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Pigeons' Use of Landmarks for Spatial Search in a Laboratory Arena and in Digitized Images of the Arena

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Pigeons were trained in a touch-screen task and in an open-field task to search for a hidden goal using an array of landmarks to guide their search behavior. The touch-screen task presented digitized images of the open field landmarks and environment. Upon completion of training in each task, tests involving the alteration, shifting, or removal of landmarks were conducted to determine which landmark(s) and stimulus feature(s) controlled search behavior. In both tasks, proximity to the goal was an important determinant of landmark control. The overall patterns of landmark control showed both similarities and differences in the two tasks. No evidence was obtained that learning about the arrangement of landmarks and goal transferred across the two tasks. © 1997 Academic Press

The processing of spatial information is a fundamental activity of virtually all organisms in that it is essential to such critical behaviors as procurement of food, establishment of a home territory, navigation through different environments, and evasion of predators. In recent years, considerable research effort has been devoted to investigating the strategies used by various animals to make accurate discriminations within a spatial context, and in particular to determining how visual landmarks control an animal's search behavior (for reviews see Cheng & Spetch, in press; Gallistel, 1990).

Pigeons' use of visual landmarks in searching for a goal has been investigated in several recent studies by Cheng, Spetch, and colleagues. Some of

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these studies have used an open-field environment, in which food is hidden under sawdust or in containers on the laboratory floor and the pigeon moves freely about in search of hidden food (e.g., Cheng, 1988, 1989, 1990, 1994; Cheng & Sherry, 1992; Spetch & Edwards, 1988; Spetch *et al.*, 1997). Other studies have used a touch-screen task in which pigeons search for an unmarked goal on the surface of a computer monitor (Cheng & Spetch, 1995; Spetch, 1995; Spetch, Cheng, & MacDonald, 1996; Spetch, Cheng, & Mondloch, 1992; Spetch & Mondloch, 1993; Spetch & Wilkie, 1994). The touch-screen task differs from the open-field in many ways including that (1) the search space is two-dimensional (2-D) rather than three-dimensional (3-D), it is vertically oriented, and it is much smaller than in open-field tasks; (2) searching in the touch screen consists of pecking at the correct location, whereas in the open field it consists of ambulatory behavior through the search space followed by pecking; and (3) in the touch screen, food is not found at the goal but instead is dispensed elsewhere when the goal location is pecked.

Despite the many differences, results to date have suggested that landmark control on the touch-screen is surprisingly similar to that seen in 3-D space. For example, Spetch *et al.* (1992) studied landmark control when the goal was located in a fixed place near one edge of the monitor screen (top edge in one experiment, and left edge in another). A single graphic landmark was located near the goal. This layout was modeled after that used by Cheng and Sherry (1992) in a task conducted on the laboratory floor. In Cheng and Sherry's study, birds searched for food that was hidden near one edge of an experimental tray and a single object landmark was located near the goal. They found that pigeons showed more control by the landmark when it was shifted parallel to the nearest edge of the tray than when it was shifted perpendicular to the nearest edge. When the landmark was shifted diagonally with respect to the edge, searching shifted more in the parallel direction than in the perpendicular direction. This same pattern of results was found in the touch-screen task (Spetch *et al.*, 1992). Other similarities between results obtained in touch-screen and open field tasks include that (1) in both tasks pigeons weigh landmarks near the goal more heavily than landmarks far from the goal (Cheng, 1989; Spetch & Wilkie, 1994) and (2) in both tasks, search behavior has been shown to be controlled by both global and local cues (Spetch & Edwards, 1988; Spetch & Wilkie, 1994).

Addition evidence that similar processes operate in the two types of tasks was provided by a recent series of studies on use of landmark configuration by pigeons and humans. In experiments initially conducted on the touch screen (Spetch *et al.*, 1996), both pigeons and humans readily learned to locate an unmarked goal that was always in a fixed place relative to an array of identical landmarks that moved about on the screen from trial to trial. However, humans and pigeons responded very differently to tests in which the array was expanded by spreading the landmarks farther apart. Humans adjusted distance to maintain the appropriate relative position with respect to the landmark configuration, whereas pigeons responded in locations that maintained the absolute training distance from individual landmarks in the array. Importantly, the pattern of results obtained for each species was subsequently replicated by Spetch *et al.* (1997) in studies conducted in open-field tasks (laboratory floor for pigeons and outdoor field for humans). This similarity of results obtained in the touch screen and the open field suggests that the touch-screen task is useful as a model for investigating general principles of landmark use.

Although the evidence to date suggests that general principles of landmark use hold in either task, it is not known whether the specific pattern of control by a particular set of landmarks presented in the open field would also be seen if those same landmarks were presented in 2-D digitized images on the touch screen. Identical patterns of landmark control across the two tasks might be expected only to the extent that the 3-D spatial relationships present in the open-field task were well preserved in 2-D images and were used by the pigeons in searching for the goal. To take a concrete example, consider a case in which Landmark A is 20 cm west and 20 cm north of the goal, and Landmark B is 20 cm east and only 10 cm north of the goal. Landmark B is closer to the goal and should show stronger control. However, in an image of the landmark array as viewed from the south at ground level, one needs to use depth cues to determine which landmark is farther from the goal. If pigeons showed an identical pattern of control by an array of landmarks presented in real space and in images, this would suggest that they are able to derive such depth information from the images.

A related question is whether pigeons would show transfer of landmark control between the two tasks. Specifically, we wondered whether learning the relationship between the goal and landmarks in one task would influence search behavior when tested with the same or a different relationship between the goal and landmarks in the other task. If pigeons responded to the images as representations of 3-D space, then birds that are transferred between tasks with the same spatial relationships between the goal and landmarks should have an advantage over birds that experience different spatial relationships between the goal and landmarks in the two tasks.

Evidence consistent with the notion that pigeons see pictures as representations of the real world has been provided by studies that have shown transfer of control between pictured and real objects or environments. For example, pigeons that were induced to display aggression by interruptions in feeding, attacked and pecked at the head area of pigeons presented in color photographs, suggesting that they viewed the photograph as a conspecific (Looney & Cohen, 1974). Watanabe (1993) found two-way transfer between real objects and photographs of the objects presented to pigeons that were trained on a natural concept (food vs nonfood). Cabe (1976) found transfer between geometric objects and pictures of the objects in pigeons. Cole and Honig

(1994) found that pigeons trained to discriminate between colored slides of two locations in a room successfully transferred the discrimination when tested in the room. Wilkie, Willson, and Kardal (1989) found that experience in an outdoor location facilitated pigeons' discrimination of photographic slides of that location, which suggested that the pigeons perceived some correspondence between the slides and the actual location. These results all suggest that pigeons are able to extract enough information from pictures to recognize similarities between the real and pictured environments. However, none of these studies specifically required the pigeons to extract three-dimensional spatial relationships from the pictures. Evidence of transfer in our work would require not only that the birds could recognize the similarities between the pictured and real environment, but also that they could transfer learned spatial relationships between the pictured and the real environment.

In the present study, some pigeons were trained and tested in the open field first and the touch screen second, and other pigeons were trained and tested in the touch screen first and the open field second. In both tasks, birds were trained with one of two spatial arrangements of the goal and an array of three landmarks, and then were given tests in which the presence, location, or features of the landmarks were manipulated. For half of the birds, the spatial arrangement was held constant across the two tasks, whereas for the remaining birds, the spatial arrangement was switched when the birds were transferred between tasks.

METHOD

Subjects

Sixteen adult Silver King pigeons were used. All birds were housed in large wire meshed individual cages with free access to water and grit under a 12 h light/dark cycle. They were maintained at approximately 85% of their free feeding weight by maple peas or mixed grain consumed during experimental sessions and by postsession supplemental feeding of pigeon chow as needed. All pigeons had prior experience in tasks conducted in standard operant chambers and in the touch-screen search tasks.

Experimental Tasks

Open-field task. The open field was a 300 × 330-cm room, with an observation window on one wall and a door on another wall. The other two walls each had windows that were covered with black cardboard. Each wall was painted white, but several distinct features were present on the walls (e.g., electrical sockets, light switch, windows and door, and a white wooden crate covering a sink attached to one wall). A wooden tray, 200 × 200 cm, with sides 5 cm high was centered flush against the wall that was opposite the door. The floor of the tray was lined with approximately 2 cm of wood chips. Forty-nine Velcro pieces, forming a 7 × 7 square, were fixed on the bottom of the tray, 25 cm apart. These were used to select landmark and goal locations, to secure the goal in place, and to divide the search space into bins for scoring. Start and finish boxes were centered flush against the wall with the door. Strings attached to openings on the boxes ran through a pulley system into the adjacent observation room so that the boxes could be opened and closed from that room. The search space was assigned a left/right dimension and an up/down dimension with the top of the space being the wall opposite the door. A video camera was centered above the search space.

Touch-screen task. The experimental chambers were equipped with a color monitor (Zenith 1492) and an infrared touch frame (Carroll Touch, 1492 Smart Frame). Each chamber was 44 cm high, 32 cm deep, and 74 cm wide (inside dimensions), with a 28 × 20-cm monitor opening centered in the back wall and 10 cm from the floor. Two Gerbrands pigeon feeders were on the back wall of each chamber with one 8 cm to the left and one 8 cm to the right of the monitor opening. In one chamber the feeders were 17 cm from the floor and in the other they were 7 cm from the floor. Photocells in each hopper measured head entries into the hopper and a light bulb within each feeder illuminated food presentations. A thin sheet of plexiglass was placed 1.5 cm in front of the monitor to protect it from direct pigeon pecks. Microcomputers in an adjacent room controlled stimuli and experimental contingencies, as well as recording peck coordinates generated by the touch frame. The touch frames were programmed to record individual pecks by detecting a break in an infrared beam followed by the beam returning to its unbroken form.

Landmark and Image Preparation

Three distinct landmarks were chosen for use in the open-field room: a pink rectangular object approximately 25 cm high and 13 × 8.5 cm wide, a black cylindrical object, approximately 25 cm high and 6.5 cm in diameter, and a green cylindrical object, approximately 17 cm high and 12 cm in diameter. The goal was a blue plastic bottle cap, 4 cm in diameter and 0.5 cm high, baited with 10 maple peas, and fixed to the center of a 16-cm-diameter white margarine lid.

The arrangement of landmarks and goal in the open-field room was videotaped and played back into a frame grabber hardware/software system (Creative Labs Videoblaster) whereby videotape frames were frozen and saved in a GIF format. These frames were then edited with Photofinish software (Zsoft) to create the images used in the touch-screen task.

Landmark Spatial Arrangements

Two arrangements of landmarks and goal were used, as shown in Figs. 1 and 2. The arrangements differed with respect to the landmark that was closest to the goal: For Group A, the green landmark was closest and the pink landmark was farthest from the goal, whereas for Group B the pink landmark

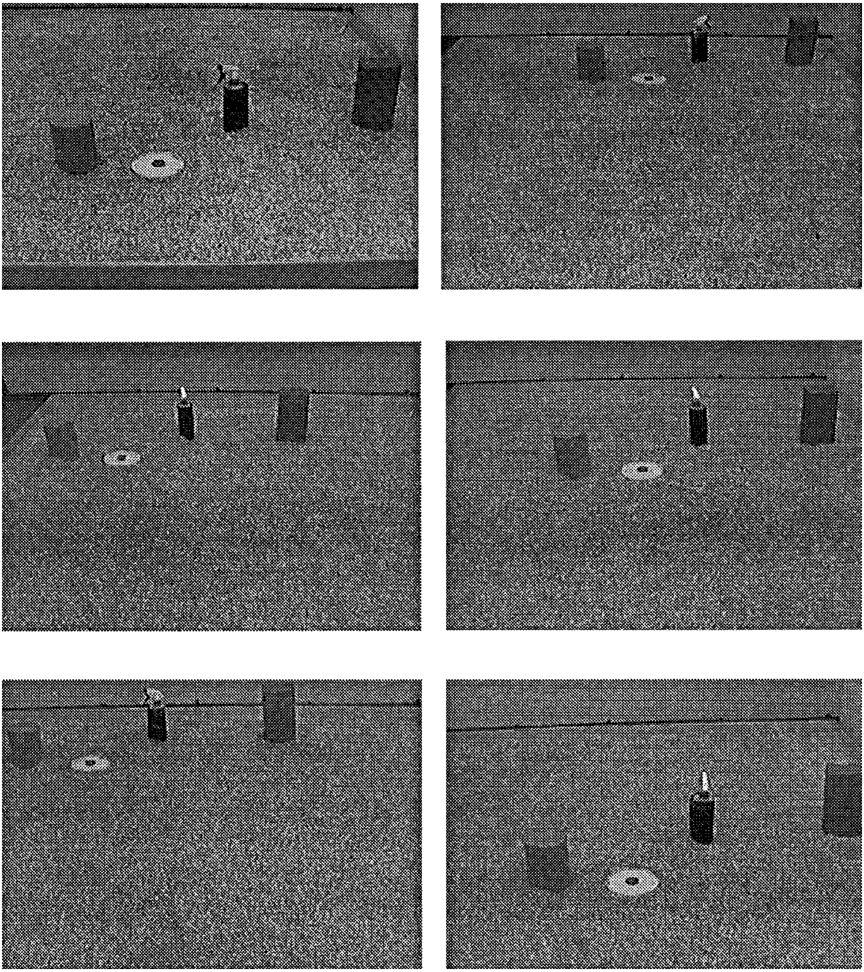

FIG. 1. The arrangement of landmarks and goal used for birds in Group A. The white circular object with a dark circle marks the goal location. This goal marker was hidden (open-field) or removed from images (touch-screen) during an early stage of training. The three landmarks differed in color. The six images shown formed the basis of all training and test images presented to pigeons in Group A of the touch-screen task.

was closest and the green landmark was farthest from the goal. The black landmark was the same distance but differed in direction to the goal for the two groups. In the open-field task, placement of the goal and corresponding landmark array in the experimental tray varied randomly across trials over 18 possible locations (6 in the up/down dimension and 3 in the left/right dimension). In the touch-screen task, birds were trained with six images that presented different views and showed the landmark array in different locations

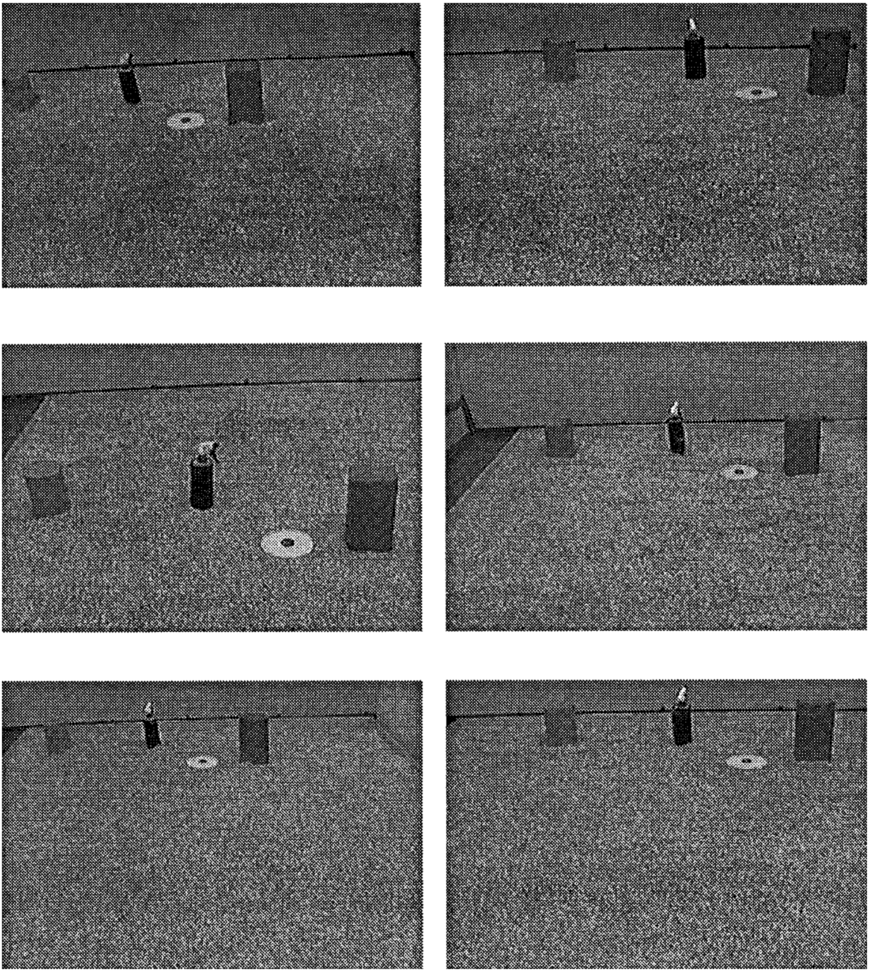

FIG. 2. The arrangement of landmarks and goal used for birds in Group B. The white circular object with a dark circle marks the goal location. This goal marker was hidden (open-field) or removed from images (touch-screen) during an early stage of training. The three landmarks differed in color. The six images shown formed the basis of all training and test images presented to pigeons in Group B of the touch-screen task.

within the experimental tray, as shown in Figs. 1 and 2. In both tasks, the landmark array was always in the same orientation with respect to the walls of the room and sides of the experimental tray, and during training, the goal was always in a fixed place relative to the landmark array. On test trials, the presence, location, color, or shape of the landmarks was altered. For the 2-D task, this was done by editing the original images. For the 3-D task, the objects themselves were manipulated.

Procedure

Preliminary search training. Each pigeon received initial search training in both tasks. Preliminary training in the open-field consisted of several sessions in which the birds were adapted to the open field, trained to exit and enter the start and finish boxes, and trained to sweep at the bedding in search of food. To begin each trial, the start box door was opened (by pulling the string from the observation room) until the bird exited into the search space. On the first trial, food (maple peas) was located in a white dish placed in front of the start box, and the finish box was open and baited with maple peas. The bird was left in the room until it ate the food from both the dish and the finish box, or for a maximum of 1 h, then was caught with the lights out. On subsequent trials, the food dish was placed in the center of the tray, and the baited finish box was opened only after the bird ate the food from the dish. If the bird entered the finish box within a fixed time period, which decreased from 30 to 2 min across trials, the door was closed behind it. Otherwise, the bird was caught in the open field. A few birds never reliably entered the finish box, and consequently were frequently caught in the open field throughout the experiment. In the next stage, birds were trained to search for hidden food using a landmark. An artificial potted yellow flower was introduced as a landmark 25 cm left of the goal. Once a pigeon reliably ate the food within about 30 s, the goal area was gradually covered with bedding until it was totally hidden from sight. For a few pigeons that initially showed low levels of search behavior, the behavior of sweeping away bedding was encouraged by also covering food in the home cage with bedding material. Across trials, the position in the tray of the goal and landmark was moved to ensure that the pigeons searched on the basis of the landmark.

Because all birds had previously been trained on the touch screen to peck at unmarked goals on the basis of visual landmarks (see Spetch & Mondloch, 1993, for a description of search training procedures), preliminary training in the touch screen consisted only of ‘‘refresher’’ sessions in the chamber to which the bird would be subsequently assigned. During these sessions, the pigeons received reinforcement for pecking at a white circle presented at various locations on a screen that was illuminated first with a brown background, and subsequently with a yellow background.

Experimental design and general procedures. Following their preliminary training, eight randomly selected pigeons were assigned to start in the open-field task, while eight other pigeons were assigned to start in the touch-screen task. Sessions were conducted 5, 6, or 7 days a week at approximately the same time each day. Sessions in the open-field consisted of 5 trials, each lasting a maximum of 10 min. In the touch screen, sessions lasted for 100 trials or a maximum of 1 h. Food was presented in the touch-screen chambers from one of the two hoppers, randomly selected on each trial, in order to minimize bias to one side of the screen. The hoppers remained available for

2 s following entry of a pigeon's head into the hopper, as detected by photocells. The screen was cleaned as necessary between sessions with window cleaner.

Open field training and testing. For the first five trials, the three landmarks were placed in the experimental tray in the assigned arrangement for each bird, and the goal was completely exposed. Over subsequent training trials, the goal was gradually covered until totally hidden from sight. When a pigeon located the hidden food on all five trials in approximately 30 s or less, partial reinforcement was introduced: Trials 1 and 3, 1 and 4, or 2 and 4 were non-reinforced (the goal and food were absent). The goal, together with the corresponding landmarks, was randomly placed in one of the 18 possible locations for the first and second trial. The goal and landmarks were then moved to a new location on the third trial. Pigeons advanced to testing when they located the food on reinforced trials within 30 s and searched (i.e., made sweeping pecks at the bedding) in approximately the correct location on non-reinforced trials.

Each test session consisted of five trials, two of which were non-reinforced test or control trials and three of which were reinforced baseline trials. On *baseline* trials, all three landmarks were present in their correct locations and the hidden goal dish containing food was present. On *control* trials, all three landmarks were present in their correct location (i.e., the trial was visually indistinguishable from a baseline trial), but the goal dish and food were absent. On *test* trials, the landmark array was manipulated in one of several ways (described below) and the goal and food were absent. Each test or control trial lasted for a maximum of 10 min or until a pigeon made approximately 50 sweeping pecks at the bedding. All reinforced trials lasted until a pigeon successfully uncovered the hidden food or for a maximum of 10 min (it was rare that reinforced trials lasted longer than 30 s). At the end of each trial, a pigeon entered a finish box containing food or was retrieved by the experimenter and then placed back into the start box to commence the next trial. Test or control trials were randomly selected to occur on trials 1 and 3, or 1 and 4, or 2 and 4. Three test series were presented, as described below. For all test series, each type of test and control trial occurred once, in a randomly determined order, in each of three blocks of testing.

The first test series consisted of *Landmark Removal Tests.* On some test trials (''One-absent tests''), one of the three landmarks was removed. On other test trials (''Single landmark tests''), only one of the three landmarks was present. Separate control trials were included for the one-absent and single-landmark tests.

The second test series consisted of *Shift Tests* with the two landmarks that were closest to the goal. Birds in Group A were tested with the green landmark shifted one unit left, the green landmark shifted one unit down, the black landmark shifted one unit right, and the black landmark shifted one unit down. Birds in Group B were tested with the pink landmark shifted one unit right, the pink landmark shifted one unit down, the black landmark shifted one unit left, and the black landmark shifted one unit down.

The third test series consisted of *Color and Shape Tests,* in which landmark features were manipulated. All pigeons received four types of these tests. In ‘‘Color swap tests,’’ the color of the closest landmark to the goal (green for Group A and pink for Group B) was interchanged with the color of the middle landmark. In ‘‘Color and shape swap tests,’’ the positions of the closest landmark to the goal and the middle landmarks were interchanged (which was equivalent to swapping both the color and the shape of these two landmarks). In ‘‘Color only tests,’’ all landmarks were the same shape as the closest landmark to the goal (retaining their normal color). In ‘‘Shape only tests,’’ all landmarks were the same color as the closest landmark to the goal (retaining their normal shape).

Touch-screen training and testing. The initial training session consisted of an autoshaping procedure. Each of the six training images, with the white goal marker visible, was intermittently and individually presented on the screen for 8 s and followed by food. A peck to the white goal area during this 8-s period caused food to be presented immediately. The intertrial interval (ITI) was 60 s. As pigeons begin to peck at the white goal more frequently, the ITI was decreased to 5 s and images remained on until a peck was made at the goal.

In a second training phase, the white goal marker was removed by editing the images with the ‘‘cloning’’ tool to cover the goal with the surrounding bedding. The edited area was blended carefully with the background, and other portions of the bedding were randomly rearranged, so that the edited area was indistinguishable from other parts of the image. Initially only part of the goal area was covered with bedding, but in subsequent images the goal was totally hidden. Pigeons had to complete (by pecking in the goal area) at least 80 of the 100 trials in a session with the goal marker absent before moving to the next stage of training.

During the third phase of training, the response requirement was gradually increased over sessions. First, the required number of pecks in the goal area was increased from 1 to 3. Subsequently, a consecutive peck requirement was introduced whereby the last two pecks had to be in the goal area. Pecks outside of the goal area reset the consecutive peck counter. This procedure prevented pigeons from obtaining food by merely sweeping their beak across the general area of the goal.

In the final stage of training, the percentage of trials that ended in reinforcement was decreased from 100 to 50%. On the randomly selected non-reinforced trials, completion of the response criteria terminated the trial and no food was presented. Before a pigeon was moved to testing it had to complete successfully at least 80 of the 100 trials in each of two consecutive sessions under the 50% reinforcement condition.

During test sessions, occasional control and test trials were randomly interspersed among reinforced and non-reinforced baseline trials. Control and test trials ended without reinforcement 8 s after the second peck recorded anywhere on the screen. Reinforced and non-reinforced baseline trials were identical to training trials and presented the six training images in a randomly determined order. Each of these six views served equally often as the control images and as the basis of manipulated images used for test trials. Each test series lasted for several sessions, and in total each type of test and control trial was presented at least 12 times for each view.

The test series conducted in the touch-screen task were the same as those conducted in the open field. For the *Landmark Removal Tests,* test images were created by cloning bedding on top of the object. For the *Shift Tests,* all landmark shifts were 2 cm in 2-D space. We excluded views for which it would be impossible to peck in the correct location according to the shifted landmark because the goal according to that landmark would be off the screen. Shifts were produced by cloning the landmark to the new location and covering the original landmark with bedding. For the *Color and Shape Tests,* images involving color changes were created by videotaping the manipulated object (i.e., the object in the changed color) and then cloning this object onto the appropriate place in the test image.

Following these three test series, a fourth *No Landmark* test series was conducted in the touch-screen task. This series presented test trials in which all three local landmark were removed from the image. The background of the image (showing the tray full of bedding and part of the room) remained.

All images created for testing were edited carefully so that edited portions blended well with the rest of the image. Examples of the images used for control and test trials are shown in Fig. 3.

Transfer between tasks. Following completion of training and testing in one task, all birds were then transferred to the other task. For half of the birds (balanced equally across initial task and landmark arrangement) the same landmark arrangement (A or B) occurred in the both tasks (*Condition Same*), whereas for the remaining birds, the landmark arrangement was switched when the birds were transferred to the new task (*Condition Different*).

For birds transferred to the touch screen, the first two sessions consisted of presentation of images showing the landmark arrangement to which the bird was assigned with no goal marker visible. On each trial, an image was presented for 8 s and then food was presented, followed by a 60-s ITI. If the bird pecked in the goal area while the image was on, food was presented immediately. Most birds failed to make any pecks at these images and only one of the eight birds made any pecks that fell within the goal. Therefore, following these two sessions, all birds proceeded through the basic steps of search training described previously for the touch-screen task. As soon as a bird completed all trials in a session with the goal marker absent and with a single peck requirement, one control-test session containing 50% control trials was presented. Training then continued until the bird reached the last stage

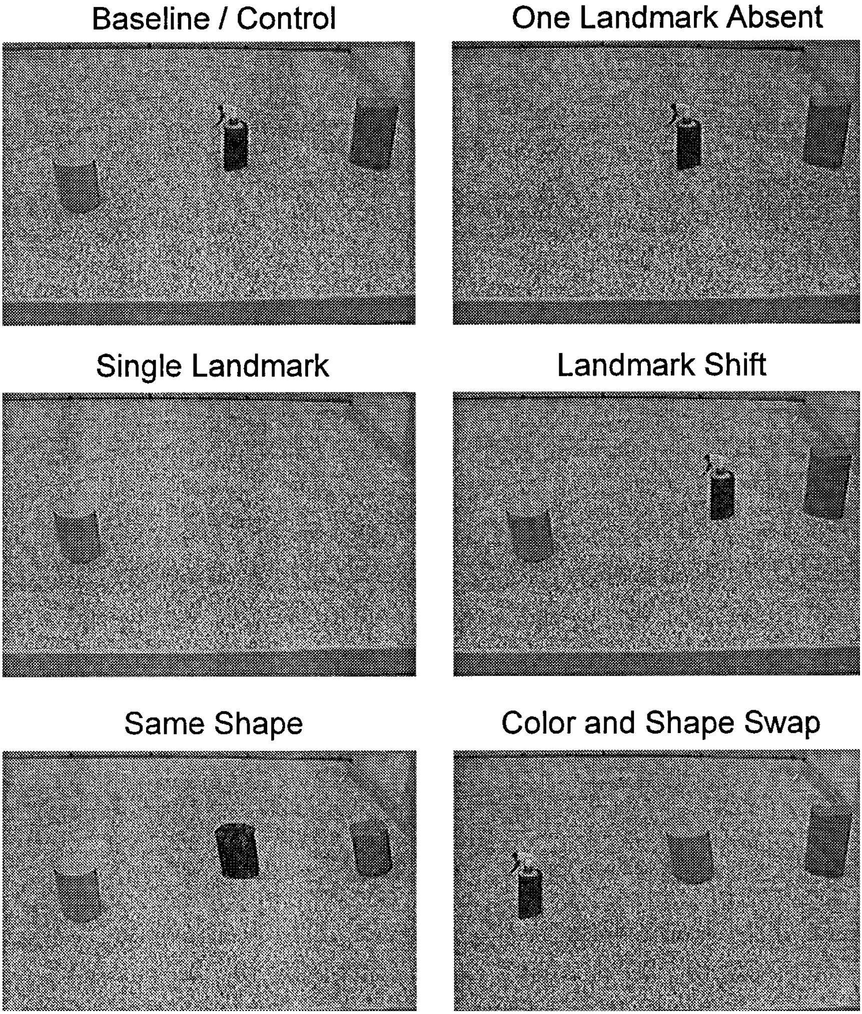

FIG. 3. Examples of test images showing a baseline trial or control test, a one-landmark absent test, a single landmark test, a shift test (middle landmark shifted left), a same-shape test, and a color and shape swap test. Each of these examples are based on one view for birds in Group A. Each type of test was conducted with multiple views, and additional tests with other landmarks were conducted in each test series.

of training (50% reinforced trials, and the two-in-a-row peck requirement). Each bird was then given one control-test session. On the following day it was placed back in the open-field task and given one control test and four reinforced baseline trials with the arrangement it had been trained with in that task (i.e., an arrangement that was either the same or different than the one being trained in the touch-screen task, depending on whether the bird was in Condition Same or Condition Different). On the next day, the bird was given another control-test session in the touch screen. The purpose of these pre and post control-test sessions was to see whether birds experiencing different arrangements in the two tasks would be more likely to show a drop in accuracy following reexposure to the open-field task.

For birds transferred to the open field, the initial session consisted of a control test in which the three landmarks were placed in the arrangement to which the bird was assigned and the bird's searching behavior was scored for a 10-min period. Because most birds showed little or no searching behavior, the next stage involved an alternation of control tests and reinforced training trials. On the first of these training trials, search behavior was reestablished with the yellow flower landmark used in preliminary training. Then the three landmarks were introduced in their assigned arrangement with the food goal visible. On subsequent training trials the food was gradually covered with bedding until it was completely hidden from view. This training continued until the bird consistently found the food on reinforced trials and was reasonably accurate on control trials. After completion of the last stage of training, each bird received a pretest session that included control tests on trials 1 and 4. On the following day the bird was returned to the touch-screen task and given a session that consisted of 50% control tests and 50% reinforced baseline trials with the arrangement on which the bird had been trained in the touch screen. On the next day, the bird was given a post-test session in the open field which again included control tests on trials 1 and 4.

Upon completion of transfer testing, each bird then received Landmark Removal Tests, Shift Tests, and Color and Shape Tests. These test series were identical to those described previously for each task.

Data Recording and Analysis

In the open field, tests and control sessions were recorded by the overhead video camera. A transparency was affixed to a television monitor and the 7 $\times$ 7 grid in the experimental tray was exposed and marked on the transparency. A test session was viewed on the television screen through an SVHS recorder (Panasonic) and a pigeon's search behavior was scored. Search behavior was operationally defined as making a sweeping peck at the bedding. Each time a pigeon's head made contact with the bedding the video tape was frozen and a mark was placed on the overhead transparency where the front-most tip of the pigeon's head appeared on the screen. The video tape was then advanced 20 frames (0.4 s) and another mark was made on the transparency if the pigeon's head was still in the act of sweeping at the bedding. When the pigeon stopped making search pecks (e.g., began walking around the tray), the video tape was advanced until the pigeon began making sweeps at the bedding again and then scoring continued as before. Scoring stopped when 50 responses were recorded. For data analysis, all test trials of each type were combined. To compute accuracy scores for each test type, we divided the number of search pecks that fell within half a unit (12.5 cm) from the center of the goal in both the horizontal and the vertical planes by the total number of search pecks recorded for that trial type. Because the goal location varied over a range of three horizontal and six vertical units, chance level accuracy was estimated to be 0.06.

In the touch screen, data from the multiple presentations of each test type were combined. To determine the center of the goal area for each training image, we noted the coordinates generated by the touch frame when the experimenter touched the center of the goal marker. Because all test images were created from the set of six training images, these coordinates also defined the center of the goal area on test trials. Pecks that fell within 25 pixels (approximately 1 cm) of the center of the goal in both the vertical and the horizontal planes were considered to be correct (and triggered reinforcement on training trials). Accuracy scores were calculated by determining the proportion of the total pecks that fell within this goal area. Across the six training images, the goal location varied over a range of 233 pixels horizontally and 242 pixels vertically. Assuming random pecking within this range of screen locations, chance level accuracy is estimated to be 0.04.

For shift tests in both the open field and the touch screen, the horizontal peak place of searching was computed using the iterated median procedure described in Cheng (1989) and Spetch *et al.* (1992).

RESULTS

The significance level for all statistical tests was set at $p < .05$. All multiple comparisons used Tukey's HSD test.

Initially, three-way analyses of variance (ANOVAs) were conducted for each test series and each task. For these ANOVAs, the factors were landmark arrangement (A or B), task order (i.e., initial or transfer task), and test condition (i.e., control and each type of test trial). In none of these ANOVAs were there any significant effects of landmark arrangement or task order, or any interactions of these factors with test condition. Consequently, for simplicity, all data from each task were collapsed across the 16 birds for data analysis and presentation.

Landmark Removal Tests

Figure 4 shows the accuracy scores on control and test trials of the one absent and single-landmark tests conducted in each task. In both tasks, the landmark farthest from the goal exerted the least control of search behavior. That is, removal of the far landmark had the least effect and presence of the far landmark alone was associated with the lowest search accuracy. However, different results appeared for the two tasks with respect to control by the close and middle landmarks. The close landmark exerted more control than the middle landmark in the open field, but not in the touch screen.

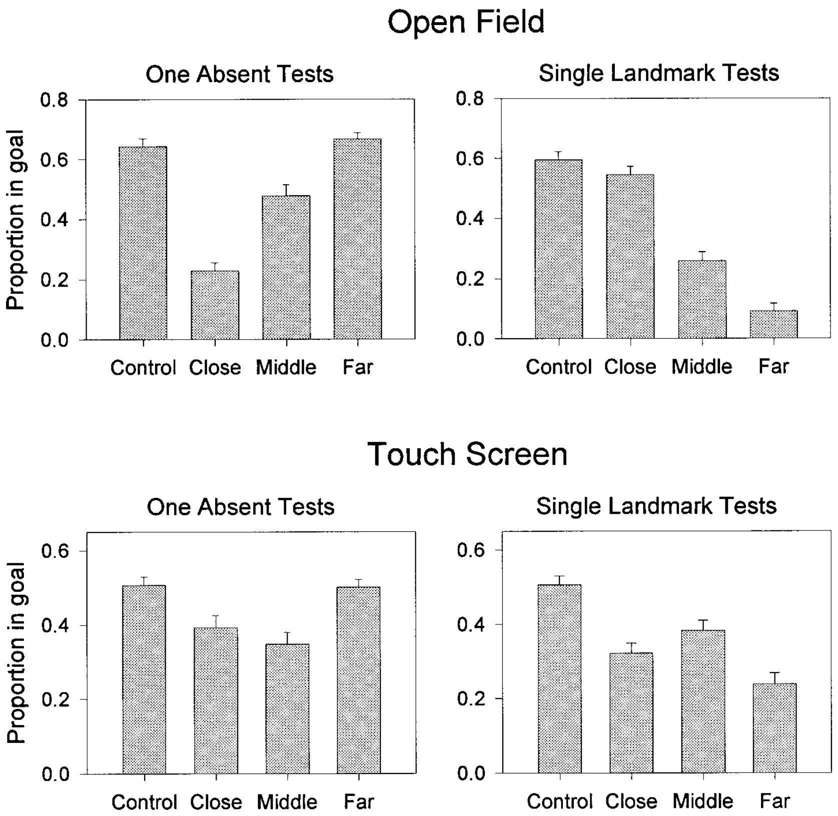

FIG. 4. Accuracy scores (proportion of pecks that fell in the goal area) during control and test trials for the one-absent and single landmark tests in each task. For the one-absent tests, the label below each bar indicates which landmark was removed. For the single-landmark tests, the labels indicate which landmark was presented alone.

In the open field, one-way ANOVAs revealed a significant effect of Test Condition, both for the one-absent $F(3,45) = 49.66$, and the single landmark tests, $F(3,45) = 79.77$. Multiple comparisons for the one-absent tests revealed the following pattern of accuracy scores: control = far landmark absent > middle landmark absent > close landmark absent. Multiple comparisons for the single-landmark tests showed the following pattern: control = close landmark only > middle landmark only > far landmark only.

In the touch screen, one-way ANOVAs revealed a significant effect of Test Condition, both for the one-absent $F(3,45) = 15.82$, and the single-landmark tests, $F(3,45) = 30.74$. Multiple comparisons for the one-absent tests revealed the following pattern of accuracy scores: control = far landmark absent > middle landmark absent = close landmark absent. Multiple comparisons for the single-landmark tests showed the following pattern: control > close landmark only = middle landmark only > far landmark only.

Shift Tests

In both tasks, shifts of the close or middle landmark resulted in shifts in search location. However, the shifts in search location were larger in the open field than in the touch screen. In addition, searching shifted more for the close landmark than for the middle landmark in the open field but not for the touch screen.

In the open field, the calculated peak place of searching shifted by 63% in the direction of shifts of the close landmark, and by 25% in the direction of shifts of the middle landmark. These shifts were significantly greater than 0 for both the close landmark, $t(15) = 10.81$, and the middle landmark, $t(15) = 5.88$, but the shifts were larger for the close landmark than for the middle landmark, $t(15) = 5.69$. In the touch screen, the calculated peak place of searching shifted by 11% in the direction of shifts of the close landmark, and by 18% in the direction of shifts of the middle landmark. These shifts were significantly greater than 0 for both the close landmark, $t(15) = 4.18$, and the middle landmark, $t(15) = 6.11$, but they did not differ significantly for the close and middle landmarks, $t(15) = 1.68$.

Color and Shape Tests

Figure 5 shows the accuracy scores on control and test trials of the color and shape tests conducted in each task. In both tasks, interchanging the shape and/or the color of two landmarks produced larger reductions in accuracy than presenting all landmarks in a single shape or color. Presenting all landmarks in a single shape or color produced some disruption of accuracy in the touch screen but had little effect in the open field.

In the open field, a one-way ANOVA revealed a significant effect of Test Condition, $F(4,60) = 18.36$, and multiple comparisons revealed the following pattern: control = same color = same shape > shape and color swap = color swap. In the touch screen, a one-way ANOVA revealed a significant effect of Test Condition, $F(4,60) = 54.61$, and multiple comparisons revealed the following pattern: control > same shape > same color > shape and color swap = color swap.

No-Landmark Tests (Touch Screen Only)

Accuracy on tests with all local landmarks removed from the image (mean = 0.136) was significantly lower than accuracy on control trials (mean = 0.504). Nevertheless, accuracy on the no-landmark tests was significantly higher than that expected (.04) on the basis of random pecking on the screen, $t(15) = 2.59$. Thus, background cues in the image (the experimental tray or walls of the room) appeared to exert some control over searching. However, it should be remembered that the location of the goal with respect to the tray

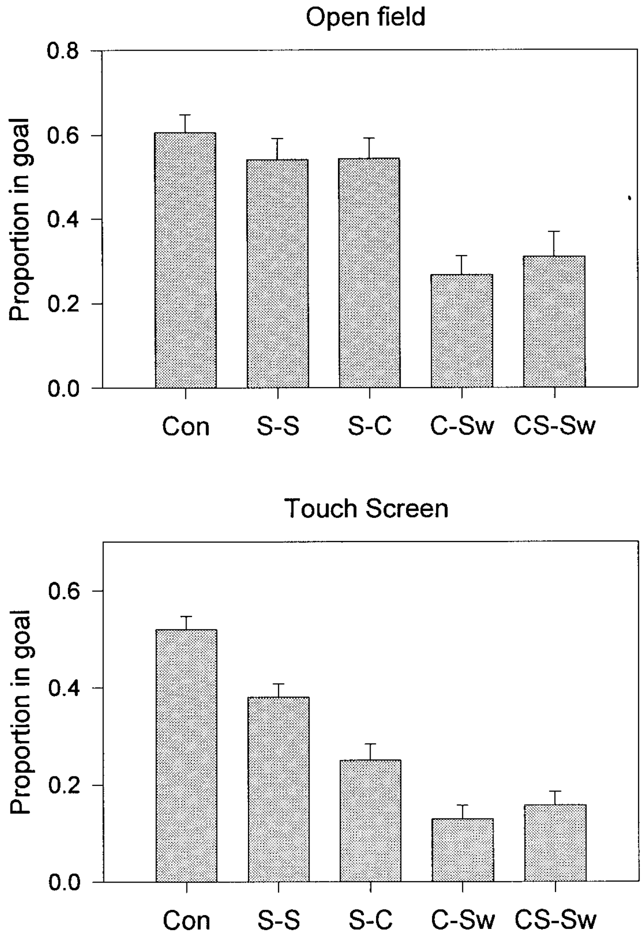

FIG. 5. Accuracy scores (proportion of pecks that fell in the goal area) during control and test trials for the color and shape tests in each task. Con, control; S-S, all landmark same shape; S-C, all landmarks same color; C-Sw, color of near and middle landmark swapped; CS-Sw, color and shape of near and middle landmark swapped.

and room cues varied across views. In order to find the goal on the basis of these cues, the birds would need to have memorized the approximate goal location in each of the six views.

Transfer between Tasks

Transfer from touch screen to open field. Initial transfer-of-control tests were compromised by low or absent levels of search behavior in some birds. On the first two test sessions, two birds failed to display any search behavior and the other birds made very few search pecks in the goal area. Accuracy scores on the subsequent tests, which were interspersed with training on the new landmark arrangement, were variable and failed to reveal any systematic advantage for birds transferred with the same landmark arrangement. For birds in Condition Same, the mean proportion of pecks in the goal area over four blocks of two control tests was 0.19, 0.19, 0.47, and 0.37. For birds in Condition Different, the block means were 0.16, .41, .36, and .43. Only the main effect for block approached significance, $F(3,18) = 2.69$.

To determine whether reexposure to the touch-screen task affected search accuracy on the open field task, pretest accuracy was subtracted from post-test accuracy for each bird. The resulting score would be positive if the bird improved in accuracy and negative if the bird showed a reduction in accuracy. Congruency of the landmark arrangement across the two tasks had no significant effect on these change scores (Mean, −0.048 for birds in Condition Same and 0.155 for birds in Condition Different, $t(6) = 1.02$).

Finally, we also looked at whether congruency of landmark arrangement affected accuracy on the one day of re-exposure to the touch-screen task. Unfortunately, the data for one bird in Condition Different were lost due to a computer problem. Of the remaining birds, however, there was no evidence of an advantage for birds experiencing the same landmark arrangement in both tasks. In fact, all birds showed a decline in accuracy on the reexposure day relative to the session that preceded open-field training: Mean proportion of pecks in the goal declined by .134 in Condition Same ($n = 4$) and by .071 in Condition Different ($n = 3$).

Transfer from open field to touch screen. Low rates of search behavior again compromised the direct assessment of transfer. Three birds failed to peck on either of the first two sessions, and only one bird (Condition Same) made any pecks in the goal area (proportion of 0.17). In the subsequent training, the mean number of sessions required before a bird completed a session with the goal marker absent did not differ significantly for the two conditions (Same = 27 sessions, Different = 14.5, $t(6) = 0.93$). Mean accuracy on the subsequent control test session also was not significantly different for the two groups (Same, .30; Different, .20; $t(6) = 1.68$).

Congruency of landmark arrangement also did not influence the effect of reexposure to the open field on accuracy in the touch-screen task. Change score (pretest−post-test) did not differ as a function of congruency (Mean, 0.043 for birds in Condition Same and −0.004 for birds in Condition Different, $t(6) = 1.64$). Thus, reexposure to the open field was not more likely to disrupt accuracy in the touch-screen task if the landmark arrangement in the two tasks differed.

Finally, there was no evidence that pigeons performed worse on their one day of reexposure to the open field if they had received a different landmark arrangement in the touch screen than if they had received the same landmark arrangement in both tasks. Two birds (one in Condition Same and one in

Condition Different) made only a few search pecks on the control test (3 and 12, respectively). If these birds are excluded, the mean proportion of search pecks in the goal declined by .259 for birds in Condition Same and by .297 for birds in Condition Different, relative to the last control test that preceded touch-screen training. If these birds are included, the mean decline was .417 for Condition Same and .100 for Condition Different. In neither case was the difference significant, $t(4) = 0.16$, and $t(6) = 1.03$, respectively.

DISCUSSION

Although there were some similarities in the pattern of landmark control observed in the two tasks, it is clear that there also were differences. Similarities included that in both tasks (1) more than one landmark or source of information controlled behavior, (2) the two landmarks closest to the goal exerted more control than the landmark that was farthest from the goal, (3) birds showed significant but partial shifts in search location in the direction of shifts of the near or middle landmark, and (4) interchanging the shape and/or the color of the close and middle landmark was more disruptive than making all landmarks the same shape or color. The main differences were that (1) the close landmark exerted far more control than the middle landmark in the open-field task, whereas a nonsignificant tendency in the opposite direction occurred in the touch screen task; (2) shifts in search location in response to landmark shifts were proportionally much larger in the open-field task; and (3) making all landmarks the same color or shape disrupted accuracy in the touch-screen task but not in the open-field task.

Assessment of transfer of control was compromised somewhat by the practical problem of low or zero rates of search behavior on initial transfer tests, which necessitated the implementation of training procedures. Nevertheless, neither the rate of learning in the new task, nor the effect of returning to the old task, provided any evidence that birds were influenced by their prior learning in the other task. That is, birds transferred with the same landmark arrangement showed no advantage over birds transferred with a different landmark arrangement.

We think that one reasonable interpretation of our results is that the birds solved the touch-screen task on the basis of the 2-D spatial relationships rather than on the basis of 3-D spatial relationships extracted from the images. Such a possibility can account not only for the lack of transfer but also for the patterns of control by the three landmarks observed in each task. First, consider that the difference between the close and the middle landmark in distance to the goal is substantial and constant in the open field, whereas the difference between the close and middle landmark in 2-D distance to the goal is minuscule and variable in the images presented on the touch screen. Second, note that the far landmark is substantially farther from the goal than either of the other landmarks, both in real space and in terms of 2-D distances in the images. Our results showed that the close landmark exerted more control than the middle landmark only in the open field, but that the far landmark exerted the least control in both tasks. This pattern is consistent with the notion that 2-D relationships controlled searching in the touch screen, whereas 3-D relationships controlled searching in the open field.

At first blush, our failure to find transfer between the real environment and images of the environment seems at odds with evidence that pigeons are sometimes capable of showing transfer between real places or objects and pictures of these places or objects (e.g., Cole & Honig, 1994; Wilkie *et al.*, 1989; Watanabe, 1993). However, these previous studies did not require the subjects to make a finely localized search response, but instead measured discriminative responding or choice behavior. Thus, the processes required for transfer of control in our experiments may extend beyond those required in previous demonstrations of picture to real world transfer. In our experiments, transfer not only would require that the birds recognize a correspondence between the pictures and the real environment, but additionally would require that they search according to the same 3-D spatial relationships in both cases. This would necessitate the extraction of depth information from the images and a scale transformation for distances. Moreover, it would require that the birds respond to the images as representations of real space and disregard the 2-D spatial information provided by each image.

It is interesting to view the pigeons' failure to show transfer in the context of some research with children. First, DeLoache and Burns (1994) found that 24-month-old children were unable to use pictures to guide search behavior in real space. They suggested that the ability to interpret pictures as representations of current reality is a formidable task that develops between 24 and 30 months of age. Thus, the task we asked of our pigeons was by no means simple. Other experiments by DeLoache (1989) may be even more relevant to our research. She investigated the ability of young children to find a hidden toy in a room after being shown the location of the toy in a small-scale 3-D model of the room. Correspondence between the model and the room was explicitly pointed out, and the children were told that the toy would be hiding in the same place in the room as in the model. Children between 30 and 32 months of age failed to retrieve accurately the toy in the room after seeing it in the model. However, children of this age were able to find a toy in the room if they saw it hidden in a photograph of the room. DeLoache suggested that the three-dimensional nature of the model prevented the children from ''perceiving its symbolic role. They were unable to inhibit their dominant response to the model as a real, manipulable thing in order to see it also as a representation of something else'' (p. 30). She suggested, on the other hand, that the primary role of a photograph is only as a representation of something else and not as a real manipulable thing. In this regard, it is interesting to consider the possibility that reinforcing the pigeons for pecking at the images in the touch-screen task may have rendered the images as ''real things'' rather than just representations. As such, the tendency to respond to the properties of the image itself (i.e., the 2-D spatial relationships) may have blocked any tendency to respond to the properties of the represented environment (i.e., the 3-D spatial relationships).

It is important to note that our failure to see correspondence and transfer of control between the two tasks should not be taken as evidence that pigeons are incapable of transferring learned spatial relationships between real and pictured environments. As is always the case when one fails to provide evidence for a process or ability, the possibility exists that procedural variations might provide different results. It is possible, for example, that transfer would be more likely if the environment used provided richer depth information, or if the touch-screen images had provided a larger set of views taken from different perspectives. What our results do clearly suggest is that caution should be taken in assuming that pigeons will respond to the properties of the represented environment in an image, rather than responding to the properties of the image itself.

Finally, the present results should not be taken as evidence against the validity of the touch-screen task as a tool for investigating general processes of landmark learning. As discussed previously, there is now considerable evidence indicating that general processes of landmark based search hold in both touch-screen and open-field tasks. Moreover, the similarities in landmark control between the two tasks found in this study should not be downplayed. For example, the general principle that landmarks near a goal are weighted more heavily than landmarks far from the goal held well in both tasks, and particularly so if one accepts that pigeons in the touch-screen task responded to the 2-D rather than the 3-D spatial relationships. Thus, we contend that the touch-screen task is an excellent tool for studying general principles of landmark-guided search, but that caution should be taken if using it to study the processing of three-dimensional spatial information.

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