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Strategies in landmark use by children, adults, and marmoset monkeys

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Abstract

Common marmosets (*Callithrix jacchus jacchus*), human children, and human adults learned to find a goal that was located in the center of a square array of four identical landmarks. The location of the landmark array and corresponding goal varied across trials, so the task could not be solved without using the landmark array. In Experiment 1, a matrix of discrete goal locations was presented and the landmarks surrounded and were adjacent to the correct location during training. After training, an expansion test was given in which the distance between landmarks was increased. Marmosets, children (ages 5–9), and adults all readily learned to use the landmarks to search accurately during training. On the expansion test, adults uniformly searched in the center of the array. Monkeys and children concentrated their searching near the landmarks rather than in the center. The monkeys, but not the children, searched more often on the directionally appropriate side of the landmarks than on other sides of the landmarks. In Experiment 2, children (ages 3–5) were trained with a continuous search space and with the goal farther from the landmarks so that a beaconing strategy rule could not be used. Several of the children failed to acquire the training task. Of those who learned to find the goal, three searched in the middle on expansion tests but most searched nearer to the landmarks. The “middle rule” strategy that is uniformly used by adult humans does not appear to be a preferred strategy for children or non-human primates.

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Landmark use in children, adults, and marmoset monkeys: Learning the configuration of a landmark array

Remembering and finding important places such as home and sources of food is one of the most fundamentally important problems faced by moving organisms. Not surprisingly, various mechanisms have evolved that allow organisms to locate and navigate to desired locations. One common place finding mechanism is to encode visual cues at or near a goal and then use cues as beacons or landmarks for piloting to the goal at a later time. Use of visual cues to find a goal has been demonstrated in numerous organisms including insects (e.g., Cartwright & Collett, 1982; Chittka, Geiger, & Kunze, 1995), fish (Sovrano, Bisazza, & Vallortigara, 2002, 2003), turtles (Lopez et al., 2000), rodents (e.g., Collett, Cartwright, & Smith, 1986; Suzuki, Augerinos, & Black, 1980), birds (e.g., Cheng, 1988, 1989; Cheng & Sherry, 1992; Spetch & Edwards, 1988; Vander Wall, 1982), non-human primates (e.g., Sutton, Olthof, & Roberts, 2000) and humans (e.g., Spetch, 1995).

There are several ways in which spatial information from visual cues near a goal may be encoded and used to remember the goal location. One of the interesting findings to emerge from recent comparative work is that strategies of landmark use show both commonalities and differences across species. Some aspects of landmark use, such as the occurrence of competition between landmarks and preference for landmarks near a goal, seem to be highly general across species from invertebrates to humans (for reviews see Cheng & Spetch, 1988 and Spetch & Kelly, *in press*). However, some interesting differences in spatial strategies have been revealed by studies investigating use of landmark configurations. For example, one situation that has been tested in several species involves training in which a goal is hidden at a fixed location relative to an array of two or more identical landmarks. The landmark array is located within a well-oriented search space which provides stable directional cues, but the landmark array and corresponding goal are moved about within the search space so that the landmarks must be used to pinpoint the location of the goal. There are several ways in which the spatial information provided by the landmarks might be used. One strategy is to encode the entire array of landmarks as a configuration and learn the location of the goal relative to this configuration. A second strategy is to encode distance and direction of the goal from individual landmarks in the array. However, if the landmarks are visually identical and the array moves within the search space, then the configuration must be used to identify the individual landmarks (e.g., to determine which is the top left landmark). Thus, this strategy involves use of the configuration for landmark identification, followed by an elemental use of individual landmarks for place finding (see Cheng & Spetch, 1998). A third strategy that could be adopted is to use the landmarks as a beacon and simply search close to the landmark array. Such a strategy could be useful if the landmarks surround and are extremely close to the goal. In this case, searching at the location that is closest to all landmarks could yield accurate search. If the landmarks are too far from the goal, then a beaconing strategy alone would not generate accurate search.

The ability to acquire accurate search with a landmark array does not by itself indicate which strategy is being used, and consequently transformation tests are

conducted. One such transformation entails expanding the landmark array by moving all landmarks farther apart. A configural strategy for encoding the goal location would lead the organism to maintain the same relative location with respect to the array. For example, if the goal was in the center of the training array, then the organism would search in the center of the expanded array. A configural strategy for identifying the landmarks coupled with an elemental strategy for encoding the goal location would lead the organism to maintain the same distance and/or direction from individual landmarks as in training. A beaconing strategy would lead to search near individual landmarks but not necessarily in fixed distances and directions from these landmarks.

Expansion tests after training with a landmark array have been conducted on various species ranging from honeybees to humans. Interestingly, of the species tested so far, only honeybees and humans have been found to spontaneously show a fully configural response to a landmark array. Cartwright and Collett (1982) trained bees to find a goal that was located at a particular distance and direction from an array of three identical landmarks and then expanded or contracted the array (moved landmarks farther apart or closer together). The bees searched farther from the landmarks when the array was expanded and closer when the array was contracted, thereby maintaining the appropriate compass directions from each landmark. This configural strategy appears to reflect the bee's image-based memory system in which the goal is encoded as a series of snap-shot like images of what the environment looks like at the goal. When an array of landmarks near the goal is expanded or contracted, the best match is to place the landmarks in the correct directions from the target, while changing target-landmark distances.

Adult humans have been found to show a configural strategy with two kinds of landmark arrays and several kinds of experimental tasks. Using both computer-screen and table-top tasks, Spetch and colleagues trained humans to find a goal that was located below and between an array of two landmarks (Spetch, Cheng, & MacDonald, 1996; Spetch et al., 1997). Like bees, humans adjusted their distance from the landmarks to stay centered between them, and many participants fully adjusted their distance to maintain the same compass bearings from the landmarks. Spetch et al. (1996, 1997) also trained humans on computer-screen, table-top, and outdoor search tasks to find a goal that was centered within a square array of four landmarks. In response to expansions of the array, participants uniformly searched in the center.

These results with honeybees and humans contrast with results of all other species tested so far. Collett et al. (1986) trained gerbils to find a goal that was located midway between and at a fixed distance south of two landmarks. On expansion tests, the gerbils concentrated their search at locations defined by the training vector from each individual landmark. The two localized search peaks appropriate to each landmark indicated that the gerbils used the configuration of the landmarks to determine which landmark was which. However, they appeared to use each landmark individually when searching for the goal location.

Spetch et al. (1996) tested pigeons' use of landmark arrays using both touch-screen computer tasks and open-field tasks conducted on the laboratory floor. In one type of training setup, the goal was located between and below two landmarks. Similar to

the results with gerbils and unlike the results with humans, the pigeons did not stay centered between the landmarks on expansion tests but instead maintained approximate vectors from individual landmarks. In another type of setup, the goal was centered in the middle of a square array of four landmarks. In contrast to humans, the pigeons again searched at approximate vectors from individual landmarks when the array was expanded; they showed no tendency to use a middle rule strategy. It should be noted that the touch-screen and open-field search tasks differed in numerous ways, including the scale of space, the nature of response, and the nature of the landmarks, and hence the consistency of the strategy used across tasks by each species suggested that the difference between species reflected differences in cognitive processes.

Recently, Sutton et al. (2000) tested two squirrel monkeys on similar array expansion tests. In one experiment, the monkeys were trained to find a goal in the middle of an array of four landmarks; in another, the goal was centered between an array of two landmarks. In neither case did the monkeys show a tendency to search in the middle on expansion tests, but instead searched near the landmarks.

It appears, then, that the middle rule strategy, which is uniformly adopted by adult humans when trained to find a goal that is centered within an array of landmarks, is not the preferred strategy used by several animal species. However, the preference for a non-relational strategy does not appear to reflect an inability to learn a relational rule. Several studies have demonstrated the learning of relational rules for landmark-based spatial search by animals when the training task cannot be easily solved using an elemental or beaconing strategy. For example, Kamil and Jones (1997, 2000) trained Clark's nutcrackers to find a goal that was located midway between two landmarks or at fixed bearings or distance from the two landmarks. During training, the distance between the landmarks varied so that learning a fixed vector from each landmark would not result in accurate search. The nutcrackers learned the tasks and transferred to novel interlandmark distances. Although less accurate than the nutcrackers, pigeons also were able to learn tasks that required the learning of a relational rule (Jones, Anotoniadis, Shettleworth, & Kamil, 2002; Spetch, Rust, Kamil, & Jones, 2003). Sutton (2002) also found that pigeons could discriminate between different configurations of the same landmarks and use this information to determine where to search. Interestingly, nutcrackers, like pigeons, show an elemental use of individual landmarks for place finding if trained with a single fixed landmark array (Kippenbrock, Kelly, Templeton, & Kamil, submitted). Thus, several species are capable of relational rule learning but do not spontaneously adopt the rule when alternative strategies allow accurate search.

The present research was designed to extend the comparative literature on strategies of landmark use in three ways. First, we extended the comparison to another primate species, the marmoset monkey. Marmoset monkeys, unlike the squirrel monkeys tested by Sutton et al. (2000), are members of the Callitrichidae family. Unlike squirrel monkeys (Roberts, Mitchell, & Phelps, 1993), marmoset monkeys have been found to have excellent spatial working memory (MacDonald, Pang, & Gibeault, 1994). Therefore, if expansion tests reveal that marmosets show similar strategies of landmark use to those shown by squirrel monkeys, this would suggest that the preferred strategies are not peculiar to one species of non-human primate.

Second, we extended the comparison to include human children. The differences found between adult humans and all other vertebrate species tested so far could reflect either an evolutionary difference or experiential factors, such as training in map reading, that are unique to adult humans. If the latter, then young children may show strategies of landmark use that are more similar to those of non-humans than to those of human adults. Finally, our studies were designed to expand on our previous research by testing with expansions of a landmark array after training on a task that could be solved by using either a beaconing strategy, an elemental landmark strategy, or a configural strategy.

In our first set of experiments, we used a search task that would permit the use of any of the three strategies outlined above: configural use of landmarks, elemental use of landmarks, or beaconing. We tested a non-human primate, the common marmoset, as well as human children and adult humans. In our second experiment, we tested children on a task more like the ones used in previous studies with adult humans and animals, namely one that does not permit beaconing. In both studies, landmark array expansion tests were used to determine the nature of the search strategy adopted by the participants.

Experiment 1

In this set of three experiments, marmoset monkeys (Experiment 1a), human children, (Experiment 1b), and adult humans (Experiment 1c) were trained to find a goal that was hidden in a discrete location and surrounded by four identical landmarks. The three experiments were conducted in different laboratories, and, although specific procedural details differed, critical aspects of the procedure were common across experiments. On each trial, a matrix of discrete but visually identical hiding places was presented for choice, with a goal hidden in one of them. Four visually identical landmarks were located adjacent to and surrounding the goal. The goal location, and the surrounding set of four landmarks, moved within the search space across trials so that the landmarks provided the only reliable cue about which hiding place contained the goal. In all cases, at least three spatial encoding strategies could be used to learn the training task: (1) participants could learn a relational “middle rule,” (2) they could use the landmark configuration to identify the landmarks but use vectors from individual landmarks to find the goal, or (3) they could use the landmarks as beacons and learn that the goal is adjacent to the landmarks (with the center hiding place being adjacent to all of the landmarks). In all experiments, training was followed by an expansion test in which the landmarks were spread apart to determine which strategy was used.

Experiment 1a: Marmoset monkeys

The spatial abilities of non-human primates are well-documented. Chimpanzees (e.g., Menzel, 1973), gorillas (e.g., Gibeault & MacDonald, 2000; MacDonald, 1994),

orangutans (e.g., MacDonald & Agnes, 1999), Old World yellow-nosed monkeys (e.g., MacDonald & Wilkie, 1990), and New World marmoset monkeys (e.g., MacDonald et al., 1994) have shown very accurate performance on tasks that require them to remember where hidden food is located. The mechanisms underlying this accurate performance, however, are less well understood.

Marmosets seem particularly likely to use landmarks in spatial search. Common marmosets and other members of the Callitrichidae family have shown good memory for spatial location, both in the wild (e.g., Garber, 1989) and in laboratory situations (e.g., MacDonald et al., 1994). Marmosets are extremely small, arboreal primates (Fedigan, 1982) that forage in a social group; the ability to remember and use landmarks and landmark configurations would greatly increase foraging efficiency. In this experiment, we focused on two questions: can marmosets learn to use the array of identical landmarks to locate hidden food, and, if so, what spatial encoding strategy do they use?

Method

Subjects

Three adult marmosets served as subjects. The monkeys were born in captivity at the Toronto Zoo in Toronto, Ontario and were on loan from the zoo for the duration of the experiments. Elvis, a 3-year-old adult male, had previously participated in a study of spatial memory in a foraging task (MacDonald et al., 1994). Jerry (a 2-year-old adult male) and Priscilla (a 4-year-old adult female) were experimentally naive. The marmosets were approximately 20 cm in body length, and each weighed approximately 400 g. Elvis and Jerry were housed in a family group of marmosets; Priscilla was housed individually but had visual and vocal contact with the marmoset group at all times.

Testing area

Testing was conducted in the room in which the monkeys were housed. The room measured 3 m wide by 4 m long by 3 m high. One door provided access to the room. The room had a cement floor and contained a sink area, a table upon which Jerry and Elvis' home cage was located, and a movable trolley upon which Priscilla's home cage was located. Both home cages measured 1 m × 1 m × 1 m; two sides of each cage were steel mesh, and two sides were solid stainless steel. The home cages contained water dispensers, food dishes, and sleeping boxes. Jerry and Elvis' home cage was connected by a 9 cm-diameter PVC tube to a large (3 m wide by 3 m high by 1 m deep) play area, which contained a variety of toys and ladders for climbing. Jerry and Elvis normally had free access to the play area but could be kept in their home cage by blocking the connecting tube. A videocamera mounted 2 m from the floor was used for live monitoring of all sessions and for video recording of all test sessions.

During testing, a table (1.1 m wide by 0.76 m deep by 0.76 m high) was placed in the testing room. Thirty small (94 ml) paper cups, approximately 5.5 cm in diameter, were glued to the table. The cups were placed in a 6 × 5 matrix, approximately 10 cm apart as shown in Fig. 1. Each cup was partially filled with 5 g of uncooked rolled

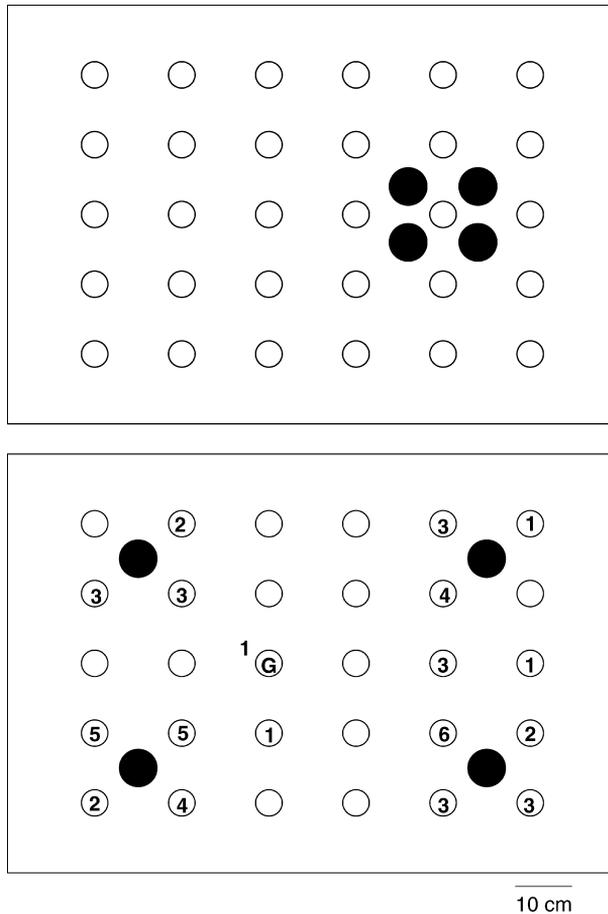


Fig. 1. (Top) Schematic diagram of the experimental setup for marmosets in Experiment 1a during the training phase. Open circles represent the food cups and filled circles represent the landmarks. (Bottom) Experimental setup and total number of choices made to each matrix location by all three monkeys during the Test phase in Experiment 1a. G represents the goal.

oats. Throughout testing, single mealworms were used as food rewards. The mealworms (a highly preferred food) were hidden under the oats in the cups. Four identical unopened 461-g cans of Zu-Preem primate food served as “landmarks”. The cans were bright orange in color and were approximately 8 cm in diameter and heavy enough that the monkeys could not move them accidentally.

The testing area was illuminated by full spectrum fluorescent light on a 12h light:12h dark cycle. Testing took place during the afternoon, between 1 and 4 pm. Test sessions were conducted three days per week, with an interval of at least one day between test sessions. The marmosets were fed their regular rations (Zu-Preem primate food and a variety of fruit) after each test session and always had free access to food and water throughout the day.

Procedure

Training phase. Monkeys were run individually, and only one monkey was run per day. Each training session consisted of 10 trials. At the start of each trial, one of the 30 food cups was baited with a single mealworm; the worm was hidden under the oats so that it was not visible. The location of the baited food cup was randomly determined on each trial, with the restriction that each of the 30 food cups was baited four times during the course of training. The four landmarks were placed around the baited cup as shown in the top of Fig. 1. The experimenter released the monkey from the home cage, then left the room and monitored the session through the video setup. The monkey was free to search all the cups; the trial ended when the monkey retrieved the worm. No time limit was placed upon the search, although most trials ended within 1 min. After each trial, the experimenter re-entered the room, put the monkey back in the home cage, cleaned any oats from the table and began the next trial. The locations of the food sites visited by the monkey were recorded; a site was counted as “visited” if the monkey made contact with the oats inside the cup (the monkeys usually searched through the oats with their hands but occasionally stuck their heads in the cups to search). Each monkey received 12 training sessions for a total of 120 trials.

Test session. Immediately after the tenth trial of the final training session, each monkey received one test trial. The procedure on the test trial was identical to that on training trials except that the food reward was hidden in a cup located near the center of the matrix (because this was a 6×5 matrix, there was no cup in the *exact* center) and the landmarks were placed near the corners of the matrix, as shown in Fig. 1. The trial was terminated after the monkey retrieved the worm from the baited cup or stopped searching. The locations of the food sites visited by the monkey were recorded.

Results and discussion

Training phase

All three monkeys received 120 training trials, but each monkey apparently learned the task before the end of training. They were all highly accurate at obtaining the hidden worm on their first choice by the last 20 trials (Elvis: 18/20 trials; Priscilla: 19/20 trials; and Jerry: 18/20 trials). This accuracy is quite surprising. Because of their small size, the monkeys actually foraged *among* the sites and so had to physically move around sites to get to the baited location. There was no penalty for incorrect choices, and so we had expected the monkeys to occasionally stop and look in sites on their way to the baited location. The landmarks appeared to exert very strong control over responding during the training phase.

Test phase

On the expansion test, only one monkey (Priscilla) ever found the baited site; this was on her 19th choice. Note that this result indicates that the monkeys were not relying on olfactory or other food-related cues to find the baited site on training

trials. The other monkeys abandoned their search after several minutes. Jerry made a total of 18 choices; Elvis made a total of 15 choices. The choices made by all three monkeys are plotted in Fig. 1, with the numbers indicating the total number of choices made to each location in the matrix. Overall, 88.5% of their choices were made to sites directly adjacent to the landmarks. There was some tendency to respond at locations that maintained the same vectors from individual landmarks as in training: the four adjacent sites that maintained the same direction from the landmark as in training were visited about twice as often (18 total visits) as the other adjacent sites (average of 9.33 visits). A one-sample *t* test confirmed that the monkeys made significantly more visits to the four directionally correct adjacent sites than would be expected on the basis of random sampling among all 16 adjacent sites $t(2) = 3.76, p < .05$, one-tailed. The monkeys also made significantly more visits to the 8 locations near the two landmarks at the bottom of the matrix than expected on the basis of random sampling among the 16 adjacent sites, $t(2) = 7.68, p < .05$, probably because they tended to enter the matrix from the bottom. Overall, there was no evidence that the monkeys used a “middle” rule. Rather, they focused their search near the landmarks. They apparently learned more than a simple adjacency rule, however, because they chose more directionally appropriate adjacent sites than other adjacent sites. Hence, the best conclusion is that the monkeys used a combination of a beacon (adjacency) rule and vectors from individual landmarks. In the case of using the vectors, the identity of the landmarks had to be determined from the configuration of landmarks.

Experiment 1b: Human children

In Experiment 1a, marmoset monkeys readily learned to find hidden food in the center of four landmarks, thus demonstrating good use of the landmarks for foraging. However, they searched near the landmarks rather than in the center of the landmark array on the expansion test, indicating that they did not use an abstract “middle” rule strategy. In Experiment 1b, we tested human children on a similar task. Even very young children have been shown to have some rudimentary spatial abilities (e.g., Rutland, Custance, & Campbell, 1993), but strategies used by children change with age (e.g., Blades & Medlicott, 1992; Cornell, Heth, & Alberts, 1994). There is evidence that children younger than 6 years use landmarks differently than older children (e.g., Blades & Spencer, 1987a; Fehr, 1980; Waller, 1986). Older children appear to use landmarks effectively to recall spatial locations (Anooshian & Young, 1981; DeLoache, 1986; Presson, 1987) and are more likely than younger children to recall landmarks when describing routes (e.g., Waller, 1986). Also, in re-orienting after disorientation, children from 18 months up use the geometric shape made by the surfaces of the testing room (Hermer & Spelke, 1996; Hermer-Vazquez, Moffet, & Munkholm, 2001; Learmonth, Newcombe, & Huttenlocher, 2001; Learmonth, Nadel, & Newcombe, 2002). Under certain conditions, they also use non-geometric cues such as the colors of walls. The use of non-geometric cues increases with age, and 6-year-olds behave like adults in using non-geometric cues in all conditions

tested so far, while 5-year-olds fail to use non-geometric cues under some conditions (Hermer-Vazquez et al., 2001; Learmonth et al., 2002). It seems likely that strategies of landmark use in tasks that allow several possible strategies might be particularly sensitive to developmental changes. Our set of participants ranged from 5 to 9 years of age; to explore the possibility that we would see developmental differences in landmark learning, we divided the data into two groups: Younger (average age: 5 years) and Older (average age: 7 years).

Method

Participants

Thirteen children, 7 boys and 6 girls, participated. The parents of the participants were acquaintances of the experimenter. Six of the children were members of the Younger group (ages ranging from 5 years 5 months to 6 years 0 months); the remaining 7 children were members of the Older group (ages ranging from 7 years 4 months to 9 years 2 months).

Apparatus

Testing was conducted in the children's homes by an experimenter who was familiar with the participants. The experimenter stood behind the children, out of view, while recording the data. The children's mothers were present during testing but also stood out of view and were unaware of the purpose of the experiment. During the session, a large (1.1 m wide by 0.76 m long) bristol board was placed on the floor of the room. Twenty-five small (94 ml) paper cups, approximately 5.5 cm in diameter, were fastened to the board by white glue. The cups were placed in a 5 × 5 matrix, approximately 10 cm apart. Each cup was partially filled with 10 g of uncooked rolled oats. On each trial, a single foil-wrapped chocolate candy serving as the reward was hidden under the oats in one cup. Four identical 4-cm wooden cubes painted bright blue served as "landmarks."

Procedure

Training phase. At the start of each trial, one of the 25 cups was baited with a single candy, hidden under the oats so it was not visible. The location of the baited cup was randomly determined on each trial, with the restriction that no cup was baited more than once. The four landmarks were placed around the baited cup; each landmark was centered approximately 7 cm diagonally from the cup. After the apparatus was set up, the child was brought into the room and told that he or she was going to play a game. The child was told that the experimenter had hidden a chocolate candy in one of the cups and that he/she could search until the candy was found. The search was terminated after the child retrieved the candy. No time limit was placed upon the search, although most trials ended within 30 s. The locations of the sites visited by the child were recorded; a site was counted as "visited" if the child made contact with the oats inside the cup. The experimenter recorded the subject's choices and landmark locations on a paper template of the matrix and also recorded any spontaneous

utterances made by the child. After each trial, the child was removed from the room by his/her mother while the experimenter set up the next trial. Training trials continued until the child found the candy on his or her first choice on 5 consecutive trials.

Test session. Immediately after the fifth consecutive correct trial, each child received one test trial. On the test, the candy was hidden in the cup located in the center of the matrix and the landmarks were placed near the corners of the matrix, as shown in Fig. 3. The child was again free to search all the cups, and the trial was terminated after the candy was retrieved from the baited cup. The experimenter recorded the location of the sites visited and any spontaneous utterances made by the child.

Results and discussion

Training phase

All 13 children met the criterion of 5 consecutive correct trials during the Training phase. The mean number of trials to achieve the criterion was 5.67 (range = 5–7 trials) in the Younger group and 6.29 (range = 5–11 trials) in the Older group; these means were not significantly different, $t(11) = .65$. Seven of the children made no incorrect choices at all in the training phase. All of the children attended to the landmarks, as evidenced by spontaneous comments made during training (e.g., “the candy must be where the blocks are”).

Test phase

During the expansion test, only one of the 13 children found the baited site on his first choice. Overall, the children took an average of 14.62 choices to find the baited site. The Younger group (mean = 16.67, range = 1–23 choices) and the Older group (mean = 12.86, range = 5–29 choices) did not differ in the number of choices taken to obtain the candy, $t(11) = -0.82$. Fig. 2 shows the matrix location of the first four choices made by children in the Older (top figure) and Younger (bottom figure) groups. Children in both age groups searched primarily in sites that were directly adjacent to the landmarks, which is similar to the strategy used by the marmosets in Experiment 1a. Unlike the monkeys, however, the children showed no tendency to choose the adjacent site that was in the correct direction from the landmark. Instead, children in the Younger group showed an almost exclusive tendency to select cups in the four outside corners of the matrix. Children in the Older group also showed a bias toward the corner cups, but chose other adjacent cups as well. The difference between groups in the proportion of choices made to the four corner cups was not significant, $t(11) = 1.39$, but, over both groups, the proportion of choices to the corner cups was significantly higher than expected on the basis of random choice among all adjacent cups, $t(12) = 8.2$, $p < .00001$. Many of the children, in both groups, seemed confident that the candy would be located beside the landmarks and expressed surprise when it was not found in those locations. All 13 children eventually found the baited site, but only one ever mentioned the possibility that the candy could be located in the middle of the matrix; that child, in the Younger group, found the candy on his first choice.

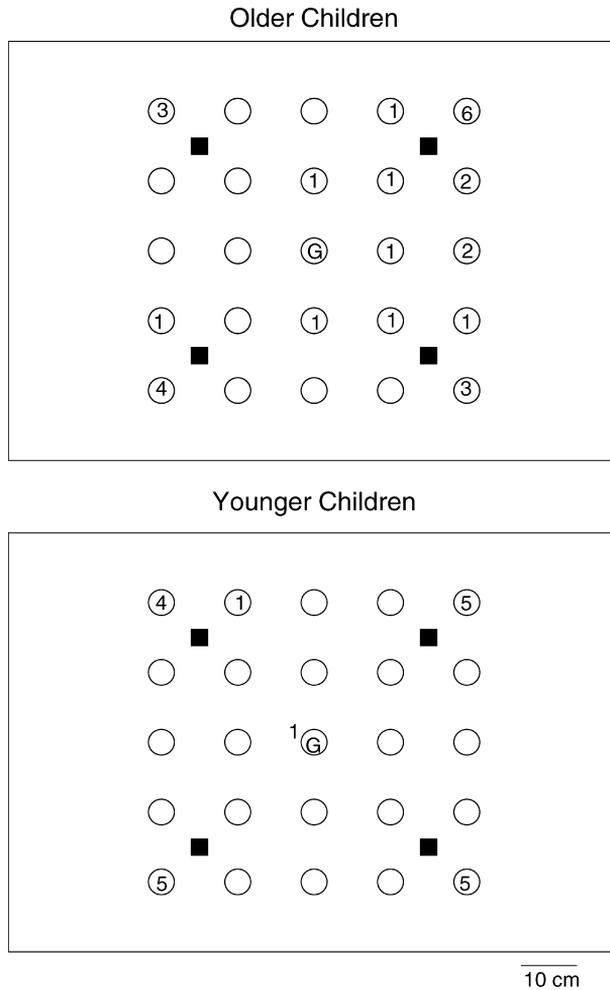


Fig. 2. Experimental setup and total number of first four choices made by the older children and younger children to each matrix location during the test phase in Experiment 1b.

Hence, the children, like the marmosets, searched near the landmarks on an expansion test. Unlike the monkeys, however, they showed no tendency to search the adjacent site that would indicate learning of vectors from the landmarks to the goal, and hence the children appeared to use a purely beaconing strategy. Their tendency to search at the corner outside of the landmark array has no ready explanation. Only one of 13 children used the middle rule.

Experiment 1c

The monkeys and children showed no tendency to use a middle rule strategy and instead searched near individual landmarks on the expansion test. Although these

results seem to contrast with the strategies used by adult humans in previous research (Spetch et al., 1996, 1997), the previous research did not use a task that could be solved on the basis of a simple adjacency/beaconing strategy. Thus it remains to be determined whether adult humans would spontaneously adopt a relational rule even when a beaconing strategy is possible.

Method

Participants

The participants were 8 undergraduate students (7 women and 1 man), ranging from 19 to 50 years of age. They participated for credit in their introductory psychology course.

Apparatus

The experiment was conducted in a small private room. Twenty-five small (94 ml) paper cups, approximately 5.5 cm in diameter, were placed face down in a 5×5 matrix on the top of a table. The matrix of cups spanned an area of approximately 60 cm^2 . The landmarks consisted of four identical black checkers pieces, 3 cm in diameter. A small cardboard chip served as the goal and was hidden under one of the cups on each trial.

Procedure

Participants were instructed that their task was to find a chip that would be hidden beneath one of the cups on each trial. The participant and the experimenter stood on opposite sides of the table. Before each trial, the participant faced away from the table while the experimenter hid the goal under a cup, arranged the landmarks, and randomly lifted and replaced cups in various matrix locations. These three activities were performed in random order to prevent the possibility that noise might serve as a cue for the goal location. On each training trial, the landmarks were placed around the goal, as shown in the top of Fig. 3. The location of the goal was selected randomly for each training trial for each participant, with the constraint that no location was used more than once. On each trial, participants removed cups until they found the one containing the goal. Training continued for a minimum of 5 trials and until the participant found the goal on his/her first choice for four consecutive trials. An expansion test trial followed in which the landmarks were arranged as shown in the bottom of Fig. 3, and the goal was placed in the cup at the center of the array. Following the test trial, participants filled out a questionnaire that asked them to indicate any strategy they used to solve the task.

Results and discussion

Seven participants met the training criterion within 5 trials, and one participant met it on the 6th trial. On the test, all 8 participants chose the center cup on their first choice (see Fig. 3). On the questionnaire, all participants used the word “middle” or “center” in describing their strategy. Clearly, adult humans used a middle strategy even when the landmarks were adjacent to the goal.

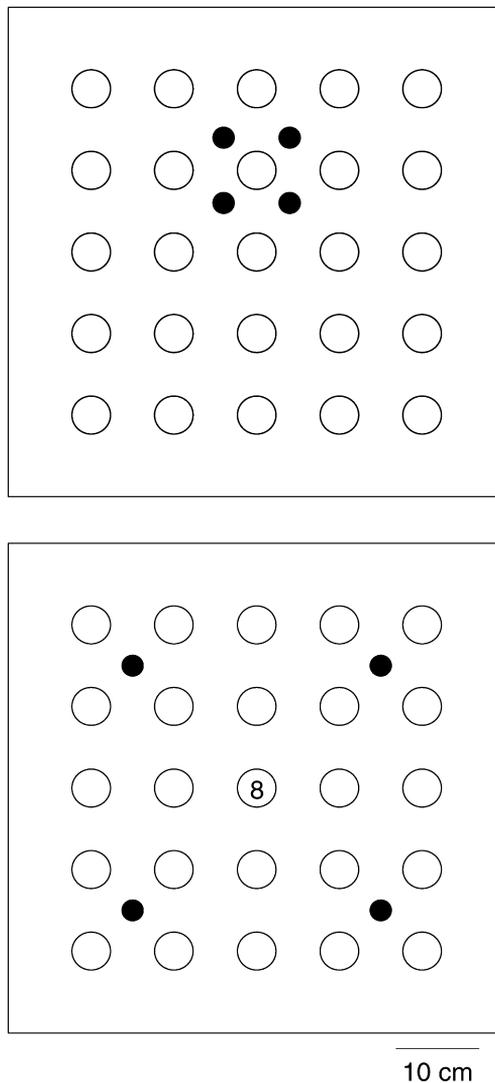


Fig. 3. (Top) Example of the setup for a training trial for adults in Experiment 1c. (Bottom) Setup and frequency with which each location was chosen on the first choice by adults on the expansion test in Experiment 3 (all 8 participants chose the center location).

Experiment 2

Experiments 1b and 1c showed that children learn a very different strategy than adults when they are trained to find a goal that is centered between and adjacent to an array of identical landmarks. The search patterns and spontaneous utterances of the children indicated that they had learned that the goal was close to the landmarks,

but there was no evidence that they had learned a middle rule. The children also showed no evidence of having learned the direction from each landmark to the goal and thus appeared to have encoded the landmarks as beacons, rather than as directional cues. Experiment 2 was designed to investigate how children would respond to array expansion tests when the goal is hidden within a continuous search space and is not directly adjacent to the landmarks during training. In this case, the task cannot be accurately solved with a beaconing strategy.

Method

Participants

Nineteen children (15 boys) ranging in age from 37 to 60 months were recruited through advertisements posted on campus and from a campus Day Care. Each child received a small toy for participating and parents were paid for transportation costs.

Apparatus

The experiment was conducted in a small private room on campus (18 children) or in the child's home (1 child). The search space consisted of a rectangular box, 94 × 69 cm and 10 cm high, lined with confetti. The landmarks were four identical green plastic toy trees, approximately 8 cm tall and 3 cm wide. The landmark array was always aligned parallel to the two axes of the tray and during training the landmarks were spaced 22 cm apart along both axes. The goal was a sticker attached to the bottom of the box with Velcro. The goal was always completely covered by the confetti. The child was given a straw to use in searching through the confetti so that the location of search behavior could be seen from the overhead camera.

Procedure

At the start of the experiment, the child was instructed that the experiment would involve playing a game in which a sticker would be hidden under the confetti and he/she was to use the straw to search for it. The child was told that each time it was hidden he/she could look for it but the experimenter would show them where it was if they could not find it. After confirming that the child wanted to play, the experimenter initiated training trials in which the sticker was hidden in the center of the array of four landmarks. The location of the sticker and corresponding landmarks was transposed across trials and followed a pre-determined random selection. Two identical boxes and sets of landmarks were used so that a second experimenter could arrange for the coming trial (out of view of the child) while the current trial was being performed.

On the first trial, the experimenter revealed the location of the sticker and then covered it back up and gave the child a plastic straw to dig for it. On subsequent trials, the child looked for the sticker without its location being first revealed. The child was given 10 s to search, and, if he or she failed to find the sticker, the experimenter uncovered it and let the child retrieve it. The child was given a sticker to keep after each trial. Training continued until the child met a criterion of finding the sticker within 10 s on three consecutive trials. If the child failed to meet the criterion within 20 trials, the experiment was discontinued.

Upon meeting criterion, an expansion test trial was presented in which the distance between the landmarks was increased to 50 cm along each axis and no sticker was placed under the confetti. The location of the landmarks and goal was randomly selected from 9 possible locations. The child was allowed to search for 10 s, and then the experimenter said she forgot to hide the sticker and gave a sticker to the child.

Following the test trial, or following the 20 training trials for children who did not meet criterion, the experimenter thanked the child and gave the child a toy.

Data recording and analysis

All trials were videotaped from an overhead camera. During the session, the experimenter recorded whether the child found the sticker and the time taken to find it, as well as any spontaneous comments made by the child. For children who met criterion, search behavior on the final training trial and on the test trial was scored from the videotape using still frame analysis. The tape was played at regular speed until the child began searching (operationally defined as the straw contacting the confetti). The tape was then advanced one frame at a time, and the location of the straw was marked on a transparency taped to the monitor screen once every 6th frame as long as the straw was still in contact with the confetti. If the child lifted the straw, scoring was halted until the straw again contacted the confetti. On training trials, because scoring terminated as soon as the child found the sticker, the number of data points recorded for each child varied. On test trials, 40–50 data points were recorded for each child, depending on how persistently the child searched during the 10-s test.

For each child and for both the training and the test trial, we calculated the peak place of searching in the up/down and left/right dimensions using the iterated median procedure used in studies of landmark-based search by pigeons and humans (e.g., Cheng, 1986; Spetch et al., 1996, 1997). This procedure finds the middle of the highest region in a distribution. First, we superimposed an 18×18 U grid on the scored data and recorded the frequency of searches that fell in each unit, with the center of the grid being at the center of the four landmarks. We then summed across the rows and columns. The median of each distribution was determined, and then the median calculation was iterated over the range in which the first median was centered. For example, if the first median was calculated over the range of 1–18 and the median was 6, then the next median calculation would include only units 1–11. This process was repeated until two consecutive calculations resulted in medians that differed by no more than .05 of a unit.

Results

Of the 19 children tested, 9 children (6 boys, 3 girls; mean age of 49.9 months) failed to meet criterion or asked to stop playing before the test trial. The remaining 10 children (9 boys, one girl; mean age of 50.1 months) met the accuracy criterion in 4–18 trials (mean = 9 trials), and all of them completed the test trial.

The calculated peak places of searching on the last training trial for the 10 children who met criterion are shown in the top of Fig. 4. All children except one searched very accurately on the last training trial.

Children's Peak Place of Searching on Sample Training Trial

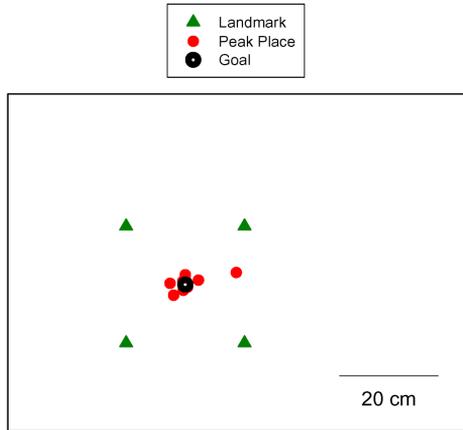


Fig. 4. Calculated peak places of searching on the last training trial for each of the 10 children who met criterion in Experiment 4.

Children's Peak Place of Searching on Expansion Test

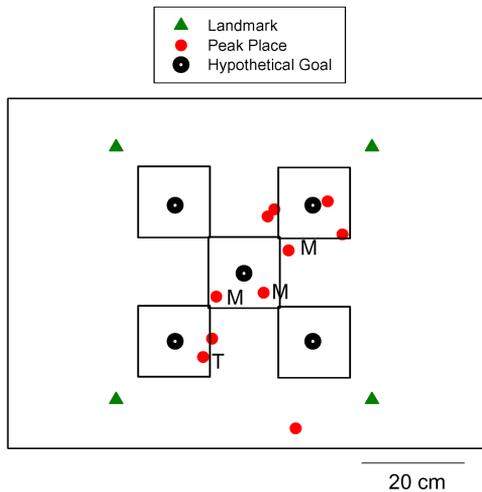


Fig. 5. Calculated peak places of searching on the expansion test for each of the 10 children who met criterion in Experiment 2. The “M” beside three of the peaks indicates the three children who used the word “middle” during training. The “T” indicates the one child who said the goal was in the trees. The outlined square indicate the areas used to calculate proportions of searching at the center and corners.

The calculated peak places of searching on the test trial are shown in Fig. 5. The hypothetical goal locations based on the center of the expanded array and the four locations that maintained the same vector from an individual landmark as in training are also shown. The peak locations varied across children, but 3 children searched closer to the center than to any of the individual hypothetical locations. One child

searched far from any of the hypothetical locations, and the remaining children searched closest to the hypothetical location specified by either the top right or the bottom left landmark.

Of the 10 children, only four made spontaneous comments related to their searching strategy. Three of these (boys, ages 60, 42, and 60 months) indicated a middle strategy: “the sticker will be in the middle,” “it’s in the middle,” and “I always find the sticker in the middle,” respectively. The peak places of searching for these three children are labeled with an M in Fig. 5. The fourth child (a boy, 37 months) stated that the “sticker will be in the trees”. His peak place of searching is labeled with a T in Fig. 5.

We also determined the proportion of choices that fell within square areas, approximately 14 × 14 cm, in the center of the array and in each of the four corners that maintained the training vector from individual landmarks. Each of these areas comprised 16 squares in the 18 × 18 scoring grid. The proportion of searches in each area expected by chance is $16/320 = .05$ (the four grid locations containing landmarks were excluded as possible search locations). In Fig. 6, we plot the proportion in the center area, the corner in which the child searched the most, and the average of the other three corners. These proportions are shown for the ten children, ordered in terms of age. The children who made spontaneous comments are labeled with M

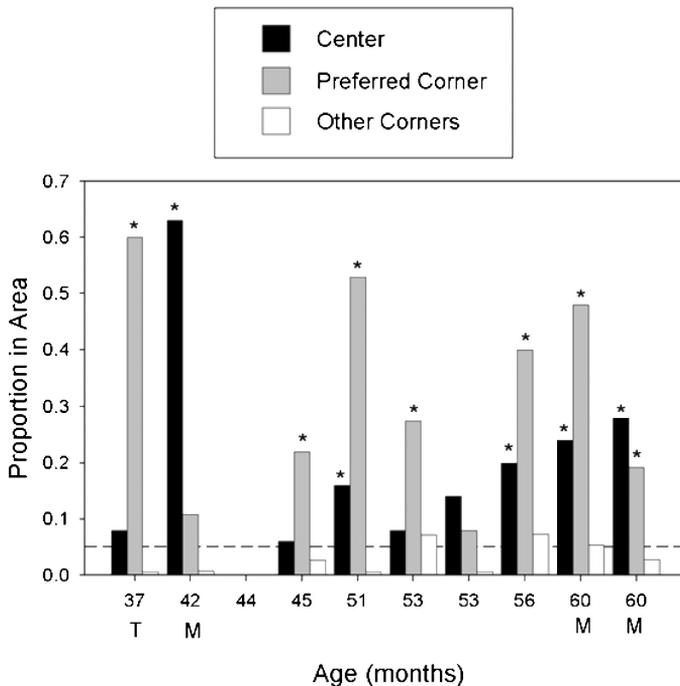


Fig. 6. Proportion of choices in the center area, the preferred corner, and the average of the other three corners on expansion tests for each of the 10 children who met criterion in Experiment 2, ordered according to age. “M” indicates the children who said “middle” during training and “T” indicates the child who said “trees.” The horizontal dashed line indicates the proportion expected by chance. The asterisk indicates proportions that were significantly above chance.

(middle) or T (trees). The three children who said middle showed the highest proportions of choices in the middle area, but one of these three children searched more in one of the corners than in the middle. To assess whether the proportions were significantly above chance, we conducted binomial z tests on each of these proportions for each child, using all search responses (approximately 50 per child). Because of the number of tests performed, a conservative α level of .001 was used. These tests indicated that four children showed significant searching in both the center area and one of the corners, one child searched significantly only in the center and three children searched significantly only in one corner. Two children did not search in either the center or a corner area significantly more than expected by chance.

Discussion

This experiment produced several notable results. First, in contrast to the discrete choice matrix used in Experiment 1b, this was a difficult task for the children to master, and almost half of the children failed to acquire the task within the allowed 20 training trials. Although additional training or a longer search period might have resulted in learning, most of the children who failed to meet criterion showed a complete lack of control by the landmarks over their search location even by the end of training. Some appeared to search randomly, some searched closest to where they were sitting, and some showed a tendency to search in the approximate location in the tray at which the sticker was found on the preceding trial. Thus, the function of the toy trees as landmarks to indicate the sticker location was not readily recognized by all children. Landmark use did not seem to vary with age: mean age did not differ between children who did or did not acquire the task ($t(17) = 0.067$); however, because our sample size was small and ages were determined by availability of participants, our experiment did not provide a strong test of age effects.

Second, of the 10 children who acquired the task, three showed clear evidence of using a middle rule. These three children searched close to the middle on the test, and they all commented that the sticker was to be found in the middle during the training trials. Although two of these children were among the oldest tested (each 60 months), one was considerably younger (42 months). Two other children (ages 51 and 56 months) also showed significantly more searching in the center than expected by chance. Thus, a few children from 42 to 60 months of age were capable of applying an abstract spatial rule to searching for a goal on the basis of landmarks. However, four of these children who searched significantly in the middle also showed significant search in one of the corners. Only one child showed exclusive search in the middle. Three children, including the one who commented on the trees, showed significant searching in a corner area only, suggesting the use of an absolute spatial rule.

General discussion

When a square array of four landmarks surrounded and was directly adjacent to a goal that was hidden in one of several discrete locations, marmoset monkeys

(Experiment 1a), human children (Experiments 1b), and human adults (Experiment 1c) easily learned to use the landmarks to locate the goal. Despite their ability to learn the task, both marmoset monkeys and human children responded very differently to expansions of the array than did adult humans. Whereas adult humans uniformly searched in the center of the expanded array, both monkeys and children concentrated their searching near the landmarks. None of the monkeys and only one of the 13 children in Experiment 1b showed evidence of using a “middle” rule strategy. These results extend the comparative literature on strategies of landmark use and suggest that, among vertebrates, adult humans appear to be the outliers.

The results for adult humans replicate and extend those found using various search tasks conducted on the touch-screen, a table-top, and outdoors. When confronted for the first time with an expanded array, all the adult humans tested in the present study and in previously published studies showed an overwhelming tendency to search in the middle of the array. Adult humans appear to unanimously adopt an abstract “middle rule” when the goal is centered between an array of landmarks. The present results show that this rule is adopted even when the landmarks surround and are adjacent to the goal and thus could be encoded as a beacon.

Marmoset monkeys were clearly able to use landmarks to find hidden food and by the end of training, they were highly accurate in finding the baited food cup. The readiness with which the marmosets learned to use the landmarks is interesting because marmosets and tamarins, both members of the Callithricidae family, have shown accurate spatial memory in foraging tasks (e.g., MacDonald et al., 1994; Menazel & Juno, 1985; Deipolyi, Santos, & Hauser, 2001). Other New World monkeys, notably titi and squirrel monkeys, both members of the Cebidae family, have not demonstrated high accuracy in spatial memory tasks (e.g., Andrews, 1988; Roberts et al., 1993). An intriguing possibility is that Callithricids’ accurate spatial memory may be related to their readiness to use landmarks. Although the marmosets in our study appeared to be somewhat more accurate than the squirrel monkeys in Sutton et al.’s (2000) study, differences in procedure and number of locations prevent a meaningful comparison. Additional research providing a more direct comparison between landmark learning in Cebidae and Callithricids would be useful.

Regardless of any possible differences in training accuracy, both the marmoset monkeys in this study and the squirrel monkeys in Sutton et al.’s (2000) study searched near the landmarks rather than in the center of the array on the expansion tests. Thus, the strong tendency to adopt a middle rule shown by humans is not shared by at least two other primate species.

Human children in Experiment 1b also readily used adjacent landmarks to find a hidden goal. The landmarks, which surrounded and were adjacent to the goal, appeared to be salient cues for the children in this task. This is consistent with other studies of children’s spatial strategies. Very young children (aged 18–24 months) can recognize landmarks, even if they do not use them to improve their performance in a spatial task (e.g., Hermer & Spelke, 1994). However, the effectiveness of landmark use appears to increase with age (e.g., Anoshian & Young, 1981; DeLoache, 1986;

DeLoache & Brown, 1983; Heth, Cornell, & Alberts, 1997; Presson, 1987). In Experiment 1b of our study, children used the landmarks in training, but their search suggested that they had not learned the direction of the goal from the landmarks. Instead they showed a strong tendency to search in the corners of the matrix which were opposite to the directions from the landmarks to the goal. The results for the children are most consistent with a beaconing strategy in which the children learned to respond as close as possible to the landmarks. Although this would explain why the children did not search in the correct direction during the expansion test, it would not explain why the children predominantly chose the site in the opposite direction on the test. At present, we do not have an explanation for the childrens' preference for sites in the corners of the matrix.

In Experiment 2, children were trained with a landmark array that was not directly adjacent to the goal, and the goal was hidden within a continuous search space rather than in a matrix of discrete hiding places. In contrast to the ease with which children used the landmarks in Experiment 1b, several children had difficulty learning to use the landmark array in Experiment 2, and they did not learn to find the goal within our criterion time. The difficulties are unlikely to be due to an inability to code distance because children as young as 16 months have been shown to encode the location of an object hidden in a long and narrow sandbox (Huttenlocher, Newcombe, & Sandberg, 1994; Newcombe & Huttenlocher, 2000), which implies an ability to encode the distance from the ends or middle of the sandbox. Any of several factors might have contributed to making our Experiment 2 task difficult.

Nevertheless, some children in Experiment 2 readily learned to use the landmarks and met criterion quickly (e.g., within 4–6 trials). Among those who learned, the results of the expansion tests revealed a divergence of strategies. In contrast to Experiment 1b, most children searched exclusively within the area defined by the landmark array on the expansion test, and none showed a strong tendency to search in the opposite corner from a landmark. Some children showed a tendency to search at the training vector from an individual landmark. However, at least three children appeared to adopt a middle rule: These children mentioned the word "middle" during training, their peaks on the expansion test were close to the middle of the landmark array, they searched in the center area significantly more than expected by chance, and their proportions of center searches were the highest of the ten children. Age of the children within the range tested did not appear to determine the ease of learning or the strategy revealed by the test. However, because our sample size and age range were small, these results are preliminary and need to be explored further in future studies. The contrast between the results of Experiments 1b and 2 is consistent with other recent work indicating that procedural and stimulus factors may alter the strategies used by young children in spatial search tasks (e.g., Learmonth et al., 2002). Because age differences also varied among our studies, more research is needed to discover what accounts for the differences.

It should be emphasized that the lack of a spontaneous tendency to use a middle rule by the monkeys and by most children does not preclude the ability to learn an abstract spatial rule. When the training task cannot be solved using absolute spatial relationships, Clark's nutcrackers (e.g., Kamil & Jones, 1997, 2000) and pigeons

(Jones, 2003; Jones et al., 2002; Spetch et al., 2003) can learn a relative rule, and pigeons can learn to use landmark configurations to determine where to search (Sutton, 2002). In our experiments, one child in Experiment 1b and three children in Experiment 2 showed evidence of spontaneously adopting a middle rule strategy suggesting that this abstract spatial rule is not beyond the capabilities of at least some 3- to 6-year-old children. The fact that most children did not adopt this strategy likely reflects the greater salience or ease with which other strategies based on beaconing or individual landmark use might be used. It is quite likely that children and monkeys, like pigeons and nutcrackers, would be able to learn to use a middle rule if trained on a task that encouraged or required the use of such a strategy.

In some circumstances, children as young as 18 months can use configural cues for relocation. This is demonstrated with a re-orientation task, first used on rats (Cheng, 1986). Typically, subjects are tested in a rectangular space, with the reward hidden at one of the corners. The rectangular shape of the enclosure provides geometric cues which are configural in nature; they are formed by the metric properties (shape and size) of the environment. In contrast to results with landmark configurations, pigeons spontaneously show scale transformations for geometric shape of an enclosure (Kelly & Spetch, 2001). In studies on children, the child is shown an object hidden at one of the corners. He or she is then disoriented and has the task of retrieving the hidden object. Children as young as 18 months use geometric cues to solve this task (Hermer & Spelke, 1996). Interestingly, Gouteux and Spelke, 2001 found that disoriented children (3- to 4-year-olds) failed to use the geometric arrangement of an array of identical discrete objects for re-orientation. They used the geometric arrangement only when the objects formed an almost continuous surround of surfaces. However, Garrad-Cole, Lew, Bremmer, and Whitaker (2001) showed that children younger than those participating in Gouteux and Spelke's study (18–24 months) were able to use the geometric shape provided by four discrete landmarks to locate a hidden toy. Although these two studies provide seemingly contradictory results, it is nevertheless possible that discrete landmarks and continuous surfaces encourage different spatial encoding strategies. Differences in spatial encoding strategies with landmarks and continuous surfaces have also been found with birds (Gray, Spetch, Kelly, & Nguyen, 2004).

The present results suggest that adult humans may be unique among vertebrate species in spontaneously and unanimously adopting a relational strategy of landmark use in a variety of tasks in which beaconing and elemental landmark-use strategies are also effective. It is interesting to speculate on why adults spontaneously and preferentially use a middle rule. Attention to relative distances and abstract spatial rules is needed for scale transformations, such as when humans construct and use models or maps that preserve spatial relationships while changing the scale of the space. By adulthood, most humans have extensive experience with scale transformations from interpreting maps or models, and hence the tendency to use abstract relational rules for encoding spatial information may dominate. Developmental data suggests that facility with scale transformations improves with age or experience. For example, most young children are capable of transferring information from a scale model to a real environment, but the readiness to do so increases with age, with children younger than 3 requiring more support in terms of instruction and similarity

in size between the model and real space (e.g., DeLoache, Kolstad, & Anderson, 1991). Similarly, although 4- and 5-year-olds can use maps or aerial photographs to navigate or find places in large-scale environments (e.g., Blades & Spencer, 1987b, 1990; Blaut, 1987; Rutland et al., 1993; Uttal & Wellman, 1989), 5-year-olds are more accurate than 4-year-olds (Plester, Richards, Blades, & Spencer, 2002). In addition, the information that children obtain from maps may change with age. For example, Scholnick, Fein, and Campbell (1990) found that younger children (4- to 5-year-olds) were more likely to simply encode landmarks from a map than older children (up to 7-year old) who were more likely to encode the relative positions of the landmarks. Chimpanzees have also been found to be capable of transferring spatial information from a scale model to a larger environment, but the ability was not displayed by all of the chimpanzees tested (Kulmeier, Boysen, & Mukobi, 1999) suggesting that it is a difficult task. Thus, ease and extensive experience with scale transformations may be one reason why adult humans seem to be unique in uniformly and spontaneously adopting a relational strategy.

Facility with language also comes to mind as a mediating factor in human adults' propensity to use an abstract middle rule. Interestingly, the children who showed clearest use of a middle rule all seemed to understand the word and concept of middle. Use of such a rule requires the ability to relate the location of the goal to more than one landmark. There is evidence that children are able to comprehend and produce mono-referential spatial terms (e.g., "in" or "on," with reference to a single object) prior to bi-referential spatial terms (e.g., "between"), and that the transition occurs about 4–5 years of age (e.g., Weist, Atanassova, Wysocka, & Pawlak, 1999). Moreover, children's performance on bi-referential problems has been found to correlate highly with their ability to reconstruct a spatial layout across changes in perspective (Weist et al., 1999). Under some circumstances in the re-orientation task, verbal understanding of the concept of left/right predicts the use of featural cues (Hermer-Vazquez et al., 2001). As well, adults encoding a spatial location under the load of verbal shadowing can fail to use featural cues (Hermer-Vazquez, Spelke, & Katsnelson, 1999). It should be pointed out, however, that by making the space larger, even much younger children with limited verbal ability (18-month-olds) can use featural cues (Learmonth et al., 2001).

In sum, children, human adults, and marmoset monkeys were trained to search in the middle of an array of four identical landmarks and then were tested with the landmarks moved farther apart from one another. Adult humans searched in the middle of the expanded array. Monkeys and most of the children searched near the landmarks. Among vertebrates, the adult human is the only one tested so far who spontaneously and unanimously uses a middle rule when encoding a goal relative to an array of discrete landmarks.

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