away from the screen to monitor the social dynamics of his troop.
W	Subject never avoided the testing cart, learned to touch the screen with a finger in the first few sessions, and progressed quickly. The subject did begin to grab at the monitor at the completion of sessions which was alleviated by rolling back the testing cart immediately following the final trial of each session. The experimenter would then solicit other trained behaviors such as the presentation of body parts in order to end the session on a positive note.
D	Subject never avoided the testing cart, learned to touch the screen with a finger in the first few sessions, and progressed quickly at the beginning of training. As the training tasks became more difficult (i.e., the square became smaller and moved locations), the subject often left the testing station or looked away from the screen to monitor the social dynamics of her troop.
P	Subject initially avoided the testing cart and it took quite some time to shape her to sit close enough to reach the screen. She also exhibited a startle response to the "correct" tone and changing content of the screen. The subject often left the testing station or looked away from the screen to monitor the social dynamics of her troop. She progressed relatively slowly through training.
J	Subject initially avoided the testing cart and threatened the unit following presentation of the "correct" tone. These reactions lasted only the first few sessions and training progressed quickly from that point forward.
T	Subject never avoided the testing cart, learned to touch the screen with a finger in the first few sessions, and progressed quickly. No significant training challenges were encountered.
N	Subject never avoided the testing cart, but always visually attended to the experimenter rather than the screen. The subject attempted to grab and shake the monitor with increased frequency across sessions. Numerous techniques were employed to draw visual attention to the stimuli presented on the monitor including varying the food rewards and content of the training tasks. After more than a year of intermittent attempts, no substantive progress was made and training was halted.

Color discrimination task

Although all seven subjects presented with the color discrimination task did attain criterion performance, complete data on the task acquisition process were collected from four subjects (W, T, P, D). These subjects ranged in their number of sessions completed prior to attaining criterion performance from 13 to 63, with a mean of 39.75 sessions (*SD* = 21.65) (see Table 3 and Figure 4).

Table 3
Acquisition of discrimination tasks

	Sessions to criterion	
Subject	Color discrimination	Shape discrimination
S	x[1]	37
L	x[1]	62
W	13	27
D	63	104
P	50	102
J	x[1]	26
T	33	38

[1]Due to a fault in the initial programming code of the color discrimination task, the number of sessions to criterion could not be calculated.

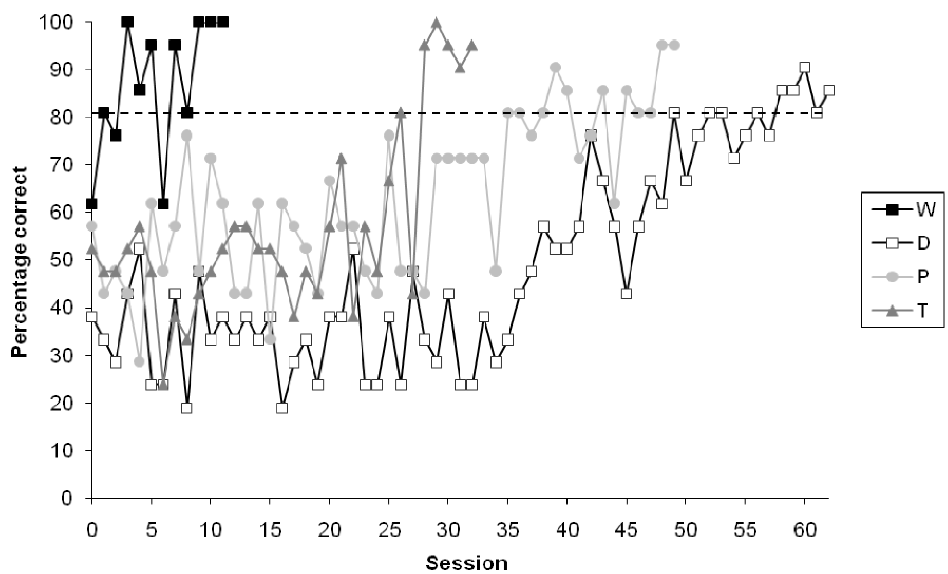

Figure 4. Acquisition curves depicting percentage of correct trials per session for individuals in the color discrimination task. The dashed line represents correct responding on 17/21 trials in a session. Criterion for mastery of the task required 5 consecutive sessions at or above this level.

An analysis of errors made by the four subjects in their first five completed sessions (task novice) indicated that errors were not distributed randomly across the three distracter colors (red, green, yellow) (G(2) = 112.78, $p < 0.001$). Of 194 total errors made by these subjects in their first five sessions, 70.62% (137 errors) were made by selecting the red distracter stimulus, as compared to 16.49% and 12.89% for the green and yellow distracter stimuli respectively (see Table 4). Errors made in the last five completed sessions (task mastery) were also not distributed randomly across the distracter colors (G(2) = 39.93, $p < 0.001$), with 82.05% (32 errors) of the 39 total errors made by selecting the red distracter stimulus, as compared to 12.82% and 5.13% for the green and yellow distracter stimuli respectively. While a fault in the initial program code invalidated the acquisition data of subjects, S, L, and J, we were able to examine their errors in five sessions post-mastery (see Table 4). Errors made by these subjects were also not distributed randomly (G(2) = 46.01, $p < 0.001$), with 84.62% (33 errors) of the 39 total errors made by selecting the red stimulus as compared to 12.82% and 2.56% for the green and yellow distracter stimuli respectively. Examination of errors made by all seven subjects in their final five sessions demonstrated that the sexes did not differ in their bias of selecting the red stimulus, with 38 of 47 total errors directed to red by the four female subjects and 27 of 31 total errors directed to red by the three male subjects (Z = 0.414, $p > 0.05$).

Table 4
Distribution of errors in the color discrimination task

	Distracter stimuli type		
Name	Red	Green	Yellow
S*	x/12	x/1	x/1
L*	x/10	x/1	x/0
W	16/5	2/1	2/0
D	44/10	9/3	11/2
P	46/12	10/1	3/0
J*	x/11	x/3	x/0
T	31/5	11/0	9/0

Data presented as (# of errorsin first five sessions/(# of errors in five sessions at task mastery)

* Due to a fault in the initial programming code of the color discrimination task, errors in the first five sessions were not recorded.

Shape discrimination task

All seven subjects presented with the shape discrimination task attained criterion performance. Subjects ranged in the number of sessions needed to attain this criterion from 26 to 104, with the average being 56.57 sessions (*SD* = 33.86) (see Table 3 and Figure 5).

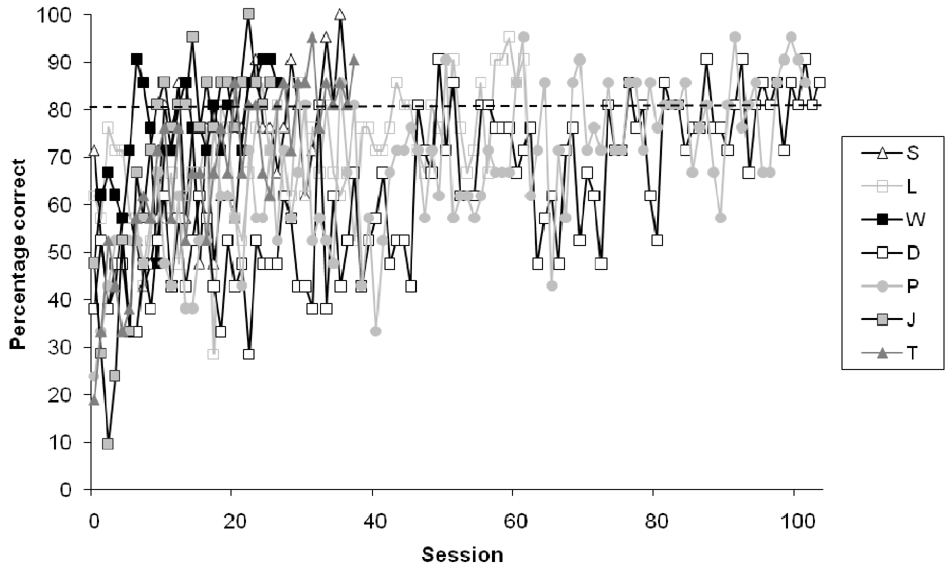

Figure 5. Acquisition curves depicting percentage of correct trials per session for individuals in the shape discrimination task. The dashed line represents correct responding on 17/21 trials in a session. Criterion for mastery of the task required 5 consecutive sessions at or above this level.

An analysis of the errors made by all seven subjects in their first five completed sessions on this task revealed that errors were not distributed randomly across the three distracter shapes (circle, triangle, diamond) ($G(2) = 31.56$, $p < 0.001$). Of the 389 total errors made by these subjects in their first five sessions, 45.24% (176 errors) were made by selecting a diamond distracter stimulus, as compared to 32.65% and 22.11% for the circle and triangle distracter stimuli respectively (see Table 5). Errors made in their final five completed sessions were also not distributed randomly across the distracter shapes ($G(2) = 202.31$, $p < 0.001$), with 93.94% (93 errors) of the 99 total errors made by selecting the diamond distracter stimulus as compared to 3.03% for both the circle and triangle distracter stimuli.

Table 5
Distribution of errors in the shape discrimination task

	Distracter stimuli type		
Name	Circle	Triangle	Diamond
S*	21/0	7/0	22/13
L*	2/0	11/1	21/9
W	7/2	6/0	30/11
D	20/0	13/2	25/14
P	26/0	12/0	28/18
J*	24/0	21/0	26/13
T	27/1	16/0	24/15

Data presented as (# of errors in first five sessions/(# of errors in five sessions at task mastery)

Discussion

The findings of this work clearly demonstrate that touchscreen-mediated testing systems are a viable method for investigating the cognitive and perceptual abilities of mandrill monkeys. Seven of eight subjects tested learned to utilize the touchscreen interface to make stimulus selections, and these subjects were also successful in learning to discriminate target stimuli from an array of distracters on the basis of color and shape characteristics. Thus, the performance of these mandrill subjects reveals that this historically understudied species has the capacity to effectively utilize touchscreen testing systems in a manner similar to that demonstrated by a variety of other primate species (squirrel monkeys: Anderson et al., 2005; capuchin monkeys: McGonigle et al., 2003; rhesus macaques: Parr, Heintz, & Pradham, 2008; and the great apes: Iversen & Matsuzawa, 2001; Vonk, 2003).

While touchscreen systems have been used successfully across the primate taxa, many of these reports do not provide detail of the initial touchscreen training procedures. That is, there is little mention as to the specific details of early training, nor the obstacles that had to be overcome prior to animals learning to be skilled users of these systems. It is therefore our hope that documentation of successful training procedures will be beneficial to researchers wishing to implement a touchscreen-based response system with their animals.

The general training procedure implemented here (see Methods) was quite successful, with only one animal being unable to complete the initial training tasks. The technique of initially placing the food reinforcers on the screen such that they were located on top of the correct stimulus was highly effective. The subjects typically learned to associate physical contact with the screen with the "correct" tone and receipt of the reinforcer within the first few sessions. Some animals initially avoided the testing cart ("L," "P," and "J," see Table 2) and this was resolved by shaping the animal to sit in close proximity to the cart for increasing periods of time. These three subjects also demonstrated a startle response to the "correct" tone and/or the changing content of the monitor. Subjects generally habituated to these events within a few sessions but the potential for this type of reaction should be considered when designing a training protocol. Finally, keeping in mind that subjects from the larger social troop were typically separated from the majority of their group while participating in testing sessions (see Methods - Subjects), it is interesting to note that subjects "L," "D," and "P" had difficulty staying focused on the tasks and were observed to leave the testing station frequently during each session (see Table 2). These subjects are in fact the dominant individuals within this larger social troop (see Table 1). Mandrill monkeys, like many of the cercopithicines, have a rigid social hierarchy within each sex that is regulated by the dominant individuals of that sex within the troop (Dixson, Bossi, & Wickings, 1993; Setchell, 1999; Setchell & Wickings, 2005). Thus, subjects "L," "D," and "P" likely had their attention diverted by their role in regulating the social hierarchy resulting in them leaving the testing station during periods of social escalation and frequently looking away from the screen to monitor the behavior of other troop members.

Upon mastering use of the touchscreen, seven subjects were administered two discrimination tasks to begin to illuminate how stimulus features impact responding in these animals. The first task required the subjects to discriminate between stimuli using color characteristics, and the second required a shape discrimination. All subjects attained criterion performance on these tasks, with no subject taking more than 104 sessions to reach this goal. Interestingly, it was the three dominant subjects on the larger troop ("L," "D," and "P") that required the highest number of sessions to attain criterion performance on both the color and shape discrimination tasks (see Table 3). These were the same subjects that were observed to be distracted by the social dynamics of their troop during initial training with the touchscreen (i.e., frequently looking away from the screen and leaving the testing station). Similar behaviors were observed during testing on the discrimination tasks and were reflected in their acquisition curves (see Figures 4 and 5). For example, in the color discrimination task, the performance of subject "D" hovered just above chance performance for approximately 35 testing sessions before it slowly started to improve. Similarly, in the shape discrimination task, the performance of subjects "P" and "D" started to meet the criteria of 17/21 trials correct in approximately their 50th session, but it took them twice that number of sessions before they could reliably perform at that level in order to meet the criterion for task mastery (17/21 correct in 5 consecutive sessions).

Conversely, subjects "W" and "T" are the most subordinate individuals of their sexes within the larger social troop and thus do not have the same responsibility of regulating the social hierarchy as dominant subjects. Both during initial touchscreen training and discrimination testing, these animals spent more time attending to the screen and were not observed to monitor the movements of dominant animals in the adjacent enclosure. These subordinate individuals required the fewest number of sessions to attain criterion in the color discrimination task and were two of the most rapid learners of the shape discrimination task. For example, the performance of subject "W" began to meet the criteria of 17/21 trials correct on only his second session on the color discrimination task. Similarly, subjects "S" and "J" comprised their own troop and therefore also did not have the same distractions of social regulation as dominant animals of the larger troop. While "S" and "J" did not contribute acquisition data for the color discrimination task, they too were rapid learners of the shape discrimination task. Thus, the acquisition rates of subjects "W," "T," "S" and "J" suggest that animals that do not have the distractions caused by a role regulating troop dynamics, whether due to subordinate status and/or the number of individuals in their social troop, demonstrate the potential to learn tasks more quickly.

In addition to examining the rate at which the mandrills acquired these tasks, analyses were also conducted to investigate errors made when they were novices to the task and again at task mastery. The distribution of errors across distracter stimuli was not random for either of these periods of acquisition in both the color and shape discrimination tasks. Among color distracters, there was a clear bias toward selecting a distracter stimulus when it was red as compared to when it was green or yellow (see Table 4). This preference is unlikely to be a simple case of color confusion since Old World monkeys are known to have tri-chromatic vision (Fleagle, 1999) and because red (635-700 nm) and blue (450-490 nm) are positioned at opposite ends of the visible spectrum. This finding is also unlikely to be due to brightness/contrast issues with the stimuli as all colors were set to 100% saturation and brightness. Instead, this error may be tied to the secondary sex characteristics of this species. Dominant male mandrills are identifiable by their elaborate coloration which includes bright red and blue on their faces and genitalia, and various shades of red, violet and blue on their rumps (Nowak, 1999; Setchell, 2005; Setchell & Dixson, 2001a,b; Shumaker & Beck, 2003; Sleeper, 1997; Wickings & Dixson, 1992). In addition to signifying dominance status to other males, these characteristics are thought to attract females for reproduction as well as coordinate group movement. Thus, this preference for blue and red stimuli may be innate and an important component of the natural history of this species. We recommend testing this hypothesis with a naïve group of mandrills by initially training them to touch stimuli of a color other than blue, such as yellow or green, and then determining if errors remain biased to red stimuli.

In the shape discrimination task, there was a clear bias toward selecting a diamond distracter stimulus over a circle or triangle distracter both when first exposed to the task and at task mastery (see Table 5). Preference for the diamond stimuli is likely due to two form-related factors. First, the diamond stimuli contain all the same local features (i.e., component features) of the correct square stimulus, they simply differ from the square in their global form (orientation in this case). That is, the diamond stimulus is in fact the square stimulus rotated 45 degrees. Therefore, the subjects had to learn to respond to the orientation of the local features (four right angles) rather than simply the presence of those features on the screen. Second, it is interesting to note that when initially exposed to the task, in addition to frequently selecting the diamond (45.24%), errors were also often made by selecting the circle stimuli (32.65%). Selection of the diamonds and circles may have been mediated by their area. That is, these stimuli had areas close to (or in the case of the diamond the same as) that of the correct blue square stimulus. Therefore, it may have been the case that subjects were initially responding based on the local features as well as the overall area of the stimuli. Upon mastery of the task, subjects clearly learned to avoid selection of the circle and continued not to select the triangle. When errors were made at task mastery, over 92% of them were made to the diamond stimuli suggesting that the similarity of local features continued to cause some degree of confusion. This bias of responding based on the local features of stimuli is not unexpected as it has also been documented in baboons and capuchin monkeys (Fagot & Deruelle, 1997; Spinozzi, De Lillo, & Truppa, 2003).

Overall, the findings of the present study support the continued use of touchscreen-mediated testing systems to further investigate the cognitive and perceptual abilities of mandrill monkeys. Interesting trends in the performance of individuals on the color and shape discrimination tasks presented here support future work examining the impact of position within the hierarchy and testing conditions on cognitive performance. Examination of error production during task acquisition provided additional insight into the features that guided responding in these subjects. Errors appeared to be guided by innate attraction to secondary sex characteristics as well as a bias to attend to the local features of objects, a perceptual process that is seen in other monkey species.

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