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Tracking and Inferring Spatial Rotation by Children and Great Apes

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Finding hidden objects in space is a fundamental ability that has received considerable research attention from both a developmental and a comparative perspective. Tracking the rotational displacements of containers and hidden objects is a particularly challenging task. This study investigated the ability of 3-, 5-, 7-, and 9-year-old children and great apes (chimpanzees, bonobos, gorillas, and orangutans) to (a) visually track rotational displacements of a baited container on a platform and (b) infer its displacements by using the changes of position or orientation of 3 landmarks: an object on a container, the color of the containers, and the color of the platform on which the containers rested. Great apes and 5-year-old and older children successfully tracked visible rotations, but only children were able to infer the location of a correct cup (with the help of landmarks) after invisible rotations. The ability to use landmarks changed with age so that younger children solved this task only with the most explicit marker on the baited container, whereas older children, particularly 9-year-olds, were able to use landmark orientation to infer correct locations.

Keywords: object search, spatial memory, rotational displacements, inferential reasoning, landmark use

Remembering the location of objects such as food, conspecifics, and predators is a fundamental skill for many animals, including humans. Finding and tracking the displacements of objects are two of the most basic cognitive skills that have been investigated in numerous species (e.g., Gómez, 2005; Schuberth, 1983). Developmental psychologists found that object search skills—"object permanence"—emerge and develop with age as a consequence of an interaction between the young child and his or her environment (e.g., Acredolo, 1978; Acredolo & Evans, 1980; Bremner, 1978a, 1978b; Piaget, 1954; for a review for animals, see Gómez, 2005).

To investigate this ability, three common methods have been used. The first one is the classical Piagetian object permanence displacement task. This task has been used to investigate object tracking ability and understanding that an object continues to exist even when it is no longer visible. Jean Piaget conducted experiments with human infants that led him to conclude that object permanence was typically achieved at around 7 to 8 months, during the sensorimotor stage of cognitive development (Stages 1–3). After 8 months, infants retrieve hidden objects, but if an object successfully retrieved from location A is then moved to location B, they search again in location A, despite having clearly seen that the object is now placed in location B (Stage 4). At 11–12 months (Stage 5), the infants start to systematically search in the last place they saw the object disappear. However, at this age infants have problems with displacements in invisible settings, such as when the experimenter hides an object with his or her hand closed ("invisible displacements"); then until 18 months of age (Stage 6), infants search only in the hand without realizing that the object was left behind. This cognitive skill emerges in human infants through a fixed series of steps with characteristic transitional errors and has been investigated by numerous investigators (Schuberth, 1983, for reviews). A number of researchers (e.g., Bower, 1974; Baillargeon, Spelke, & Wasserman, 1985) have suggested that young infants' failure to search for hidden objects results not from a lack of object permanence but from an inability to perform coordinated actions. These researchers conducted studies that did not require manual search to assess object permanence and reported that much younger infants than in Piaget's study showed emergence of this skill (see Baillargeon, 1995; Baillargeon et al., 1985; Bower, 1974; and Bower & Wishart, 1972, for review). Comparative research has shown that many species can track visible displacements and that unlike other species tested, a few species such as apes and parrots are capable of solving Stage 6 invisible displacements such as double adjacent displacements (see Doré & Dumas, 1987, and Tomasello & Call, 1997, for a review; Call, 2001; de Blois, Novak, & Bond, 1998; Pepperberg et al., 1997). Moreover, apes develop object permanence skills in exactly the same sequence as human infants but at a slightly faster speed than humans (Doré & Goulet, 1998; Gómez, 2004, 2005).

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The second paradigm is the spatial transposition task (Sophian, 1984). This task consists of switching the location of the cover containing the target object with that of another empty cover. Similar to object permanence displacements, spatial transpositions entail a displacement of the target object from its original location to another location, but unlike object permanence displacements, spatial transpositions also involve the displacement of containers, which in object permanence remain stationary. Doré, Fiset, Goulet, Dumas, and Gagnon (1996) argued that solving transpositions is critical to determine whether individuals have fully mastered object permanence. Sophian (1984, 1985) reported that the ability to solve the transpositions gradually increases with age. Although there are still open questions concerning the age at which they start to solve this problem without difficulties, younger children (20- to 30-month-olds) show a strong tendency to search the initial hiding location. Barth and Call (2006) found that 30-month-old children capable of solving Stage 6 invisible displacements failed to perform above chance in spatial transpositions. In contrast, great apes tested with the same procedure performed above chance levels, confirming the positive results of previous studies with apes (Beran & Minahan, 2000; Call, 2003). Pepperberg, Willner, and Gravitz (1997) reported that two African grey parrots passed transposition trials, whereas cats and dogs failed them (Doré, et al., 1996)

The third paradigm that has been used to investigate object tracking in space is the rotational displacement task. It consists of an angular displacement of the substrate supporting an array of containers, thus modifying the original location of containers. For instance, a 180° turn of two containers resting on opposite sides of a platform produces an exchange of the original locations of those containers, whereas a 360° turn would leave the original locations of the containers unchanged. Lasky, Romano, and Wenters (1980) conducted a series of experiments that investigated young children's ability to retrieve a target after a change in the position of the child or the target. Two- to 4-year-old children were rotated 90°, 180°, 270°, or 360° and asked to find a hidden toy after their own change of spatial orientation. The children performed this task significantly better than chance, but their errors reflected either their response biases in the absence of any information as to the location of the target or the repetition of a response that had been successful in retrieving the target before the change in position. Bremner (1978a, 1978b) reported that 9-month-old infants failed to track a hidden object after they were rotated 180°. Interestingly, infants were better at locating the object after they had moved than they were after the object had moved. Barth and Call (2006) also found that 30-month-old children found rotation displacements of the test stimuli particularly difficult. These findings suggest that as infants begin to crawl, they become better at taking into account their own displacements within a stable space but difficulties with the displacements of objects still remain. From a comparative perspective, chimpanzees, bonobos, and orangutans have been reported to solve rotational displacements of 180° and 360° (Beran & Minahan, 2000; Call, 2003), although this is the hardest of all displacement tasks (Barth & Call, 2006).

Given the difficulty of rotational displacements, several researchers have added additional cues that could facilitate the tracking of the displaced objects. Bremner and Bryant (1977) presented the hiding locations on different backgrounds, but there was no evidence that such landmarks helped infants to find the correct position. Older children, however, were capable of using not only the presence of a background cue but also its orientation. Lasky et al. (1980) conducted an experiment in which the tabletop was rotated 90°, 180°, 270°, and 360°. A target object was hidden under one of two identical covers, one to the left of the child and the other to the right. A landmark (a face outlined with a salient color) was painted on the tabletop near the child to serve as a cue. The entire tabletop was then rotated while the child watched. The performance of 7-year-old children was virtually perfect. Younger children were also capable of tracking rotational displacements when covers of different colors were used on an uniform background (Bremner, 1978a, 1978b; Butterworth, Jarrett, & Hicks, 1982). Butterworth et al. (1982) suggested that it is only by linking the successive positions of the object that infants perceive its identity over the move. If the visual field was not suitably structured, these authors argued, the infants would not have a perceptual framework in which to register the object's new position once it went out of sight, and so they will go back on searching at the old place.

Although many animals use landmarks to navigate in space and find food locations (see Healy, 1998, and Thinus-Blanc, 1996, for reviews), much less is known about landmark use in combination with object displacements. From a cognitive point of view, this combination represents an interesting problem because subjects have to inhibit choosing the original location on the basis of the new location of the landmark (or the features associated with it). There are multiple factors that determine whether humans use spatial information, feature information, or both. The exposure to certain cultural practices and artifacts and the use of language are two contributing factors to the way children encode spatial and feature information and how they use it to make inferences. Comparing how children solve these problems with how our closest living relatives, the great apes, solve them can help us identify ancestral characters common to all great apes and specific human adaptations. Beran, Beran, and Menzel (2005) reported that chimpanzees can track the movement of a hidden item (while the subject remains stationary) in an array of identical cups even when they never see the item itself but see only a temporarily presented marker for the location of that item. In contrast, Call (2003) failed to find positive evidence in this task. Apes were able to track the rotational displacement of the reward under a cup if they had seen its initial location but failed to do so if the initial location of the reward was indicated by a marker that was removed before the rotation took place. Subjects, however, were capable of using the position of the marker to locate the reward in the absence of displacements. Hoffman and Beran (2006) also found that apes were able to track the position of a baited container after the subjects (not the containers) moved to the opposite side of the table, thus undergoing a 180° perspective change.

Lasky et al. (1980) also included a condition in which children did not witness the displacement of the containers, only the initial location of the reward and the orientation of the landmark. After the rotation of containers had taken place, children had to infer the location of the reward on the basis of the new orientation of the landmark and its relation to the reward's location. The ability to make such an inference developed more slowly than visual tracking of rotational changes. Although the visual tracking of 7-year-old children was virtually perfect, it was not until 10 years of age that children showed good performance in the inferential task. Potì

(2000) used a similar setup to test capuchin monkeys, although the landmark information was less subtle because it relied on presence or absence of the landmark rather than on its orientation. Two identical boxes and a landmark were placed on a round platform that could be rotated 90°, 180°, 270°, and 360°. After the monkeys witnessed the baiting of one of the boxes, a screen was lowered to hide the particular platform rotation. Monkeys were successful when the landmark was close to the baited box, but not when the landmark was close to the empty box. This suggested that monkeys used the location of the landmark to find the reward without inferring the rotational displacement undergone by the platform while occluded.

For younger children, preserving the identity of the covered object itself is more helpful than its surrounding landmarks. Later, they gradually develop the skill to use landmarks as adequate spatial cues. However, previous studies mostly focused on the situation in which there were different colors under each cover (one color per cover) or markers on or next to the covers. These situations only investigated a one-to-one correspondence between a cover and its landmark. Moreover, in Lasky et al.'s (1980) study, the landmark was a schematic face that was painted on the table midway between the two covers and near the edge of the board. This face landmark was very salient to the children and also had directional properties in itself. The children were told that they could tell how the board had been rotated by watching the face (upright or inverted). The board was always initially positioned such that the face was immediately in front of the child. To investigate children's ability to comprehend the spatial relationship from an allocentric perspective between all elements surrounding the covers, the previous setting might not be sufficient because of its additional information, such as directional cues. Thus, we need to assess whether the covers share an environmental landmark that has only spatial distinctiveness in itself and could be used as an adequate spatial cue for identifying the new location of the correct cover during the containers' displacements.

In sum, rotational displacements are some of the hardest object displacements both for children and for great apes. However, infants improve their performance when nonidentical containers are used, certain objects that act as beacons are introduced, and the background under the various containers or the orientation of landmarks are varied. It appears that younger children find the identity of the covered object more helpful than its surrounding landmarks. Finally, children between the ages of 7 and 10 years become capable of inferring that an object has undergone a location change by using the changes in the orientation of the background or landmarks. However, there is no study that has systematically investigated the effect of rotational displacements across a wide age range. More important, although previous studies have investigated the effectiveness of various types of landmarks in guiding object search, few studies have directly compared them, especially in relation to inferring changes of an object location after nonvisible rotational displacements have taken place. In addition, no study has contrasted the ability of children of different ages with that of great apes both in tracking rotations and inferring rotations by the changes in orientation of landmarks. In this study, we investigated the ability of 3-, 5-, 7-, and 9-year-old children and great apes (chimpanzees, bonobos, gorillas, and orangutans) to track rotational displacements of a baited container on a platform and to infer its displacements by noticing the changes of orientation of various landmarks, including the color of container, the color of the platform, and the presence of a marker directly on the container.

STUDY 1: HUMAN CHILDREN

Experiment 1

In this experiment, children saw the initial location of the reward under one of two cups and had to find it after it underwent a rotational displacement. In the visible condition, children were allowed to witness the rotation (either 180° or 360°) of the platform, whereas in the invisible condition, children were not allowed to witness the rotation but had to infer the position of the reward by the changes in the landmark orientation. In both visible and invisible displacements, we used three different types of landmarks by manipulating the color of the cup and the color and orientation of the platform. This means that children received six conditions (2 types of rotation × 3 types of landmark).

Method

Participants

Sixty-four children participated in this experiment. Sixteen 3-, 5-, 7-, and 9-year-old children were tested at the Center for Child Studies located at the University of Louisiana at Lafayette (3-year-olds: M = 40.9 months old, range = 36–46; 5-year-olds: M = 64.8 months old, range = 60–70; 7-year-olds: M = 89.5 months old, range = 84–94; 9-year-olds: M = 106.5 months old, range = 110–118). Half of the children in each group were male, and the other half were female. Recruitment flyers describing the study were distributed in the local community, and interested families contacted us by phone to enroll in the study. Infants were recruited from these sources and from a list of parents who had previously expressed interest in participating in research. The participants were primarily from a working and middle-class population of Caucasian, African American, Hispanic, and Asian backgrounds. No information regarding parental income or education level or the ethnicity of the children involved was systematically collected. Full informed parental consent was obtained for each child before testing. Parents did not receive an honorarium for their participation. Study procedures were approved by the university Institutional Review Board. Regardless of age group, children were asked to visit the center on 3 separate days, 1 day for each condition. The 2nd and 3rd days of testing took place within 4 weeks after their first visit. The data from 5 additional children were discarded because they did not come back after their 1st or 2nd day of testing.

Apparatus and Materials

Three different rectangular display boards were used, each measuring 75 × 26 cm and presented with the longer side facing the child. Two cups (diameter 8.4 cm × height 7.5 cm) placed in an upside-down orientation were used to hide the prize (a little rubber dinosaur toy). The distance between the cups was 54 cm. A lightweight trifold screen (54 cm × 81 cm) was used to occlude the rotating process. The display boards and screen were placed on a table (tabletop 90 × 70 cm, height 56 cm). The child sat on a

chair in front of the table, positioned between the two cups and at a distance that allowed him or her to reach the cups. All testing was recorded on digital video.

Experimental Design

This experiment consisted of a 2 (rotation) × 3 (landmark) design (Figure 1a). In the visible rotation condition, the child could visually track the displacement of the cups. In the invisible rotation condition, the screen was used to hide the rotation from the child's view. The child had to infer the rotation and position of the hidden object from the new position of the landmarks. There were three different landmarks. In the colored cup condition, two cups (one red and one blue) were placed on a gray board. In the vertical condition, two identical white containers were placed on a board with the left side painted red and the right side painted blue (with the two colors divided by a vertical line) from the child's view. In the horizontal condition, two identical white cups were placed on a board with the inner (near) half painted red and the outer (far) half painted blue (with the two colors divided by a horizontal line) from the child's view. Depending on the presentation condition (visible or invisible), the children either had to visually track the baited container or use the cup color or the orientation of the colored board to infer the position of the reward.

Procedure

Warm-up period. Children visited the Center for Child Studies individually and by appointment. On arrival, the child played with the experimenters in the waiting room for approximately 10-20 min to allow him or her to get acquainted with both the experimenters and the surroundings. During this time, the child's parents read a consent form describing the study, asked any questions, and signed the form. Once the child appeared comfortable, the experimenter asked whether the child wanted and encouraged him or her to play a hide-and-seek game to find a dinosaur. Then the child was escorted to the testing room while the parent or parents were shown the one-way mirror from which they could observe the child as he or she played the game.

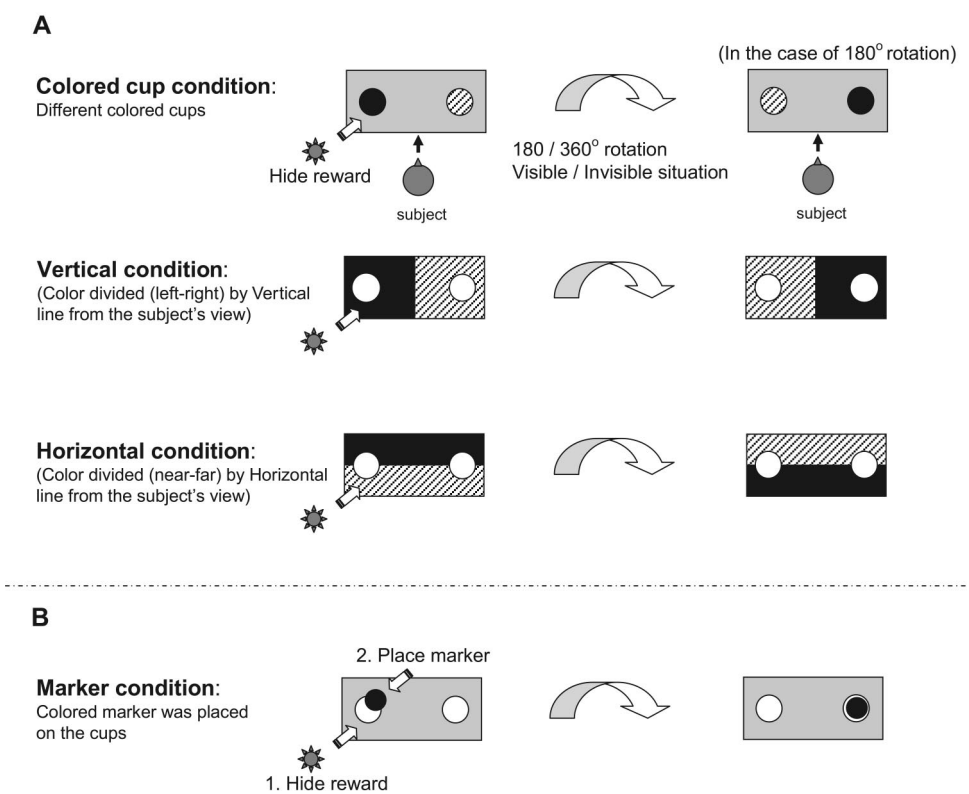

Figure 1. A: Three main conditions classified by using three different testing boards that were painted differently. Colored cup condition: Two different color cups (red and blue) were placed on a solid-colored (gray) board. Vertical condition: Two identical cups (white) were placed on a board with the left side painted red and the right side painted blue (two colors divided by a vertical line) from the children's view. Horizontal condition: Two identical cups (white) placed on a board with the inner (near) half painted red and the outer (far) half painted blue (two colors divided by a horizontal line) from the children's view. These conditions were used in Experiments 1 and 3. After hiding the reward, the testing board was rotated either 180° or 360° in front of children (visible situation) or behind the screen out of sight from the children (invisible situation). B: Marker condition: Two identical cups (white) placed on a solid-color (gray) testing board. Laminated stickers (red or blue) were used as markers and placed on the cup. These conditions were used in Experiment 2 and 4.

Practice phase. On entering the testing room, Experimenter 1 sat the child at the table and Experimenter 2 sat across the table from the child and was responsible for hiding the prizes and rotating the board. Three sessions were administered to each child, one session for each landmark depicted in Figure 1. The order of the landmarks and presentations was randomized across children. Each session began with two training trials in which the child had to retrieve the prize (the dinosaur toy) from each of the two cups before proceeding to the testing trials. This allowed the child to understand the nature of the hide-and-seek game aimed at retrieving prizes located under cups. As Experimenter 2 hid the prize, the experimenters said things such as "here we go" or "let's watch" to ensure that the child attended to the hiding location. Once the prize was hidden, the display board was pushed forward to the child's edge of the table. No board rotation conditions took place during the training trials. This procedure was repeated again using the other cup as a hiding location so that the child had experience retrieving a prize from his or her right and left. After these practice trials, the child received the testing phase.

Testing phase. In each of the three testing sessions, 16 testing trials were administered in four four-trial blocks (A–B–B–A block design). The first and fourth block consisted of visible rotations, and the second and third blocks consisted of invisible rotations. Within each block of four trials, two trials were the 180° rotation and two trials were the 360° rotation, administered randomly. The location of the prizes, colored cups, and colored boards was counterbalanced and randomized within the rotation conditions so that in each rotation condition, the prize was hidden on the child's left and right or blue and red an equal number of times. The experimenter did not mention that the board was rotated in all trials (both visible and invisible).

Each test trial began with the board recessed from the child. Experimenter 2 placed the prize underneath the appropriate cup as the child watched and rotated the board either 180° or 360°, always in a clockwise direction. In the invisible rotation, Experimenter 1 placed a screen between the board and the child after hiding the prize so that the rotation took place out of the child's sight and removed the screen on completing the rotation. In both conditions, the board was then pushed forward to the edge of the table so that it was positioned within the child's reach, while Experimenter 2 bowed her head to eliminate the possibility of any inadvertent cues toward the child. After the board had been positioned, the child was then prompted to find the prize with verbal instructions such as "Okay, find the dinosaur." To control for sound cues, felt was placed underneath the board, and when Experimenter 2 rotated the boards she lifted them slightly to avoid sounds made by the friction of the board against the table. This precaution was intended to deprive the child from using auditory cues in finding the prize, a particularly relevant issue in the invisible rotations. Likewise, to avoid sound cues made by Experimenter 2's movements as she rotated the display board, the movements and their length of time were held constant for each trial in the invisible rotation so that the rotating movements and their time period were the same in the 180° and the 360° conditions. We considered these precautions to be required to minimize the possibility of children perceiving rather than inferring the rotations in invisible trials. To ensure a maximum of comparability between the children and the apes, the experimenter did not mention any words related to rotation such as *rotating* or *turning* (the experimenter said, "Let's watch" or called the child's name to keep his or her attention). However, the children sometimes spontaneously mentioned how they solved the task or asked how they can remember the correct cup. However, these reports were not quantified because of their sporadic nature.

Data Analysis

The percentage of trials in which children selected the baited cup was our dependent variable. Our independent variables included the age of the children (3, 5, 7, and 9 years of age), the visibility of the rotation (visible or invisible), the degree of the rotation (180° or 360°), and the type of landmark (colored cup, vertical, or horizontal). Because the data did not meet the supposition of homogeneity of variance, we analyzed them with nonparametric statistics. We used the Kruskal-Wallis and the Mann-Whitney tests for independent samples with $k > 2$ and $k = 2$, respectively. We used the Friedman and the Wilcoxon test for paired samples with $k > 2$ and $k = 2$, respectively. We focused on the main effects of each factor, but we also analyzed the data separately within each factor when visual inspection of the data suggested that there might be an interaction between factors. On detecting a significant main effect, we depicted such an effect in the figures and followed it up with pairwise multiple comparisons when necessary. All multiple comparisons were corrected with the Bonferroni-Holm method (Holm, 1979). We also calculated whether children performed above chance in the various conditions by comparing the chance value of 50% (children could choose one of two alternatives) to the observed percentage of correct trials. To assess interobserver reliability, an additional coder watched all video recordings from all children and rated their behavior. The agreements and kappa results between the observers were excellent (99.7 %, $\kappa = .995$).

Results

180° Rotations

Figure 2a presents the percentage of correct trials as a function of age and type of landmark for visible rotations. There were no overall significant differences between landmark types, Friedman test $\chi^2(2, N = 46) = 4.55$, $p = .103$. Older children performed better than younger ones, Kruskal-Wallis test $\chi^2(3, N = 57) = 27.46$, $p < .001$. Pairwise Mann-Whitney tests indicated that 3-year-olds performed worse than all the other groups ($p < .001$ in all cases). In fact, all age groups except 3-year-old children were above chance in all conditions (Wilcoxon test against 50%, $p < .01$).

Figure 2b presents the percentage of correct trials as a function of age and type of landmark for invisible rotations. There were overall significant differences between landmark types, Friedman test $\chi^2(2, N = 46) = 17.86$, $p < .001$. Pairwise Wilcoxon tests revealed that children performed worse in the horizontal condition compared with the colored cup ($p = .008$) and vertical conditions ($p < .001$).

Overall, older children performed better than younger ones, Kruskal-Wallis test $\chi^2(3, N = 57) = 33.65$, $p < .001$. Pairwise Mann-Whitney tests indicated that 3-year-olds performed worse

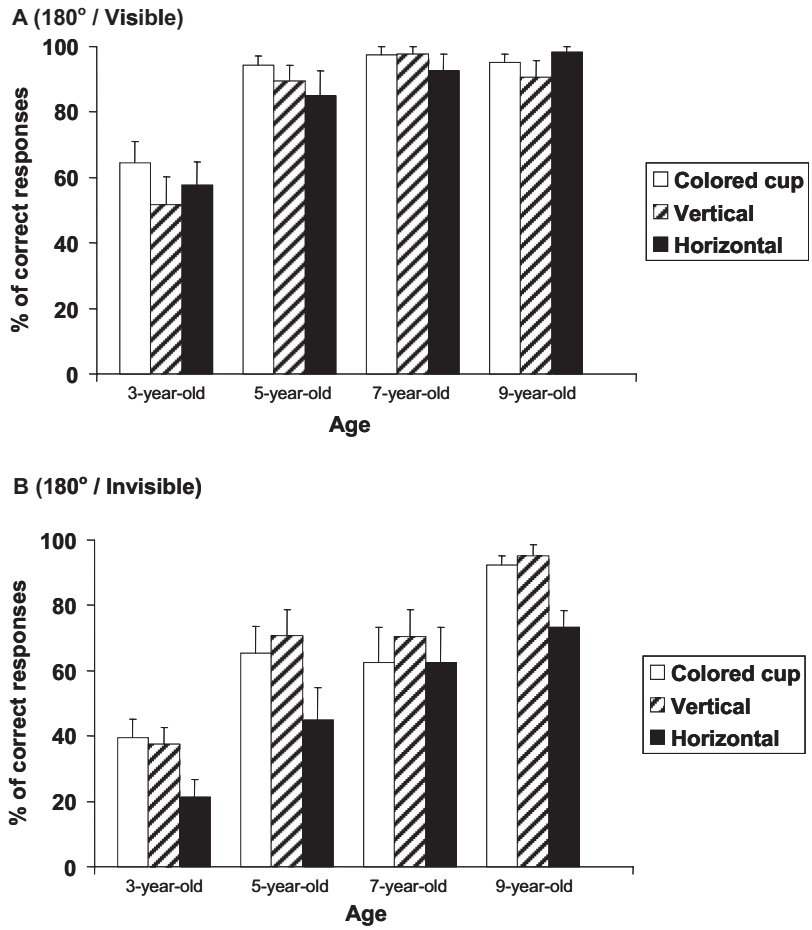

Figure 2. A: Mean percentage of correct trials as a function of age and type of landmark in the 180° visible rotation. B: Mean percentage of correct trials as a function of age and type of landmark in the 180° invisible rotation. Error bars indicate the standard error of the mean.

than all the other groups ($p < .001$ in all cases). Five- and 7-year-old children also performed worse than 9-year-olds ($p = .005$). All groups except the 9-year-old children found invisible rotations significantly harder than visible rotations (Wilcoxon tests: 3-year-olds, $z = 2.95$, $p = .003$; 5-year-olds, $z = 3.19$, $p = .001$; 7-year-olds, $z = 3.19$, $p = .001$; and 9-year-olds, $z = 1.72$, $p = .085$).

Nine-year-old children were above chance in all conditions (Wilcoxon test against 50%, $p < .01$), whereas 3-year-olds were above chance in none of them. In fact, 3-year-olds were below chance in the vertical board ($p = .035$) and horizontal board conditions ($p = .004$). Five- and 7-year-old children were above chance only in the vertical board condition ($p < .05$ in both cases).

360° Rotations

Figure 3a presents the percentage of correct trials as a function of age and type of landmark for visible rotations. There were no overall significant differences between landmark types, Friedman test $\chi^2(2, N = 46) = 5.77$, $p = .056$. Older children performed better than younger ones, Kruskal-Wallis test $\chi^2(3, N = 57) = 28.53$, $p < .001$. Pairwise comparisons indicated that 3-year-olds performed worse than all the other groups (5-year-olds, $p = .028$; 7- and 9-year-olds, $p < .001$). Similarly, 5-year-olds performed worse than 7- and 9-year-olds ($p < .025$). All age groups were above chance in all conditions (Wilcoxon test against 50%, $p < .05$) except 3-year-old children in the horizontal condition ($p = .11$).

Figure 3b presents the percentage of correct trials as a function of age and type of landmark for invisible rotations. There were overall significant differences between landmark types, Friedman test $\chi^2(2, N = 46) = 6.11$, $p = .047$. Children performed worse in the horizontal condition compared with the colored cup condition ($p = .009$). Older children performed better than younger ones, Kruskal-Wallis test, $\chi^2(3, N = 57) = 9.57$, $p = .023$. Pairwise comparisons indicated that 3-year-olds performed worse than 9-year-olds overall ($p = .042$). Three-year-old children were above chance in all conditions (Wilcoxon test against 50%, $p < .05$). The remaining age groups were above chance in all conditions (Wilcoxon test against 50%, $p < .05$) except the horizontal condition (Wilcoxon test against 50%, $p > .052$ in all cases). Additionally, 7-year-old children failed to reach above-chance performance in the colored cup condition ($p = .22$).

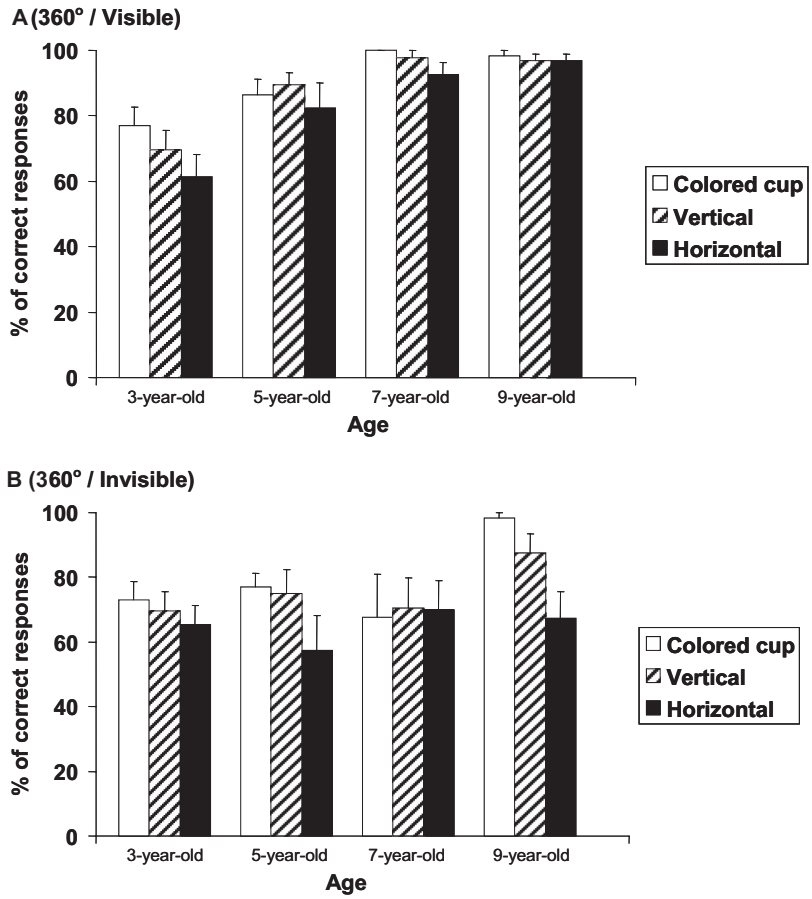

Figure 3. A: Mean percentage of correct trials as a function of age and type of landmark in the 360° visible rotation. B: Mean percentage of correct trials as a function of age and type of landmark in the 360° invisible rotation. Error bars indicate the standard error of the mean.

Comparisons Between Rotation Degree and Visibility

All age groups except the 3-year-old children found invisible rotations significantly harder than visible rotations (Wilcoxon tests: 3-year-olds, $z = 0.09$, $p = .93$; 5-year-olds, $z = 2.39$, $p = .017$; 7-year-olds, $z = 2.83$, $p = .005$; and 9-year-olds, $z = 2.82$, $p = .005$). Three-year-old children found 180° rotations harder than 360° rotations (Wilcoxon test: $z = 3.30$, $p = .001$). In contrast, all other age groups performed at the same level in both types of rotations (Wilcoxon test: 5-year-olds, $z = 0.87$, $p = .38$; 7-year-olds, $z = 0.12$, $p = .91$; and 9-year-olds, $z = 0.0$, $p = 1.0$).

Discussion

The ability to track and infer rotational displacements increased with age. Whereas 9-year-olds performed well in all conditions involving 180° rotations, 3-year-olds showed important shortcomings. Three-year-olds' superior performance with the 360° rotations compared with 180° rotations suggests that they simply selected the cup where they had last seen the prize, particularly after invisible rotations. In general, visible rotations were easier than invisible rotations, although the differences changed with age and type of landmark. Children were able to use various landmarks to infer 180° rotations that took place outside of sight, although some landmarks facilitated the task more than others. Thus, the colored cup and the vertical conditions were easier than the horizontal condition. This result offers an alternative to the hypothesis that a differentiation of covers provided more salient cues to allocentric position than a differentiation of the area around the two locations. Another possibility is that the uniformity of the area surrounding the location independently of whether it is in the cover or the background is what provides a more salient cue of the reward's position. Note that the reward location was surrounded by a uniform cue in both the colored cup and the vertical conditions, whereas in the horizontal condition the reward location was surrounded by two colors on each side of the horizontal axis of the platform.

The current results suggest that the ability to infer the positional change by using landmarks developed gradually with age and was good but not perfect even at 9 years of age when children could not rely on a uniform cue surrounding the location but only on a change of the background orientation (horizontal condition). Here 9-year-old children performed at the same level as 3-year-old children in the 360° invisible rotation, although they outperformed 3-year-old children in other invisible conditions, including those

involving the 180° rotations. This suggests that older children used a different strategy than did 3-year-olds. Younger children appeared to have a strong tendency to search the initial location where they had seen the prize being hidden, including visible displacements trials, thus confirming the results of previous studies (Barth & Call, 2006; Lasky et al., 1980; Sophian, 1984). Sophian (1984) reported that this tendency was much reduced by 42 month of age, thus permitting correct responding. However, 3-year-old children in our study, unlike those in other studies (e.g., Lasky et al., 1980, but see Barth & Call, 2006), were unable to locate the reward above chance levels. We do not have a good explanation for this discrepancy other than suggesting that 2–3 years of age may be the time when children begin to master the ability to track visible rotational displacements.

Unlike previous studies with 9-month-old infants and 3-year-old children (Bremner, 1978a; Butterworth et al., 1982; Haun, Call, Janzen, & Levinson, 2006), our 3-year-olds appeared to ignore the color of the cups (and other landmarks) after invisible displacements but instead targeted the prize's initial location. It is conceivable that rotating the board in the current study created a harder problem than in previous studies. Bremner (1978a) reported that infants were better at solving the task when they were rotated rather than when the board on the table was rotated. Haun et al. (2006) used a transposition task, not a rotation task, and it has been shown that the former is easier than the latter (Barth & Call, 2006). It is likely that providing a more salient landmark would help children overcome the difficulties caused by the board rotation. In the next experiment, we tested 3-year-old children in a condition in which the experimenter placed a marker on top of the baited cup after the hiding procedure was over. We expected that children would perform better in this new condition because they could track and remember the marker easily by its salience.

Experiment 2

Method

Participants

Sixteen 3-year-old children (M = 40.5 months old, range = 36–47 months old) who had not participated in Experiment 1 were included. Half of the children were male, and the other half were female. The location in which the experiment was conducted and the recruiting procedure of children were the same as in Experiment 1.

Apparatus and Materials

We used the same two white cups and gray-colored display board as in Experiment 1. Additionally, we used blue and red laminated stickers (diameter = 7.6 cm; see Figure 1b) as a marker.

Design

The design was the same as in Experiment 1 except that there was only one type of landmark (marker condition) that consisted of the experimenter placing the marker on the correct cup after hiding the prize.

Procedure

The procedure was the same as in Experiment 1. Only one session was administered to each child (Figure 1b). Once the prize was hidden, the experimenter placed one of two markers (red or blue) on the cup. Then the display board was pushed forward to the edge of the table within reach of the child.

Data Analysis

We scored and analyzed the data as in Experiment 1. To assess interobserver reliability, an additional coder watched 25% of all video recordings from all children and rated their behavior. The agreements and kappa results between the observers were excellent (100%, $\kappa = 1$).

Results

Figure 4 presents the percentage of correct trials as a function of the degree of rotation and its visibility. There were no significant differences between conditions, Friedman test $\chi^2(3, N = 16) = 0.73$, $p = .87$. Children were above chance in all conditions (Wilcoxon test against 50%, $p < .001$).

We compared these results with those obtained by 3-year-old children in the colored cup condition of Experiment 1, which was the condition in which children obtained the best scores (see Figures 2 and 3). The colored cup condition was significantly harder than the marker condition in every variation (Mann-Whitney tests: 180°–invisible, $z = 4.20$, $p < .001$; 180°–visible, $z = 3.20$, $p = .001$; 360°–invisible, $z = 3.05$, $p = .002$; and 360°–visible, $z = 1.98$, $p = .048$).

Discussion

Three-year-old children were able to use the presence of marker to track the position of the reward after it had undergone an invisible 180° or 360° rotation. The high performance exhibited in this experiment demonstrated that the marker was a more effective landmark than the color of the cups or the platform on which the cups rested, used in Experiment 1. This result confirmed that external landmarks are more effective than background cues in individuating the location of the reward.

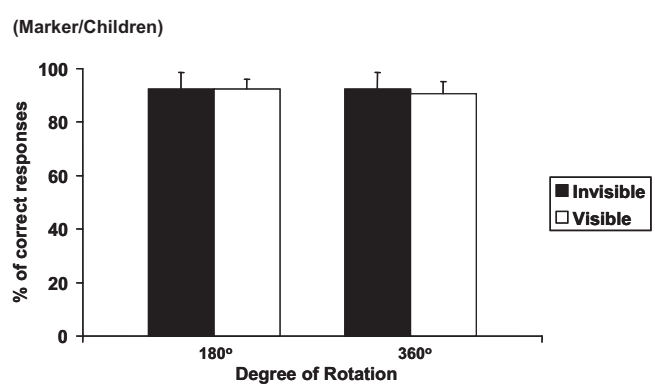

Figure 4. Mean percentage of correct trials in the marker condition as a function of the degree of rotation and its visibility. Error bars indicate the standard error of the mean.

STUDY 2: GREAT APES

Experiment 3

In this experiment, we tested 17 great apes of various species using the same conditions and setup as in Experiment 1.

Method

Subjects

Five chimpanzees (*Pan troglodytes*), 4 bonobos (*Pan paniscus*), 4 gorillas (*Gorilla gorilla*), and 4 orangutans (*Pongo pygmaeus*) participated in this experiment. All apes were socially housed in indoor and outdoor areas at the Wolfgang Köhler Primate Research Center at the Leipzig Zoo. Our sample included 4 males and 13 females between 4 and 29 years old. All apes had participated in a number of other cognitive studies (Table 1).

Apparatus and Materials

We used the same apparatus and materials as in Experiment 1. A piece of fruit was used and hidden under the cup as a reward. The display boards and screen were placed on a table (tabletop 40 cm × 80 cm). The experimenter sat on a chair between the two cups, facing the ape. A Plexiglas partition with two response holes (3.7 cm in diameter) in front of each cup location separated the experimenter and the ape. The board was pushed forward within the ape's reach so that it could select one cup by inserting a finger through one of the response holes. All testing procedures were videotaped.

Design

Experimental design was the same as in Experiment 1.

Table 1
Species, Name, Gender, and Age of the Subjects in Study 2

Species and name	Gender	Age (years)
Chimpanzee (*Pan troglodytes*)		
Brent	M	4
Fifi	F	11
Jahaga	F	11
Natascha	F	24
Fraukje	F	28
Bonobo (*Pan paniscus*)		
Kuno	M	7
Limbuko	M	8
Joey	M	21
Ulindi	F	10
Gorilla (*Gorilla gorilla*)		
Ruby	F	6
Viringika	F	9
Bebe	F	24
N'diki	F	26
Orangutan (*Pongo pygmaeus*)		
Padana	F	6
Toba	F	10
Dokana	F	15
Pini	F	16

Note. M = male, F = female.

Procedure

The experiment was conducted in an experimental room at the Wolfgang Köhler Primate Research Center at the Leipzig Zoo. The procedure was the same as in Experiment 1. Three sessions were administered to each ape, one session per day for each condition as depicted in Figure 1a. The conditions were randomized across apes. Each session began with two training trials as in Experiment 1. Once the food reward was hidden, the board was pushed forward so that the apes could make their selection.

Data Analysis

We scored and analyzed the data in the same way as in Experiment 1 except that we replaced the variable age with species. A choice was scored when an ape touched one of the cups. To assess interobserver reliability, an additional coder watched 25% of all video recordings from all apes and rated their behavior. The agreements and kappa results between the observers were excellent (100 %, $\kappa = 1$).

Results

180° Rotations

Figure 5a presents the percentage of correct trials as a function of species and visibility of the rotation. Overall, apes performed significantly better in visible compared with invisible rotations (Wilcoxon test: $z = 3.53$, $p < .001$). In fact, they performed above chance in visible rotations (Wilcoxon test against 50%, $z = 3.59$, $p < .001$), but below chance in invisible rotations (Wilcoxon test against 50%, $z = 2.99$, $p = .003$).

Although there was an overall significant difference between conditions in visible rotations, Friedman test $\chi^2(2, N = 17) = 7.03$, $p = .03$ (see Table 2), pairwise Wilcoxon tests failed to confirm this difference ($p > .10$ in all cases). There were no significant differences between conditions in invisible rotations, Friedman test $\chi^2(2, N = 17) = 3.29$, $p = .19$ (see Table 2).

There was an overall significant difference between species in invisible rotations, Kruskal-Wallis test $\chi^2(3, N = 17) = 7.92$, $p = .048$, with orangutans receiving the lowest scores. However, pairwise Mann-Whitney tests failed to confirm this result statistically ($p > .15$ in all cases). There were no significant differences between species in visible rotations, Kruskal-Wallis test $\chi^2(3, N = 17) = 2.31$, $p = .51$.

360° Rotations

Figure 5b presents the percentage of correct trials as a function of species and the visibility of the rotation. Apes performed equally in all rotations regardless of the presence of the barrier (Wilcoxon test, $z = 0.92$, $p = .36$). Apes performed above chance in both invisible trials (Wilcoxon test against 50%, $z = 3.64$, $p < .001$) and visible trials (Wilcoxon test against 50%, $z = 3.66$, $p < .001$).

There were no significant differences between conditions in either the visible, Friedman test $\chi^2(2, N = 17) = 0.26$, $p = .88$, or invisible rotations, Friedman test $\chi^2(2, N = 17) = 1.48$, $p = .48$ (see Table 2). There was an overall significant difference between species in both the invisible, Kruskal-Wallis test $\chi^2(3, N = 17) =$

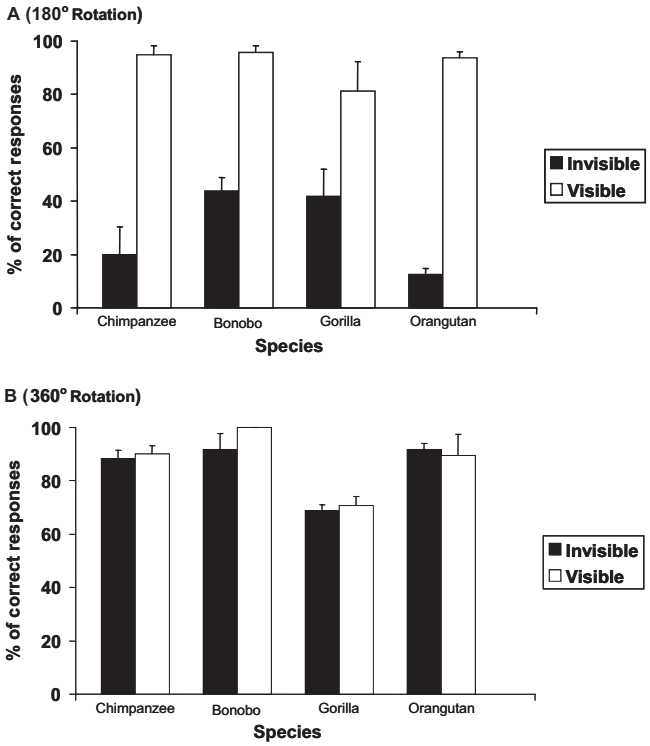

Figure 5. A: Mean percentage of correct trials as a function of species and the visibility of the 180° rotation. The results from all landmarks are pooled together because there were no significant differences between conditions. B: Mean percentage of correct trials as a function of species and the visibility of the 360° rotation. The results from all landmarks are pooled together because there were no significant differences between conditions. Error bars indicate the standard error of the mean.

8.72, $p = .033$, and visible rotations, Kruskal-Wallis test $\chi^2(3, N = 17) = 9.70$, $p = .021$. In both cases, gorillas received the lowest scores, but pairwise Mann-Whitney tests failed to confirm this result statistically ($p > .15$ in all cases). Nevertheless, comparing gorillas with the other ape species pooled together showed that gorillas performed significantly worse than the other ape species (Mann-Whitney test, $z = 2.88$, $p = .004$).

Apes found 180° invisible rotations harder than 360° invisible rotations (Wilcoxon test, $z = 3.52$, $p < .001$). In contrast, there was no significant difference between 180° visible and 360° visible rotations (Wilcoxon test, $z = 1.27$, $p = .21$).

Discussion

Apes could track the baited cup in visible rotations but could not infer its location when the displacement took place behind a barrier independent of the type of landmark that signaled its location. In the invisible trials, apes simply selected the location where they saw the experimenter place the reward. These results confirmed previous studies that have shown good performance in tracking visible rotations (e.g., Barth & Call, 2006; Beran & Minahan, 2000; Call, 2003) but difficulties with using markers to infer the position of rewards after displacements (Call, 2003; Potì, 2000; but see Beran et al., 2005). This suggests that visually tracking object movement and using a landmark from the environment are two fundamentally different search strategies. In the next experiment, we investigated whether increasing the salience of the landmark (marker condition) would improve the apes' performance in the invisible condition as it did with 3-year-old children.

Experiment 4

Method

Subjects, Apparatus and Materials, Design, and Procedure

The same 17 great apes from Experiment 3 served as subjects in the current experiment. We used the same apparatus and materials, design, and procedure as in Experiment 2.

Data Analysis

We scored and analyzed the data as in Experiment 3. To assess interobserver reliability, an additional coder watched 25 % of all video recordings from all apes and rated their behavior. The agreements and kappa results between the observers were excellent (100%, $\kappa = 1$).

Results and Discussions

Figure 6 presents the percentage of correct trials as a function of the degree of rotation and its visibility. There were no overall significant differences between species, Kruskal-Wallis test $\chi^2(3, N = 17) = 1.71$, $p = .64$. In contrast, there were significant differences between conditions, Friedman test $\chi^2(3, N = 17) = 40.11$, $p < .001$. Pairwise Wilcoxon tests indicated that apes performed significantly worse in the 180° invisible condition compared with all other conditions ($p < .005$). Additionally, apes performed worse in the 360° invisible condition compared with the 180° visible condition ($p = .033$). Apes were above chance in all conditions (Wilcoxon test against 50%, $z > 3.40$, $p < .001$) except the 180° invisible condition, which was below chance (Wilcoxon test against 50%, $z = 2.23$, $p = .026$).

We compared these results with those of the colored cup condition from Experiment 2 as we had done with the children. The colored cup condition was significantly harder than the marker condition but only in the 180° visible condition (Wilcoxon tests: 180°–invisible, $z = 0.22$, $p = .83$; 180°–visible, $z = 2.11$, $p =$

Table 2
Mean Percentage (and Standard Deviation) of Correct Trials as a Function of Type of Rotation and Landmark in the Great Apes

	Landmark		
Type of rotation	Colored cup	Vertical	Horizontal
Visible			
180°	85.3 (4.8)	94.1 (3.4)	95.6 (2.4)
360°	89.7 (3.7)	85.3 (6.5)	88.2 (4.8)
Invisible			
180°	38.2 (7.5)	22.1 (6.4)	26.5 (6.2)
360°	80.9 (4.6)	88.2 (4.4)	86.8 (4.4)

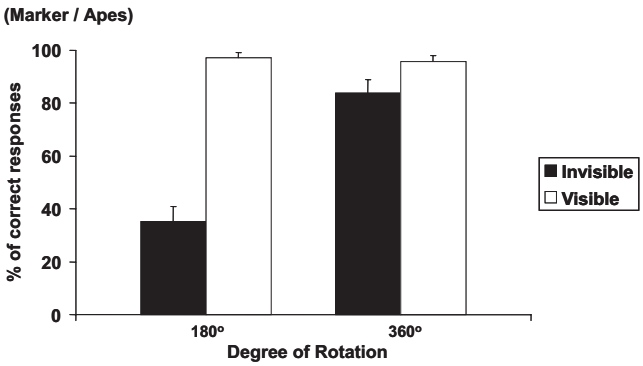

Figure 6. Mean percentage of correct trials as a function of the degree of rotation and its visibility in the marker condition. All species are pooled together because there were no significant differences between them. Error bars indicate the standard error of the mean.

.035; 360°–invisible, $z = 0.37$, $p = .71$; and 360°–visible, $z = 1.63$, $p = .10$).

Unlike 3-year-old children, the apes still could not find the baited cup when the rotation took place behind a barrier, but they succeeded with 360° rotations. However, this pattern of results suggests that apes simply searched for the baited cup in the original location in which the reward was deposited by the experimenter. Thus, the performance of this experiment confirms the data from Experiment 3. Apes can track visible spatial rotations but do not appear to infer the location of the cup with the help of landmarks when the displacement takes place behind a barrier.

GENERAL DISCUSSION

Apes and children older than 3 years of age performed well in visible rotations, whereas apes performed poorly when they had to infer the baited cup location after invisible rotations independent of the type of landmark. Children's performance in the invisible rotation task was dependent on the type of landmark, with 3-year-olds succeeding only when a marker indicated the baited cup. Older children also succeeded in invisible rotations with more subtle landmarks consisting of colored cups or colored boards. The board painted with a top–bottom pattern proved to be particularly challenging because only 9-year-old children were able to solve the task in this condition. In general, 5- and 7-year-old children displayed data consistent with a gradual transition between the youngest and the oldest age groups in invisible displacements but a more abrupt transition between 3-year-olds and older children in visible displacements. This study provides some good developmental and comparative contrasts that we discuss next.

From the point of view of human development, there was a clear age progression for tracking 180° visible rotations. Children mastered this task by age 5 independently of the type of landmark used. In contrast, inferring rotations was mastered at a later age and depended crucially on the type of landmark used. More salient landmarks such as a marker placed on top of the cup substantially facilitated the task so that even 3-year-olds were able to find the prize. More subtle landmarks based on the orientation of the colored board were only solved by older children. It is conceivable that younger children did not actually infer the rotation of the board but simply used the most salient landmark to locate the reward, although solving this task in this way still required them to ignore the initial location of the prize. In contrast, the landmark based on the orientation of the colored board is much harder to explain in this way. Indeed, using this landmark may have required children to actually infer a rotation of the board, not just ignore the initial position. If this is the case, it would mean that the ability to infer spatial rotations may only be consolidated in 9-year-old children. Children of this age might need to have more sophisticated logical or deductive thinking such as if–then: "The red-painted side is close to me. If the blue-painted side is close to me after the screen went up, then the tabletop must have been rotated 180°, and the correct container is now on the other side." Deductive thinking involves combining existing information by following specific mental operation (Goswami, 2002). Piaget thought that certain mental operations could only be applied to information by children older than around 6 to 7 years old. Previous research with 6- through 13-year-old children investigating their ability to recognize the logical necessity of a conclusion reported that there was considerable difficulty among even 8-year-old and older children (Shapiro & O'Brien, 1970). Such ability seems to develop and consolidate gradually (Fabricius, Sophian, & Wellman, 1987). Alternatively, older children might be more apt than younger children at processing global as opposed to local cues. This would explain why older children can pay attention both to cues that surround the baited cup and to cues that are either part of the baited cup or placed on top of the baited cup. This hypothesis, however, awaits empirical support.

From a comparative view, this study uncovered important similarities and differences between children and great apes. First, like 5-year-old and older children, the great apes were able to track the rotational displacement of the baited cup. Unlike children, the great apes failed to use landmarks to infer a change in position of the baited cup. Such a lack of attention to landmarks in this task confirmed previous studies showing that apes relied more heavily on place than on feature information to locate hidden rewards (Call, 2003; Haun et al., 2006). This does not mean that apes are unable to use landmarks to infer object locations. Beran et al. (2005) showed that two chimpanzees were able to use landmarks to track rotational displacements, and Menzel (1996) found that other primates such as longtail macaques used landmarks to identify potential new food locations. Moreover, the great apes' reliance on the spatial location of objects was not rigid enough to prevent them from ignoring the initial location of the object in visible displacements—something that 3-year-old children were not able to do without the support from a detached landmark.

Thus, although the skill for tracking visible rotational displacements is well developed in apes, we found no evidence for inferring a change of location via a landmark's change of orientation. This difference cannot be attributed to a lack of inferential abilities in the great apes because they can solve a variety of inferential problems involving spatial, object, and object–object relations (Boysen, Berntson, Shreyer, & Quigley, 1993; Call, 2004, 2006; Hashiya & Kojima, 2001; Premack & Premack, 1994). Likewise, the difference between apes and humans cannot be explained as being because of an inability to inhibit reaching for the cup under which the food was initially placed because these species perform well in the A-not-B task (e.g., Barth & Call, 2006; de Blois et al., 1998). Instead the differences between humans and nonhuman

apes may arise from the increased attention that humans pay to landmarks that have not been directly associated with food acquisition in the past. Because all great apes in this study showed the same pattern, it appears that this skill may be specific to humans. However, this putative difference needs to be qualified because 3-year-old children did not show the same pattern as older children, and Haun et al. (2006) showed that 1-year-old infants, like apes, relied on spatial rather than feature information when searching for hidden rewards. This suggests that epigenetic factors may have crucially contributed to the differences observed in the present study.

As part of their interaction with cultural artefacts and practices, children learn a massive amount of information about spatial transformations and object features. Little of this rich information is experienced by the apes that we tested in the current study. Interestingly, the chimpanzees studied by Beran et al. (2005) that succeeded in inferring the rotation of containers by using landmarks had been exposed from an early age to cultural artefacts including symbolic training. Although Beran et al. argued that their chimpanzees could use the landmark appropriately because they had received a sufficient number of trials in which they could use it, our study also had an adequate amount of trials but our subjects were unable to use any of the landmarks. Moreover, Call (2003) found that subjects that could use a marker to locate food did not use it to locate the baited cup after a visible rotation had taken place.

Language may have enabled an attentional shift from spatial information (which is well developed in the great ape clade) to feature information (Haun et al., 2006). Language provides labels for objects, and this may have helped individuals to focus attention on the features of containers rather than on their spatial location (e.g., Spelke, 2003; Vygotsky, 1962). Additionally, humans may deploy their attention more broadly than other primates. Humans process pictorial compound stimuli more globally than chimpanzees and baboons, although chimpanzees also show a more global processing than baboons (Fagot & Deruelle, 1997; Fagot & Tomonaga, 1999). Processing information more globally may also be implicated in the establishment of analogies (i.e., focusing on relations between relations) of various sorts that children begin to show in their preschool years (Goswami, 2002; Rattermann & Gentner, 1988). Although chimpanzees can also establish analogies (Premack, 1983; Thompson, Oden, & Boysen, 1997), these appear more limited than those observed in children.

Another contributing factor for the differences observed between older and younger children might be related to children's development of map-reading skills (e.g., Presson, 1982) because this requires encoding the relative location of each color on the board as critical information (near–far) from themselves when reasoning about new environments. Piaget and Inhelder (1956) proposed that even preschool children can conceptualize space in topological terms (e.g., ideas such as "next to," "on," and "near") that permit the child to represent spatial relations in configurational terms. However, inferring a spatial representation after spatial changes might require more complex cognitive strategy.

Obviously, the factors proposed here are not mutually exclusive because cultural practices influence the socialization of attention and, in addition, play a crucial role in language development, which in turn is an important factor contributing to the development of map-reading skills and the focusing of attention on particular features of the environment. The interaction between these factors is complex, and future studies combining developmental and comparative insights are necessary. There are multiple ways in which this research could continue. Here we suggest two possible future research directions. One possibility is to compare the attentional scope of children and apes by varying the physical distance between landmarks and target locations. Additionally, sets of landmarks, not just single landmarks, forming configurations could be rotated out of sight to see whether subjects can infer the degree of rotation that has taken place. Another avenue for future research consists of administering the tasks used in the current study to apes that can use symbols to identify colors. The question is whether these apes would be more likely to locate the target location after invisible displacements than the apes included in this study.

In conclusion, great apes and 5-year-old and older children can track visible rotations of a baited cup, but only children can infer the location of a baited cup with the help of landmarks when rotations take place outside of view. The ability to use markers to make these inferences changes with age, with more prominent landmarks such as an object placed on top of a cup appearing first and subtler ones based on background patterns appearing relatively late in human development.

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