

Learning the Configuration of a Landmark Array: I. Touch-Screen Studies With Pigeons and Humans

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Pigeons and humans searched on a touch-screen monitor for an unmarked goal located relative to an array of landmarks presented in varied screen locations. After training with the goal centered in various square arrays of 4 landmarks, humans, but not pigeons, transferred accurately to arrays with novel elements. Humans searched in the middle of expanded arrays, whereas pigeons preserved the distance and direction to a single landmark. When trained with the goal centered below 2 identical horizontally aligned landmarks, humans responded to horizontal expansions or contractions of the array by shifting their search vertically, preserving angles from landmarks to goal. Pigeons did not adjust their search vertically. Humans trained with a single landmark adjusted search distance when landmark size was changed. Both pigeons and humans use the configuration of a landmark array, but the underlying processes seem to differ.

Experimental work has demonstrated that many animal species can encode the location of an important place in terms of nearby visual landmarks (see Gallistel, 1990, and Collett, 1992, for reviews). In several investigations of landmark use, a goal was located near an array of two or more local landmarks, with a directionally stable frame of reference provided by other cues (e.g., Cartwright & Collett, 1983; Cheng, 1989; Cheng, Collett, Pickhard, & Wehner, 1987; Collett, Cartwright, & Smith, 1986; Spetch & Mondloch, 1993). Consider, for example, a situation in which distal cues in a spatial arena provide stable directional information (i.e., the polarity of the arena is not manipulated) and the goal bears a consistent spatial relationship to

an array of local landmarks that moves without rotation within the arena over trials. If the spatial relationship of each individual landmark to the goal remains constant and each landmark in the array is distinct, subjects could attend only to a single landmark or subset of the landmarks to solve the task (e.g., Cheng & Spetch, 1995; Spetch & Mondloch, 1993); that is, encoding a vector from a single distinct landmark might suffice. However, if the landmarks in the array are not distinct, or if individual landmarks in the array do not bear a consistent relationship to the goal, then subjects cannot solve the task on the basis of a single landmark. Instead, subjects would need to use the configuration of the array to locate the goal.

Landmark learning in situations involving an array of identical landmarks that move about in the search space has been investigated in two species, and these investigations have yielded interesting and divergent results. Cartwright and Collett (1983) trained bees to find a goal at a particular distance and direction from an array of three identical landmarks and then tested their response to expansions and contractions of the array. When the landmarks were spread farther apart (i.e., array expansion tests), the bees searched farther from the landmark array. When the landmarks were moved closer together (array contraction tests), the bees searched closer to the landmark array. In both cases, the bees maintained the appropriate compass directions from each landmark, triangulating compass bearings from each landmark to determine where to search.

A different pattern of results was obtained in a study on gerbils conducted by Collett et al. (1986). In their study, the goal was located midway between two identical landmarks and a small perpendicular distance away from the line connecting the two landmarks. On a test in which the landmarks were moved farther apart, the gerbils did not show triangulation; instead, they showed two peaks of

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searching, one at each location defined by the training vector from an individual landmark. Because the gerbils had not shown localized searching when only a single landmark was present, the two localized peaks of searching at locations appropriate to each landmark indicated that the gerbils did rely on both landmarks to determine in which direction from each landmark to search during the expansion tests. Beyond that, however, they appeared to use each landmark singly to localize.

Although landmark learning in pigeons has been investigated extensively (Cheng, 1988, 1989, 1990, 1994; Cheng & Sherry, 1992; Cheng & Spetch, 1995; Spetch, 1995; Spetch, Cheng, & Mondloch, 1992; Spetch & Mondloch, 1993; Spetch & Wilkie, 1994), pigeons have not been studied in situations involving identical landmarks that move about in a search space. Cheng (1989), however, trained pigeons to find a goal that was located between two landmarks that occupied fixed locations within the spatial arena. The goal was closer to one landmark than the other. During tests in which the landmarks were moved apart, the birds typically searched at a location that matched the absolute training distance of the goal from the nearest landmark. Only 1 of 12 data points were approximately in the location that would be expected if the birds responded to the proportional rather than the absolute distance from the two landmarks. By contrast, 8 data points followed approximately the absolute distance from the nearest landmark. It is interesting that Cheng's results with pigeons are similar to those obtained with gerbils. Because the distance of the two landmarks from the goal was so discrepant in Cheng's study, however, the tendency to maintain the correct absolute distance from the nearest landmark may simply reflect maximal weighting of the nearest landmark. Moreover, because the landmarks did not move within the search space, the pigeons were not forced to use both landmarks to solve the task.

Studies in which pigeons were trained with an array of visually distinct landmarks (Spetch & Mondloch, 1993; Spetch & Wilkie, 1994) failed to show that the pigeons learned the configuration of the array, but in such cases the task could be solved without attending to the configuration of stimuli. In the current experiments, we used an array of identical stimuli or an array whose individual elements changed across trials. Because these arrays moved about within the search space across trials, subjects were forced to use the configuration of the array to solve the problem.

Our research was designed to extend knowledge of how organisms learn the location of a goal in a configuration of landmarks. As reviewed earlier, tests involving expansions or contractions of arrays of identical landmarks have revealed an interesting difference between bees and gerbils. Results by Cheng (1988) suggest that pigeons may respond to expansions of an array in a fashion similar to gerbils, but this has yet to be studied in a situation that forced the use of configuration. Our research therefore provided a systematic investigation of pigeons' responses to expansions or contractions of landmark arrays in tasks that could not be solved without attending to the array of landmarks.

We also compared pigeons' responses to manipulations of

landmark arrays with those of adult humans. Humans were of comparative interest because previous research comparing pigeons and humans on a landmark-based search task revealed similarities in landmark control (Spetch, 1995). In fact, certain features of landmark-based search, such as the greater weight given to nearby landmarks than to faraway landmarks, appear to be general across species ranging from invertebrates to humans (e.g., Bennett, 1993; Cheng, 1989; Cheng et al., 1987; Spetch, 1995; Spetch & Wilkie, 1994). However, responses to expansions and contractions of arrays of landmarks appear to differ across species, and our preliminary data suggested that humans respond much differently to these manipulations than do pigeons. Also interesting are some data suggesting developmental changes in human responses to array expansions and contractions, which we are documenting in a separate work (MacDonald, Spetch, & Cheng, 1996).

In the studies reported here, we used the touch-screen spatial search task that was first introduced by Spetch et al. (1992). In this task, the vertical surface of a color monitor serves as a two-dimensional spatial arena, the goal is a 2-cm² area, and stimuli projected onto the monitor screen serve as landmarks. The touch-screen task differs in several ways from more traditional spatial search tasks conducted on the laboratory floor, including that (a) food is not found at the goal but instead dropped in a hopper in a different location and (b) the search space is vertical and viewed at close range. These differences might be expected to change the way the pigeons perceive the touch-screen "environment." Pigeons have two separate visual systems: a short-distance binocular frontal field and long-range monocular fields for each eye (for reviews, see Zeigler & Bischof, 1993). The touch-screen task presents stimuli to the frontal field of pigeons. On the laboratory floor, however, both kinds of visual fields are called into play. McFadden (1993) found that stereoacuity breaks down beyond 20 cm for pigeons. Many stimuli in the laboratory room were more than 20 cm away from the target of search. Despite these differences, patterns of results from search tasks on the touch screen and laboratory floor have been similar (Spetch et al., 1992; Spetch & Mondloch, 1993; Spetch & Wilkie, 1994). Demonstrations that landmark-based search follows similar principles in situations that differ in many ways and that involve different parts of the visual system are important because they suggest that general processes are operating. We continue, however, to compare results obtained on the touch-screen monitor with counterparts from the laboratory room. Our research showing that the results obtained here generalize to studies in the laboratory room are reported in a separate work (Spetch et al., 1996).

In the current studies, we tested pigeons and humans with two types of configurations, one in which the goal was in the center of a square arrangement of four landmarks (Experiments 1, 2, and 3) and one similar to that used by Collett et al. (1986) with gerbils, in which the goal was below and between an array of two identical landmarks (Experiment 4). Although several tests were conducted, the primary focus was on how subjects responded to expansions of the landmark array. A fifth experiment, using a single landmark

with humans, was conducted as a follow-up to the results obtained in Experiment 4 with humans.

General Methods

Subjects

In Experiments 1–4, the pigeon subjects were adult Silver King pigeons (Palmetto Pigeon Plant, Sumter, SC) that had varied experimental histories (described in each experiment). The birds were housed in large individual cages under a 12-hr light/dark cycle (lights on at 6:00 a.m.). All birds were maintained at approximately 85% of their free-feeding weights by mixed grain obtained after experimental sessions and rewards (grain or pellets) during experimental sessions. Water and grit were available ad lib in the home cages. The human subjects used in Experiments 1, 2, 4, and 5 were undergraduate students who participated in the experiment for extra credit in their introductory psychology course.

Apparatus

For both pigeons and humans, the stimuli were displayed on Zenith (Model 1490 or 1492; St. Joseph, MI) flat-screen color monitors (640 × 480 pixels) with attached infrared touch frames (Carroll Touch 1490 or 1492 Smart Frames; Round Rock, TX). The touch frames had a resolution of 3 mm and were programmed to detect individual responses (i.e., detection of a beam break and then a return to unbroken beams before another response would be recorded).

The pigeons were tested in one of three operant chambers. Chamber 1 was a modified rectangular pigeon chamber (BRS/LVE; Laurel, MD) with a large opening for the monitor cut into one end wall. A thin sheet of Plexiglas covered the monitor screen, and the touch screen was spaced approximately 1.6 cm from the screen. A Plexiglas food cup was centered on the wall below the screen, and a lamp beneath the cup illuminated food presentations. A Colbourn pellet dispenser, attached to the top of the chamber, dispensed 45-mg pellets through an attached tube into the food cup. Chamber 2 was a large custom-built chamber, 44 cm high, 32 cm deep, and 74 cm wide (inside dimensions). The monitor was placed against an opening centered in the back wall, 10 cm above the chamber floor. Spacers recessed the touch frame by approximately 3 cm from the opening and separated the frame from the monitor by approximately 1.6 cm. Two Gerbrands (Arlington, MA) pigeon feeders were mounted on the back wall, one on each side of the monitor. The feeder openings began 8.5 cm from the sides of the monitor opening, and 17 cm from the floor. Lamps located within each feeder illuminated feeder presentations, and photocells measured head entries into the hoppers to limit eating times. Chamber 3 was identical to Chamber 2 except that the feeder openings were 7 cm from the floor. Microcomputers, located in an adjacent room, controlled experimental contingencies and recorded peck coordinates.

For humans, the experiment took place in a small private room that contained the touch-screen-equipped computer. Subjects sat in front of the monitor and searched by touching the screen with the eraser end of a pencil.

Search Space and Stimuli

The search space was a rectangular area, approximately 26 × 20 cm on the surface of the monitor. Because the pigeons were free to

move about in their chamber, the stimulus display could be viewed from a maximum distance of about 55 cm for birds in Chamber 1 and 40 cm for birds in Chambers 2 and 3. Casual observation suggested that the pigeons typically viewed the display from less than 20 cm away prior to pecking. Viewing distance for humans depended on how they sat in the chair, but it was estimated to be approximately 45 cm. The landmarks were colored graphic stimuli described in the individual experiments. The monitor was always illuminated with a dark gray background color. The goal was an area of approximately 2 cm² that was undifferentiated from the background except during preliminary training. The location on the screen of the goal area was varied from trial to trial. The location of the center of the goal was randomly selected within three constraints: (a) The goal was placed only in locations that allowed room for all landmarks; (b) the two lowest goal locations possible given the first constraint were not used because pigeons have difficulty pecking accurately at targets low on the screen; (c) the center of the goal was midway between two infrared beams in both dimensions (to ensure that the goal always contained the same number of possible response coordinates).

General Procedures for the Pigeons

Sessions were conducted at approximately the same time each day, 5 or 6 days per week. Sessions lasted until all scheduled trials (approximately 100) were completed or for a maximum of 1 hr. The monitor screen was cleaned at the beginning of each day and between sessions as needed.

Preliminary Training

Birds were initially trained to eat from the food hoppers and were then given several sessions of autoshaping. Each autoshaping trial began with illumination of a solid 2-cm yellow square that marked the goal against the dark gray background. The location of the goal and its marker varied across trials, as described previously. The goal marker remained illuminated for 8 s or until a peck in the goal area was recorded; food was then presented (two pellets in Chamber 1 or 2 s of eating time from a randomly selected food hopper in Chambers 2 and 3). Trials were separated by a 60-s intertrial interval (ITI), during which the monitor was illuminated only with the dark gray background. Once a pigeon pecked on at least 80% of the trials in a session, the ITI was reduced to 5 s and a peck in the goal area was required to terminate the trial and produce the food. This peck training continued until a pigeon successfully completed at least 80 trials in a session.

Search Training

During the first phase of search training, pigeons were gradually trained to find the goal on the basis of landmarks rather than the marker. First, the graphic landmarks (described in the *Procedure* section of the individual experiments) were introduced, but the goal marker was still present. The pigeon then received a series of sessions in which the goal marker was faded out within and between sessions by gradually changing the graphic fill pattern from solid to empty at a rate that depended on the bird's accuracy. This training phase continued until the bird completed at least 80 trials in a session with the goal marker absent.

During the next phase of training, the response requirement was increased over sessions. First, the number of pecks required to the goal area was increased from one to three. A consecutive peck requirement was then added so that the last two pecks had to be in

the goal area. Pecks outside the goal area reset the consecutive peck counter. This requirement ensured that a bird could not trigger reinforcement by simply sweeping its beak around in the general vicinity of the goal. Each increment in the response requirement was implemented only if the bird completed 80 trials in a session.

Finally, the density of reinforcement for meeting the response requirement was decreased to 50% in preparation for testing. On nonreinforced trials, completion of the response criteria resulted in initiation of the ITI. Thus, by the end of training, all birds were accustomed to responding to the goal area several times each trial and to receiving food reinforcement only 50% of the time that they met the response criteria. Each bird remained on the baseline 50% reinforcement condition for a minimum of five sessions and advanced to the test phase only after it completed at least 80 trials on each of the last two sessions.

Testing

All test sessions consisted of a mixture of (a) reinforced and nonreinforced trials, (b) control trials that were visually identical to baseline trials but terminated in the same way as test trials, and (c) test trials. On both control and test trials, the trial terminated without reinforcement 8 s after the second peck recorded anywhere on the screen. The specific types of tests presented are described in the individual experiments.

General Procedures for the Humans

At the beginning of each session, students were provided with the following information: Their task would be to locate a goal area, which would be marked on initial trials but thereafter would be unmarked. A point, which would be available only on some trials, could be earned by accurately responding in the goal. When a point was earned, the cumulative points would be displayed. Points would sometimes not be available, and the trial would end after a certain number of touches, regardless of whether the subject was correct. The session would end after the subject obtained a certain number of points or after a maximum of 45 min.

The experimenter then ran a demonstration program and showed the students that at the beginning of their session they would be asked to enter their age and gender. While demonstrating how to input these data, the experimenter explained that it was important to hold the pencil straight and to remove the pencil from the beams between touches. Students were then presented with two demonstration trials. During the first trial, the goal was marked with a rectangle outlining its area and the letter *T* (for *target*) at its center. The goal marker was absent on the second demonstration trial. Two touches were required on each demonstration trial, and each trial ended with a point. Any procedural question posed by a student was answered with "I'm sorry, but I cannot provide any further information until after you have completed the experiment." After obtaining confirmation that the student wished to participate, the experimenter started the program and left the room.

The student's program began in the same manner as the demonstration program, and the first 2 trials were identical to the demonstration trials. The next 18 trials were baseline trials in which the goal was unmarked, and a variable response requirement was in effect: To complete a trial, the student was required to make either zero, one, or two initial touches in the goal, followed by either one, two, or three consecutive goal touches. Thus, the minimum number of correct touches required varied from one to five, but on trials requiring two or three consecutive touches, the

actual number of correct touches could exceed this minimum because each touch outside of the goal reset the consecutive touch counter. Reinforcement (i.e., a point) was available on a randomly determined 50% of baseline trials. On nonreinforced trials the screen went blank for 2 s after completion of the response requirement, but no message was presented, and the point counter was not incremented.

From the 20th trial until the end of the session, trials consisted of a mixture of (a) reinforced and nonreinforced baseline trials, (b) control trials that were visually identical to baseline trials, and (c) test trials. During control and test trials, the fourth touch recorded anywhere on the screen initiated an interval that varied randomly from 1 to 3 s, after which the first response anywhere on the screen terminated the trial. The students were fully debriefed after completion of the session.

Data Recording and Analysis

Response coordinates were recorded in units that were approximately 1 cm². For each trial, this resulted in an 18 × 25 unit matrix. All trials of each type were combined across all test sessions. Because the goal location varied across trials, units were defined relative to the goal. The variable goal location meant that response units far from the goal were not available on all trials. To adjust for this differential availability of response units, the data were weighted by dividing the number of responses in each unit by the number of times the unit was available. Accuracy scores were computed by determining the proportion of total weighted responses that fell in the four units making up the goal location. For some tests, we calculated the proportion of responses made in hypothetical goal locations according to particular landmarks. Note that chance-level accuracy is low. For example, in Experiments 1–3, 209 units served as goal areas during training, and in Experiments 4 and 5, 153 and 132 units, respectively, served as goal units during training. If subjects responded randomly in these locations during a test, the proportion of responses expected to fall within the four goal units on the basis of chance would be only .02 or .03. It is possible that birds might learn to peck in the general vicinity of the landmarks without learning the direction from landmarks to search. If one assumes random responding within an 8 × 8 unit area (i.e., approximately a goal's distance away on all sides of a landmark), the level expected by chance would still be only .06.

For several tests, we also computed peak places of searching in horizontal and vertical dimensions, using the iterated median procedure described by Cheng (1989) and Spetch et al. (1992). These peaks were derived from the weighted response distributions. For all statistical tests, our criterion for statistical significance was the .05 level. All a posteriori multiple comparisons used Tukey's honestly significant difference test.

Experiment 1

In this experiment, pigeons and humans were trained to find a goal that was in the center of a square array of four identical landmarks (see Figure 1). Because the landmarks were identical and the landmark array moved about on the screen across trials, the only way to solve the task was to learn the location of the goal in the configuration of the array. After training, subjects were tested with expansions of the array, with arrays composed of novel landmarks, and with single landmarks.

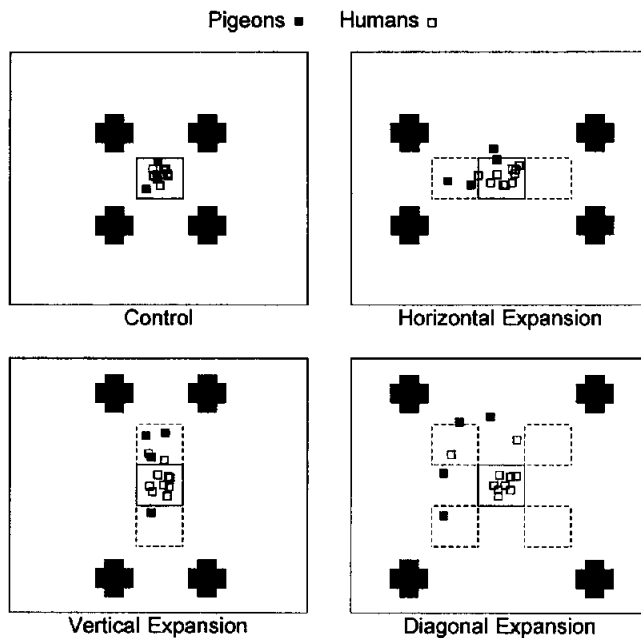


Figure 1. Landmark array used in training (control) and arrays used in expansion tests of Experiment 1. The landmarks were white crosses (shown here in black) on a grey background. Each small filled symbol represents the calculated peak place of searching for one pigeon, and each small open symbol represents the calculated peak place of searching for one human subject. The solid outlined square indicates the location of the unmarked 2-cm² goal in the training array (control) and the middle of the array on expansion tests. The dotted-line squares indicate hypothetical goal locations that maintain the absolute distance and direction from one of the individual landmarks as in training. The search space was larger than the area shown, and the location of the arrays on the screen varied across trials. See text for details.

Method

Subjects

The 4 pigeons used in this experiment had previously participated in an experiment using digitized images as landmarks in a touch-screen task (Spetch & Wilkie, 1994). Prior to that, 2 of the subjects (243 and C204) also had participated in Spetch and Mondloch's (1993) study. The human subjects were 10 women aged 18–44 years.

Procedure for the Pigeons

Training. Because all birds were experienced at searching for an unmarked goal, they required only two preliminary training sessions to reestablish pecking at the goal marker. Search training began on the third session and proceeded as described in the General Methods section. The stimulus array used in training consisted of four white crosses arranged in a square with the goal in the middle (see Figure 1).

Testing. Each subject received three test series, each separated by two baseline sessions. In the first series (novel array), the four white landmarks were replaced with four novel landmarks (magenta stars) on test trials. In total, each bird received 20 control

trials and 20 novel array test trials. The second series (array expansion tests) involved tests in which the original landmark array was "stretched" vertically, horizontally, or both by shifting landmarks outward from their normal position in the array (see Figure 1). In total, each bird received 16 control trials and 16 trials with each type of expansion test. In the last series (single-landmark tests), each landmark was presented alone. In total, each bird received 10 trials with each landmark presented alone and 10 control trials.

Procedure for the Humans

The training procedure was as described in the General Methods section. Five types of test trials were presented: novel array, single landmark, vertical expansion, horizontal expansion, and diagonal expansion. These tests were identical to the corresponding tests used for pigeons. For the single-landmark test, however, we presented only the top left landmark alone, rather than each of the four landmarks alone, to minimize the number of test trials needed.

Results

Training

Pigeons learned the task rapidly. All birds completed training in fewer than 20 sessions (range = 15–19).

Novel-Array and Single-Landmark Tests

None of the pigeons showed evidence of transfer to an array of novel landmarks. Accuracy on control trials ($M = .532$) was significantly higher than on novel landmark tests ($M = .049$), $t(3) = 6.51$. Pigeons were unable to accurately locate the goal on the basis of a single landmark, which was expected given that the landmarks were identical. The mean proportions of responses in the goal were .067, .024, .054, and .072 for tests with each of the four landmarks presented alone, compared with .502 on control trials of the single-landmark test. An analysis of variance (ANOVA) revealed a significant effect of trial type, $F(4, 12) = 15.62$, and subsequent multiple comparisons revealed that accuracy was significantly higher on control trials than on each of the single-landmark test trials.

In contrast to pigeons, humans transferred completely to an array of novel stimuli. The mean proportion of touches in the goal was .770 on control trials and .685 on novel-array trials. As expected, the proportion of touches in the goal dropped to a low level (.159) on single-landmark test trials. An ANOVA revealed a significant difference among these three trial types, $F(2, 18) = 61.03$, and subsequent multiple comparisons indicated that accuracy was higher on control trials and novel-array trials than on single-landmark trials. Accuracy on novel-array trials did not differ significantly from that on control trials.

To directly compare the results for pigeons and humans, we conducted a two-way ANOVA with species and trial type (control, single landmark, and novel array) as variables. For this analysis, we used the average of the control scores from the three test series for the pigeons. In addition, we used only the results of the single-landmark tests with

the star landmark because that was the only one tested for humans. The ANOVA revealed significant main effects of both species, $F(1, 120) = 16.77$, and trial type, $F(2, 24) = 48.20$, as well as a significant Species \times Trial Type interaction, $F(2, 24) = 13.39$.

Array Expansion Tests

On the array expansion tests, pigeons were more likely to respond at a location that maintained the correct absolute distance and direction from one of the landmarks, whereas humans were more likely to respond in the middle location. Figure 1 shows the calculated peak places of responding for the 4 pigeons (filled symbols) and the 10 humans (open symbols) during the control tests and each type of expansion test. For horizontal and vertical expansions, three goal areas are outlined: one for the middle location and one for each of the two locations that would maintain the correct vector from an individual landmark (hereafter referred to as "individual-landmark locations"). For the diagonal expansion, five goal areas are outlined because there are four individual-landmark locations. Across the three tests, only 1 of the pigeons' peaks fell in the middle area, whereas 7 peaks fell in one of the individual-landmark locations. By contrast, 25 of the peaks for humans fell in the center location and only 3 fell in the individual-landmark locations.

Experiment 2

In this experiment, pigeons and humans were trained with the goal at the center of an array of four landmarks that differed in color and shape (see the top left diagram of Figure 2). For subjects in one group (fixed), each landmark maintained a fixed position in the array during training (e.g., the star was always in the top left position). For subjects in the other group (rotated), the landmark positions rotated across trials such that each landmark appeared equally often in each position in the array. Thus, solving the task on the basis of individual landmark-goal vectors instead of position in the array was possible for the fixed group but not for the rotated group. After training, subjects were tested with single landmarks, expansions of the array, and novel combinations of landmarks in the array.

Method

Subjects

The 8 pigeons in this experiment all had previous experience in standard operant chambers, but they were naive with respect to the touch-screen task. Four subjects were assigned to each group. The human subjects were 4 men and 4 women aged 18–22 years. Two men and 2 women were assigned to each group.

Procedure for the Pigeons

Training. All birds received several sessions of preliminary training as described in the General Methods section. During search training, the rotated group received four types of baseline

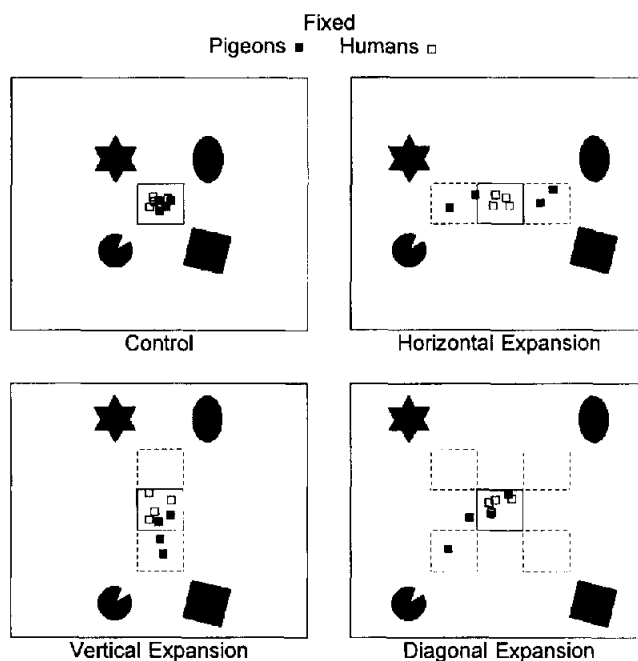


Figure 2. Training arrays (control) used for subjects in the fixed groups of Experiment 2, and the arrays used in expansion tests, with peak places of searching for pigeons (filled symbols) and humans (open symbols) in the fixed group. The four landmarks were distinctly colored (star = green, ellipse = coral, pie = blue, and box = red).

trials that occurred equally often in mixed order within each session. For one type of baseline trial, the positions of the four landmarks were as shown in Figure 2. For the other three types of trials, each landmark was rotated clockwise by one, two, or three positions, respectively. Thus, the direction of each landmark from the goal varied across trials, but the goal was always in the center of the array, and the clockwise order of the four landmarks with respect to each other was always the same. For the fixed group, the arrangement of landmarks on all baseline trials was as shown in the top left diagram of Figure 2.

Testing. Each subject received two blocks of four test sessions. Two baseline sessions separated the blocks. Each block contained one of each of four types of tests. All control and test trials were identical for the two groups, but baseline trials for the rotated group differed from those of the fixed group as during training. All control trials used the arrangement shown in Figure 2. During single-landmark tests, each landmark was tested alone. The position of the singly-presented landmark relative to the hypothetical goal was the same as on control trials. During identical-landmark tests, the four distinct landmarks were replaced with four instances of the same landmark. Tests with four stars, four boxes, four pies, or four ellipses were presented equally as often. During scrambled tests, the positions of the four landmarks were randomly rearranged. Starting from the top left landmark position and moving clockwise, the order of landmarks during the four types of scrambled test trials was as follows: star, pie, box, and ellipse; ellipse, star, pie, and box; pie, star, ellipse, and box; and ellipse, box, star, and pie. During array expansion tests, the landmark array (consisting of the four distinct landmarks in the positions occupied on control trials) was stretched vertically, horizontally, or both by shifting landmarks outward from their normal position in the array. Subjects received 20 trials of each type of test.

Procedure for the Humans

The training procedure was as described in the General Methods section. The stimulus arrays presented during training and baseline trials for the fixed and rotated groups were the same as those presented to the corresponding groups of pigeons. Control and test trials were identical for the two groups and were based on the stimulus arrangement shown in Figure 2. Five types of test trials were presented to each subject: three array expansion tests (vertical, horizontal, and diagonal expansions), one single-landmark test (with the star landmark), and one identical-landmarks test (with an array of four pies). These tests were the same as the corresponding tests described for the pigeons.

Results

Training

From the beginning of search training, pigeons in the fixed group completed training in 13, 15, 17, and 26 sessions; those in the rotated group completed training in 17, 20, 20, and 43 sessions.

Testing

Figures 2 and 3 show peak places of searching on control and array expansion tests for pigeons and humans in the fixed and rotated groups, respectively. As in Experiment 1, pigeons in both groups showed more peaks in locations that maintained the correct distance from an individual landmark than in the middle of the expanded arrays. This was especially true for birds in the rotated group. By contrast, for

both groups of humans, all peaks fell in the center of the expanded arrays. Collapsing across the two groups, 18 peaks for pigeons fell in an individual-landmark location and 4 fell in the middle, whereas no peaks for humans fell in an individual-landmark location and 24 fell in the middle.

The top panel of Figure 4 shows the accuracy scores of pigeons in the two groups on control and test trials of the single-landmark tests, identical-landmarks tests, and scrambled tests. The control data were averaged over the three types of tests, and the test data were averaged over the all test trials of a particular type (e.g., single-landmark tests were averaged over tests with each of the four landmarks presented singly). The bottom panel of Figure 4 shows the accuracy scores of human subjects on control, single-landmark, and identical-landmarks tests.

For pigeons, the performances of the fixed and rotated groups were remarkably similar on the single-landmark tests but diverged somewhat on the other tests. An ANOVA revealed that the main effect of group was not significant, $F(1, 6) = 3.88$, but there was a significant effect of trial type, $F(3, 18) = 41.3$, and a significant Group \times Trial Type interaction, $F(3, 18) = 8.20$. Subsequent multiple comparisons indicated that for the fixed group, control accuracy differed from accuracy on each of the three tests, which did not differ from each other. For the rotated group, control accuracy differed from accuracy on single and identical tests but not from accuracy on scrambled tests. In addition, accuracy was lower on single tests than on either identical or scrambled tests.

Both groups of humans performed well on the identical-landmarks tests and poorly on the single-landmark tests, although this pattern was strongest for the rotated group. A two-way ANOVA revealed a significant main effect of trial type, $F(2, 12) = 74.40$, but not of group, $F(1, 6) = 4.43$. The interaction between group and trial type was significant, $F(2, 12) = 9.04$. Subsequent multiple comparisons indicated that for both groups, accuracy was higher on control and identical-landmarks trials than on single-landmark trials. Accuracy on identical-landmarks trials did not differ significantly from that on control trials for either group.

To compare the results for humans and pigeons, we conducted a three-way ANOVA, with species, group, and trial type (control, single landmark, and identical landmark) as variables. For pigeons, only the single-landmark tests using the star landmark and the identical-landmarks tests using pie landmarks were used because these were the only ones tested on humans. The ANOVA revealed significant main effects of species, $F(1, 12) = 67.63$, and trial type, $F(2, 24) = 98.00$, as well as significant interactions between group and trial type, $F(2, 24) = 4.96$; between species and trial type, $F(2, 24) = 24.42$; and among group, species, and trial type, $F(2, 24) = 7.20$.

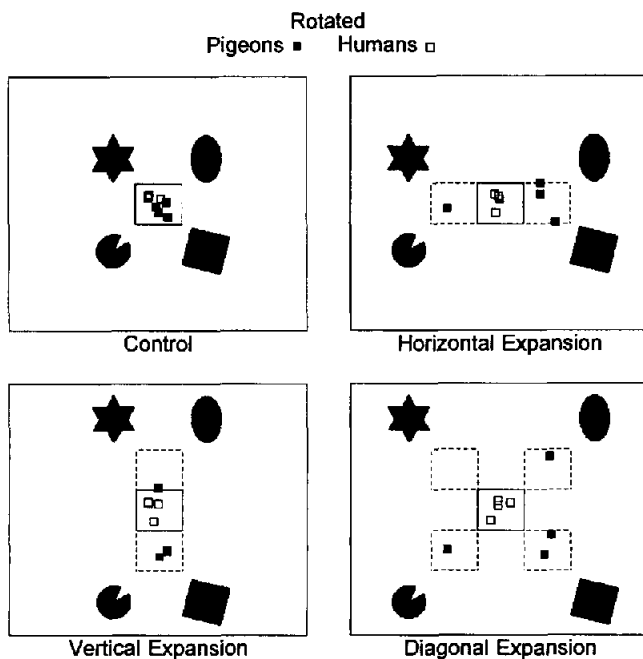


Figure 3. Peak places of searching for subjects in the rotated group in Experiment 2.

Array Expansion Tests of Experiments 1 and 2

Figures 1–3 clearly suggest that pigeons and humans responded differently to expansions of an array; humans

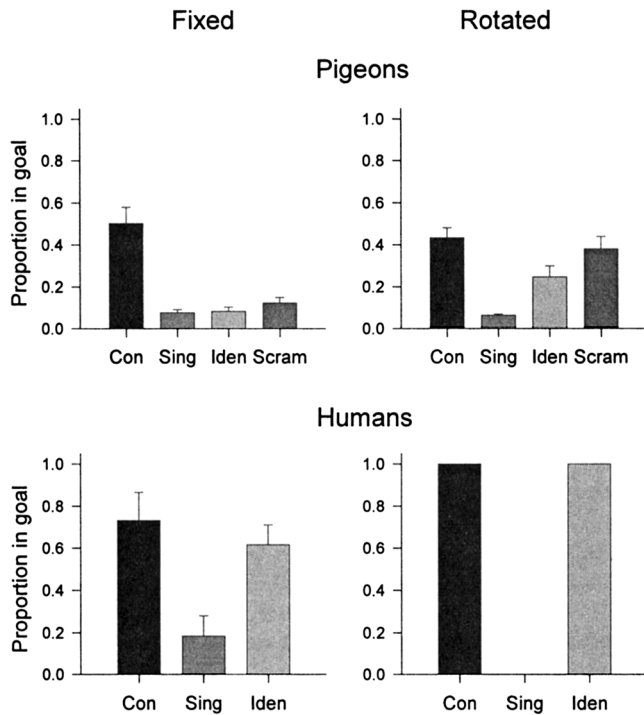


Figure 4. Proportion of responses in the goal area for pigeons and humans in the fixed and rotated groups in Experiment 2 on control tests (Con), tests with a single landmark (Sing), tests with four identical landmarks in the same configuration (Iden), and tests with the four training landmarks rearranged in a new array of the same configuration used in training (Scram).

responded almost exclusively in the center of expanded arrays and pigeons responded primarily in locations that would maintain the training distance and direction from individual landmarks. To confirm this statistically, we needed analyses that would account for the differential opportunities to respond in the two or four individual-landmark locations versus the single middle location. Two such analyses were conducted on the data from expansion tests in Experiments 1 and 2.

First, we corrected the total number of responses falling in individual-landmark locations by dividing each count by the number of individual-landmark locations available (two for horizontal and vertical tests and four for diagonal tests) and compared this with the number of responses falling in the middle location. After correction, the 12 pigeons across the three types of expansion tests pecked significantly more in individual-landmark locations ($M = 30.56$) than in the middle location ($M = 13.46$), $t(11) = 3.77$. The 18 human subjects in Experiments 1 and 2, in contrast, made significantly more responses in the middle location ($M = 13.1$) than in individual-landmark locations ($M = 2.1$), $t(17) = 6.39$. A two-way ANOVA on the data from both species revealed a highly significant Species \times Response Location interaction, $F(1, 28) = 46.62$.

Second, each individual pigeon tended to peck mostly in a single individual-landmark location on a test, and this

location showed consistency across the three expansion tests. To quantify these observations, we used the results of the diagonal expansion tests to predict the individual-landmark location that each subject should respond to most on the horizontal and vertical tests. For example, a subject that responded most to the bottom left location on the diagonal tests was expected to respond most to the left location on horizontal tests and to the bottom location on vertical tests. For the vertical tests, the pigeons made a mean of 67.7 responses in the predicted preferred location compared with 15.73 in the other individual-landmark location and 20.4 in the middle location. For the horizontal tests, subjects made a mean of 57.8 responses in the predicted preferred location compared with 17.9 responses in the other individual-landmark location and 11.8 responses in the middle location. ANOVAs revealed significant effects for both the vertical tests, $F(2, 22) = 10.25$, and horizontal tests, $F(2, 22) = 5.91$ and subsequent multiple comparisons revealed that in both cases, responses were higher in the predicted preferred location than in either the other individual-landmark location or the center location. These analyses strongly suggested that the pigeons were not responding randomly on the expansion tests but instead were responding to maintain the correct distance and direction from one individual landmark.

Discussion of Experiments 1 and 2

Both pigeons and humans are clearly capable of learning the location of the goal in a configuration of landmarks. Their failure to locate the goal on tests with only a single landmark confirmed that accurate searching depended on the configuration of landmarks, not just on a single landmark. Nevertheless, the results of the novel-array and landmark expansion tests suggested a difference between pigeons and humans in how the configuration controlled search behavior. Pigeons showed no evidence of transferring to an identically arranged array of novel stimuli, and they showed little tendency to respond in the middle when the training array was expanded. Human subjects, in contrast, showed complete transfer to an array of novel landmarks in the same configuration, and they continued to respond in the middle when the training array was expanded. Human subjects appeared to have extracted a "middle" rule that they applied to novel landmark arrays or expanded arrays of the training landmarks. Pigeons, in contrast, appeared to respond so as to maintain the appropriate distance from an individual landmark, using the landmark configuration to determine which direction from that individual landmark to search.

Experiment 3

The results of Experiments 1 and 2 suggest that pigeons, unlike humans, do not learn an abstract "middle" concept when they are trained to locate a goal in the center of an array of landmarks. In Experiment 3, we examined whether pigeons would learn an abstract middle rule if trained with

more than one array in which the goal was in the middle. Studies of other kinds of concept learning in animals have indicated that pigeons become more likely to learn a generalizable concept when they are trained with more exemplars of the concept (e.g., Wasserman & Bhatt, 1992; Wright, Cook, Rivera, Sands, & Delius, 1988). In this experiment, pigeons were trained with five arrays of landmarks in which the goal was always in the center.

Method

Subjects

The 4 pigeons in this experiment had previously served in experiments using standard operant chambers. Two of the pigeons also had served in a touch-screen search task with displays consisting of digitized images of objects in a room. None had previously viewed the graphic landmarks used in this study.

Procedure

Training. The 2 birds with no previous experience in touch-screen tasks received several sessions of preliminary training. The 2 experienced birds required only two preliminary training sessions to reestablish reliable pecking to the goal marker. During search training, all birds received five types of baseline trials that occurred equally often in mixed order within each session. The stimulus arrangements on these five types of baseline trials differed in the landmarks that made up the array, but the configuration of each array was identical. In all cases, four landmarks formed a square array with the goal in the center. The configuration was identical to that used in the previous experiments except that the landmarks were spaced slightly farther from the goal (see the left diagrams of Figure 5). For Array 1 the landmarks were four green stars; for Array 2 they were four coral ellipses; for Array 3 they were four blue pies; for Array 4 they were four red boxes and for Array 5 they (starting from the top left and moving clockwise) were a green star, a red box, a coral ellipse, and a blue pie.

Testing. Each subject received two test series, one with novel array tests and one with expansion tests. For the novel-array tests, sessions included control trials with the fifth training array and test trials in which each of the four landmarks was replaced with a white cross-shaped stimulus. For the expansion tests, Array 1 was used for the horizontal tests, Array 3 for the vertical tests, and Array 4 for the diagonal tests. Each expansion test session included vertical, horizontal, and diagonal test trials as well as control trials with each of the three arrays used for tests.

Retraining. During this phase subjects received training trials with diagonal expansions of Arrays 1 and 4, intermixed with normal baseline trials with Arrays 2, 3, and 5. For trials with diagonal expansions, subjects were reinforced for responding in the 2-cm² goal at the center of the expanded array. Retraining began with the goal marker present and a fixed ratio-1 response requirement and then proceeded through each step of search training.

Retesting. This phase involved tests with the arrays that had been trained with diagonal expansion (Arrays 1 and 4) as well as diagonal expansion tests with two of the arrays that had not been trained with expansion (Arrays 2 and 3).

Pigeons

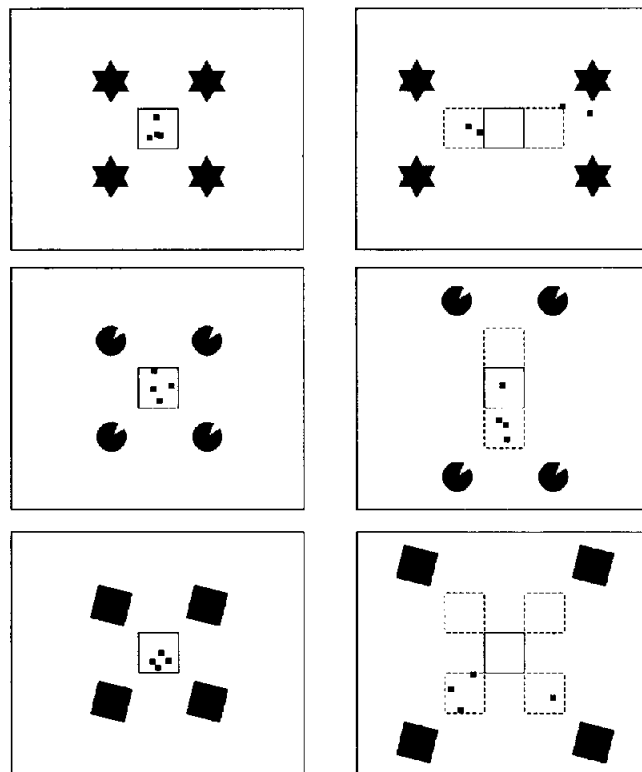


Figure 5. Peak places of searching on control trials with three of the arrays used during training (left three diagrams) and on expansion tests (right three diagrams) for pigeons in Experiment 3.

Results

Despite training with five different arrays, the pigeons showed little transfer of learning to the novel array. Accuracy on novel-array trials ($M = .115$) was significantly lower than accuracy on control trials ($M = .344$), $t(3) = 3.30$.

Figure 5 shows the peak place of responding for each bird on control and test trials for the horizontal, vertical, and diagonal expansion tests. Across the three tests, nine peaks fell in one of the locations defined by an individual landmark, whereas only one peak fell in the middle location. An analysis of the average number of responses in individual-landmark locations (corrected for opportunity as in Experiments 1 and 2) also revealed that pigeons made significantly more responses in individual-landmark locations ($M = 20.2$) than in the middle location ($M = 7.3$), $t(3) = 3.53$.

Figure 6 shows the peak place of responding for each bird on the expansion tests that followed retraining with two expanded arrays. All of the peak places on tests with the two expansion-trained arrays fell in the middle location. The peak places on tests with the untrained arrays were variable; only 1 bird showed peaks in the middle.

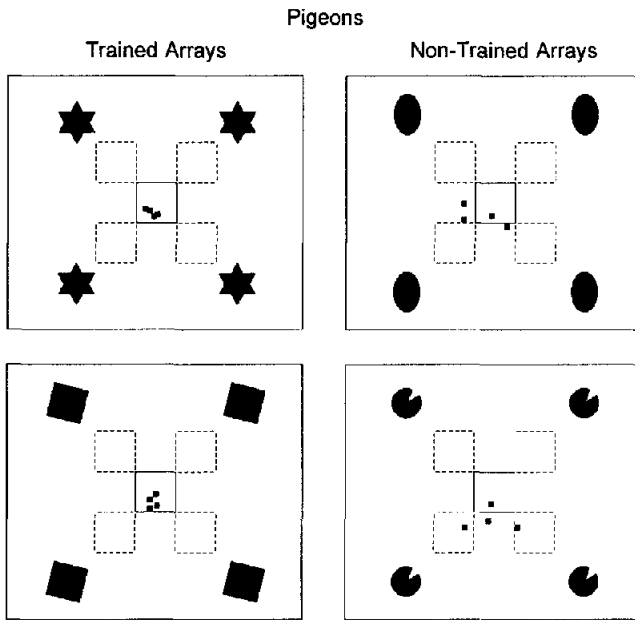


Figure 6. Peak places of searching on expanded arrays for arrays that were trained in the expanded configuration and arrays that were not trained in the expanded configuration, for pigeons in Experiment 3.

Discussion

Training pigeons with five arrays in which the goal was in the middle did not produce a tendency to respond in the middle of expanded or novel arrays. Similarly, the retraining to respond in the middle of two expanded arrays, although showing that pigeons are capable of learning the configuration of a large array, did not produce a strong tendency to respond in the middle of other expanded arrays. Pigeons seem disposed against solving such a task on the basis of a generalizable middle rule. This does not mean, however, that pigeons are incapable of learning a middle concept. It remains possible that training with a much larger set of arrays, or training with arrays that differed in size, would result in the learning of a generalizable middle rule.

Experiment 4

In this experiment, pigeons and humans were tested with a two-landmark array similar to the one used by Collett et al. (1986) with gerbils. Specifically, the goal was located between and below two identical landmarks (see the top diagram of Figure 7). On test trials, the array was expanded or contracted horizontally. In the Collett et al. study, gerbils searched at locations that maintained the training distance and direction from the individual landmarks when given array expansion tests. Bees, on the other hand, responded to expansions and contractions of a similar array (but with three landmarks) by searching at altered distances from the landmarks so as to maintain the learned compass bearings from all landmarks (Cartwright & Collett, 1983). On the

basis of the results of Experiments 1–3, we expected that pigeons, like the gerbils, would maintain the absolute training distance from individual landmarks during array expansion and contraction tests. Although we expected that humans would adjust their horizontal distances to respond midway between the two landmarks horizontally, we were not sure whether they would show triangulation of compass bearings and, like the bees, alter their distance from the landmarks in the vertical dimension.

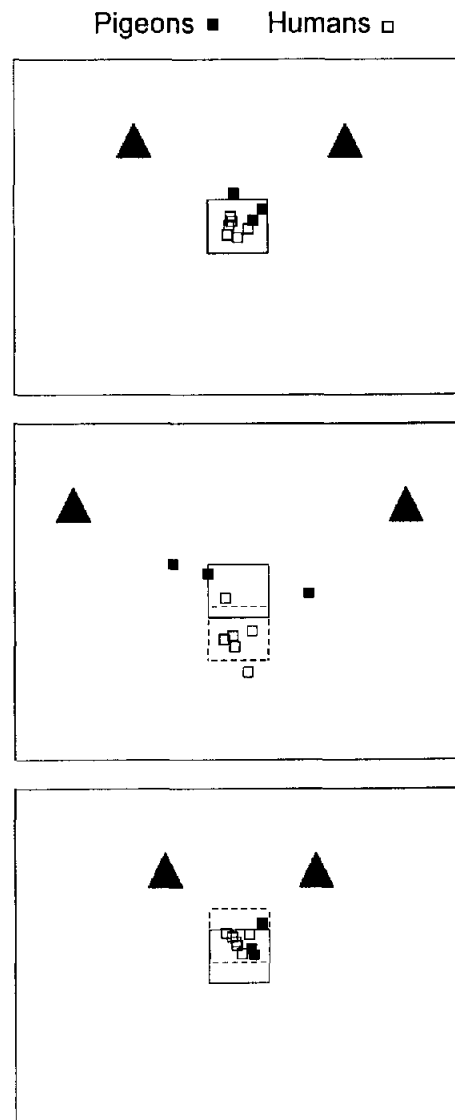


Figure 7. The array used in Experiment 4 on training and control trials (top), the arrays used on expansion tests (middle), and contraction tests (bottom), with the peak places of searching for 3 pigeons (filled symbols) and 6 human subjects (open symbols). The solid outlined square indicates the location of the 2-cm² hypothetical goal prior to shifts of the landmarks. The dotted-line outlined square (in the middle and bottom diagrams) represents the location of the hypothetical goal that would preserve the same shape formed by the landmarks and goal as during training.

Method

Subjects

The 5 pigeons in this experiment all had previous experience in standard operant chambers. Two of the birds also had served previously in touch-screen tasks but with different landmark arrays from those used in this study. The humans were 2 men and 4 women aged 18–21 years.

Procedure for the Pigeons

Training. The touch-screen-naïve birds received preliminary training as described in the General Methods section. During search training, which proceeded as described earlier, all birds were trained with the arrangement of landmarks and goal shown in the top diagram of Figure 7.

Testing. Each subject received two test sessions, each separated by a baseline session. Each test session included two types of array manipulation tests: (a) expansion tests, in which both landmarks were shifted horizontally by 2 cm away from each other (thus expanding the distance between the landmarks by 4 cm), and (b) contraction tests, in which both landmarks were shifted horizontally by 1 cm closer together (thus contracting the distance between the landmarks by 2 cm). In total, subjects received 16 test trials of each type.

Procedure for the Humans

The training procedure was as described in the General Methods section. The stimulus array presented during training and baseline was as shown in the top of Figure 7. Each subject received expansion and contraction tests. The stimulus manipulations of these tests were the same as those described for pigeons.

Results

Training

Two birds (one with previous touch-screen experience and one without) failed to acquire the task within 3 months of training and were dropped from the experiment. The remaining 3 birds required 30–75 sessions of training. Thus, this arrangement of landmark and goal seemed considerably more difficult for pigeons to learn than the ones used in Experiments 1–3, perhaps because of the greater distance of the goal to the landmarks.

Testing

Figure 7 shows the peak places of responding on control and test trials for the 3 pigeons that reached the testing phase and for the 6 humans. On test trials, humans responded midway between the two landmarks in the horizontal dimension. In the vertical dimension, the humans shifted away from the landmarks when the array was expanded and closer to the landmarks when the array was contracted, suggesting that they were attempting to maintain the same shape of triangle formed by landmarks and goal. The pigeons, on the other hand, did not shift their vertical

distance from the landmarks in response to the expansion or contraction tests.

To assess whether subjects were responding so as to maintain the same triangular shape formed by the landmarks and goal as in training, we calculated the expected vertical shift on the basis of shape preservation, using measurements taken from the closest point of each landmark to the center of the goal. Figure 8 shows that predicted and obtained values were close for the humans but not for the pigeons, who showed virtually no vertical shift with expansions or contractions. For the humans on expansion and contraction tests, respectively, the vertical shifts were significantly different from zero, $t_s(5) = 5.27$ and 8.77 , and were not significantly different from the shifts expected on the basis of shape preservation, $t_s(5) = 0.31$ and 2.37 . For pigeons on expansion and contraction tests, respectively, the vertical shifts were not significantly different from zero, $t_s(2) = 1.71$ and 1.99 , whereas they were significantly different from the shifts expected on the basis of shape preservation, $t_s(2) = 12.51$ and 10.68 . An ANOVA on the shift data with species and test (expansion or contraction) as variables confirmed that there was a significant interaction between species and test, $F(1, 7) = 25.60$.

Discussion

Because the two landmarks used in the array were identical, the subjects must have been using the configuration of the array to determine the location of the goal. However, the pattern of results obtained in this experiment is consistent with that of previous experiments in suggesting that the way in which the configuration controlled behavior differed for

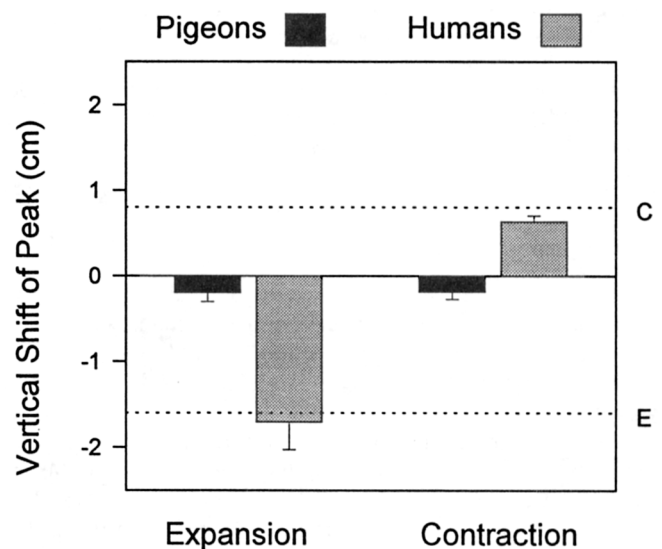


Figure 8. Average shift of peak place of searching on expansion and contraction tests relative to control tests in Experiment 4 for pigeons and humans. The dotted lines indicate the theoretical extent of shift on contraction tests (C) and expansion tests (E) if the subjects preserved the shape formed by the landmarks and the search location.

pigeons and humans. Humans, once again, followed the expansion and contraction. Pigeons showed no such tendency, and on expansion tests they appeared to respond in locations that would preserve the distance and direction to individual landmarks.

Experiment 5

Because the results of Experiment 4 showed that humans responded to horizontal expansions and contractions of a two-landmark array in a fashion similar to that shown by honeybees (Cartwright & Collett, 1983), we wondered whether they also might respond to manipulations of the size of a single training landmark in the same way as bees. When trained with a single landmark, honeybees adjust their distance of search from the landmark in response to manipulations of its size (Cartwright & Collett, 1983), searching closer when the landmark is smaller and farther when the landmark is bigger. In this experiment, humans were trained with a goal that was a constant distance and direction from a single landmark. On crucial tests, the landmark was made either bigger or smaller.

Method

Subjects

The human subjects were 2 men and 5 women aged 19–25 years.

Procedure

The landmark was a yellow circle. The goal was to the right of the landmark (5 cm center to center or 3.5 cm edge to edge) and was centered with the landmark vertically (see the top of Figure 9). Training was as described in the General Methods section. Each subject then received tests in which the landmark was made smaller (decreased from 12 to 8 pixels in radius) and tests in which the landmark was made larger (increased from 12 to 16 pixels in radius).

Results

The peak places of responding for each subject on control test trials are shown in Figure 9. Subjects searched closer to the landmark when it was made smaller and farther from the landmark when it was made larger. The shift in search location relative to control trials was significantly greater than zero for both the small landmark tests ($M = 1.032$ cm leftward), $t(6) = 3.083$, and the large landmark tests ($M = 1.228$ cm rightward), $t(6) = 3.164$. These shifts were also larger than that expected if the subjects had been using the edge of the landmark to measure distance to the goal (the decrease in landmark radius would increase the distance from the nearest edge of the landmark to the goal by 0.16 cm, and the increase in landmark radius would decrease this distance by 0.24 cm). For both the smaller and larger tests, the shifts were significantly greater than these values, $t(6) = 2.61$ and 2.55, respectively. However, the shifts

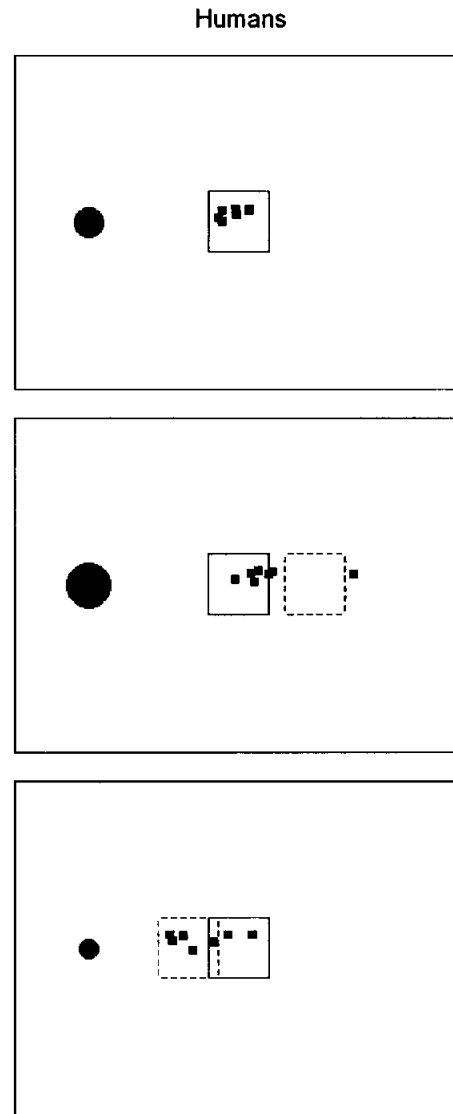


Figure 9. The array used in Experiment 5 on training and control trials (top) and the arrays used on test trials in which the landmark was made larger (middle) or smaller (bottom), with the peak places of searching for humans. The solid outlined square indicates the location of the 2-cm² hypothetical goal if subjects ignored the change in landmark size. The dotted-line square indicates the location of the hypothetical goal if distance was judged proportionally to the landmark size.

were not as large as would be expected if subjects had been judging distance entirely on the basis of landmark size. For example, the landmark manipulations increased and decreased the size by a factor of 1.5. Using the center-to-center estimate of distance (5 cm), a similar proportional shift in distance would lead to expected shifts of 1.67 cm leftward for the smaller landmark and 2.5 cm rightward for the larger landmark. The obtained shift was not significantly less than this expected shift for the smaller landmark, $t(6) = 1.91$, but it was significantly less for the larger landmark test, $t(6) = 3.28$.

Discussion

These results suggest some compromise between searching at a distance that was proportional to the size of the landmark and searching at a location that maintained the same absolute distance of the landmark to the goal as in training. Cartwright and Collett (1983) concluded that honeybees judged distances from landmarks primarily by the retinal size projected by the landmark. From their results, however, it appears that the bees did not always adjust their distance of search exactly as predicted according to the sole use of retinal size. In particular, they tended to shift less than predicted by the retinal-size-only hypothesis when the landmark size was increased, and they sometimes shifted more than predicted when the landmark size was decreased. Human subjects likewise showed a partial, but not a complete, tendency to gauge distance according to landmark size on the touch screen.

General Discussion

The results of these experiments show that both humans and pigeons can learn the location of a goal relative to the configuration of an array of local landmarks. When trained with four identical landmarks in a square array or with four distinct landmarks whose positions within a square array varied, both pigeons and humans learned the task. In such cases, the spatial relationship between any individual landmark and the goal is not defined except with reference to its position within an array. Therefore, the configuration of the array must be used in spatial localization.

Two sets of results suggest, however, that this learning reflects different processes in the two species. First, humans showed complete transfer of the learned spatial relationship between the goal and the landmark array to an array composed of novel stimuli in the same configuration, whereas pigeons failed to show such transfer, even when trained with five different arrays exemplifying the same landmark-goal configuration. Second, on expansions and contractions of arrays, humans appeared to adjust their distances from the landmarks to preserve relative spatial relationships, whereas pigeons responded in ways that maintained the absolute distance from individual landmarks, as they do on the laboratory floor (e.g., Cheng, 1988).

Humans behaved similar to honeybees in response to array expansion and contractions (Experiments 1, 2, and 4) and, to some extent, to manipulations of the size of a single landmark (Experiment 5). Nevertheless, we do not believe that our human subjects in the touch-screen tasks were doing what honeybees do. Honeybees appear to shift their distance from the landmarks to maintain the same retinal image encoded during training (Cartwright & Collett, 1983). By adjusting their distance when faced with an expanded or contracted array of landmarks, they could match the location of each landmark in their current image with that in the training image. When faced with expansions or contractions of a single training landmark, they could match the size of the landmark in their retinal image by

adjusting their distance. That they do not always follow precisely the predictions of the retinal image hypothesis might mean that another mechanism, most likely motion parallax (discussed later), is also used to estimate distance. The humans, on the other hand, responded with their hands rather than their whole body and hence did not view the landmarks from the location at which they were responding. Therefore, it would not be reasonable to assume that their search behavior was controlled by a process of matching retinal images. Instead, we hypothesize that adult humans are using an abstract rule in spatial search not found in the rest of the animal kingdom. However the rule is formulated, it generates goal locations according to euclidean rules of geometric expansion and contraction. Several subjects did spontaneously verbalize such a rule after they had completed their task, even though they were not asked to provide a reason for the way they responded.

We further suggest that the processes used by bees are in fact more similar to those used by other animals than they are to those used by adult humans. Pigeons (Experiments 1, 2, and 3), honeybees (Cartwright & Collett, 1983), gerbils (Collett et al., 1986), marmoset monkeys and young children (MacDonald et al., 1996), and perhaps all other creatures who exhibit landmark-based spatial memory appear to be attempting to maintain the correct distance between individual landmarks and the target. We believe that bees behave differently from pigeons and gerbils on expansion and contraction tests because they differ in the visual mechanisms used for perceiving distance. Honeybees appear to have only two mechanisms of depth perception. One is to rely on the projected retinal size of an object, and the other is motion parallax (Lehrer, Srinivasan, Zhang, & Horridge, 1988; Srinivasan, Lehrer, Zhang, & Horridge, 1989). In following the expansion and contraction of arrays of landmarks and of single landmarks, then, the honeybees are shown to rely heavily on projected retinal size as a mechanism of judging distance. In following the expansion and contractions of arrays, they are matching the projected angle subtended by a pair of landmarks, whereas in the case of a single landmark, they are matching the angle subtended by the edges of the landmark. Other organisms, such as pigeons and gerbils, do not seem to rely heavily on projected retinal size for judging distance, although gerbils have been shown to be sensitive to the retinal size projected by a platform in gauging the distance to jump to the platform (Goodale, Ellard, & Booth, 1990). Thus, the different response shown by bees than by these other creatures to expansions and contractions of arrays and landmarks may reflect nothing more than different ways of judging distance. In either case, we have no reason to invoke an abstract geometric rule.

Besides our major conclusion of a difference between adult humans and pigeons (and other animals), we should not overlook many similarities. In this research, we have shown that both humans and pigeons can learn to use the configuration of a landmark array in spatial search. All creatures found to use landmark-based spatial memory use metric information (angles and distances) in spatial search. Studies in the real world (Cartwright & Collett, 1983; Cheng, 1988, 1989, 1994; Cheng & Sherry, 1992; Collett et

al., 1986) and on the touch screen (Spetch et al., 1992; the current experiments) corroborate this point. On the touch screen, humans appear to weigh landmarks near the goal more heavily than landmarks far from the goal (Spetch, 1995; Spetch & Wilkie, 1994), a finding that is common to several species and several kinds of spatial tasks (e.g., Cheng, 1989; Cheng et al., 1987). In addition, Spetch (1995) found that for both pigeons and humans in the touch-screen task, the control of searching acquired by a given local landmark can be overshadowed by the presence of an additional landmark that is closer to the goal. Thus, some aspects of landmark-based search show considerable cross-species generality.

The use of search tasks on the touch screen raises the question of ecological validity: Do processes used in searching on the monitor reflect processes used in searching in the real world? We posit that the answer is yes. In published work, we have shown that pigeons behaved similarly in experiments with landmark shifts on the touch screen and on the laboratory floor (Spetch et al., 1992). Certain principles, such as the greater weight given to landmarks near the goal than to landmarks far from the goal, seem common to both environments (e.g., Cheng, 1989; Spetch & Wilkie, 1994). In a companion paper, Spetch et al. (1996) also show that the pattern of results found in the tasks reported here are found in search tasks on the laboratory floor. We suggest, on the basis of our results with pigeons, that search tasks on the touch screen and laboratory floor are tapping some unitary spatial representation system that transcends the different viewing conditions and the anatomies of the visual systems.

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