ORIGINAL ARTICLE

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Do apes and children know what they have seen?

Abstract Chimpanzees and young children understand much about what other individuals have and have not seen. This study investigates what they understand about their own visual perception. Chimpanzees, orangutans, and 2.5-year-old children were presented with a finding game in which food or stickers were hidden in one of two or three tubes. We varied whether subjects saw the baiting of the tubes, whether subjects could see through the tubes, and whether there was a delay between baiting and presentation of the tubes to subjects. We measured not only whether subjects chose the correct tube but also, more importantly, whether they spontaneously looked into one or more of the tubes before choosing one. Most apes and children appropriately looked into the tubes before choosing one more often when they had not seen the baiting than when they had seen the baiting. In general, they used efficient search strategies more often than insufficient or excessive ones. Implications of subjects' search patterns for their understanding of seeing and knowing in the self are discussed.

Key words Metacognition · Uncertainty · Self-knowledge · Mental attribution · Primates

Introduction

Following the gaze of other individuals can provide much information about the social and physical environment. Several studies have shown that chimpanzees and other primates follow the gaze direction of their conspecifics (e.g., Emery et al. 1997; Tomasello et al. 1998) and humans (Itakura 1996; Povinelli and Eddy 1996; Call et al. 1998; Anderson and Mitchell 1999). Related studies extend these findings by investigating chimpanzees' understanding of the link between seeing and knowing in others (Povinelli et al. 1990; Call et al. 2000). In these studies, chimpanzees use the pointing gestures or gaze direction of two human experimenters – one who has seen in which of two locations food was hidden and one who has not seen – to decide which location to choose. Neither study found any clear evidence that chimpanzees understand the link between seeing and knowing in others; however, these studies used human experimenters and a somewhat unnatural object-choice situation. Using a more natural procedure, with conspecifics, Hare et al. (2000) have found that chimpanzees behave differently in a food competition situation depending on whether their conspecific competitors have or have not seen the location of the food. It is thus clear that chimpanzees know at least what other individuals have and have not seen, and that they can use this information to obtain food.

Young human children, too, understand a great deal about others' gaze direction. Children begin to follow others' gaze direction as early as 3 months of age (D'Entremont et al. 1997; see, e.g., Moore 1999, for a recent review of the gaze-following literature). There is ample evidence that children as young as 2 (O'Neill 1996) or 3 years of age understand something about the link between seeing and knowing in others. For example, 3- and 4-year-old children understand that a person who has looked into a box knows what is in the box but a person who has touched the box but not looked inside does not know (e.g., Pillow 1989; Pratt and Bryant 1990). Young children thus also know what other individuals have and have not seen, and that seeing leads to knowing in others, and they can use this information to obtain rewards.

However, less research has been done on what chimpanzees and children understand about seeing and knowing in *themselves*. Surely, animals and young children use perceived information to guide their behavior and to

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search for food or other rewards. However, it is unclear whether these individuals also have some meta-knowledge of what they have and have not seen, and, if so, whether they can access and use this information flexibly. The understanding of seeing and knowing in oneself may be a precursor or a "stepping stone" for the development of an understanding of what others see and know (or this understanding for self and other may develop at the same time). We are aware of no previous studies of whether apes know what they themselves have seen – whether they understand that they have to see (or otherwise perceive) something to know where it is, for example.

For children there have been several studies involving understanding of perceptual sources of information and the relation between seeing (or other forms of perception) and knowing in the self. In some of these studies, children were asked what they would need to do in order to know the color, shape, or sound of an object in a container (Pillow 1993). In other studies, children were asked whether they knew what was in a container (Wimmer et al. 1988; Pillow 1989; Pratt and Bryant 1990) or how they found out what was in a container (e.g., did they see, were they told, or did they infer? Gopnik and Graf 1988; O'Neill and Gopnik 1991; Povinelli and de Blois 1992). Although many 3-year-old children have difficulty with some of these tasks, the tasks are reliably achieved by 4-year-olds. These tasks all involve verbal questions and answers, however, so they may underestimate young childrens' abilities.

In this study, we investigated whether apes and 2.5-year-old children have access to information about their own visual perception, and whether they can use this information flexibly to maximize their attainment of rewards. We presented subjects with a nonverbal finding game in which rewards (pieces of food for apes or stickers for children) were placed by an experimenter into one of two or three tubes. We varied whether subjects saw the baiting of the tubes (i.e., whether or not a screen was placed between the tubes and the subject during the baiting) and whether the tubes were presented to subjects for their choice immediately following baiting or instead after a short delay. We measured how often subjects correctly chose the baited tube. More importantly, we also measured how often and in what circumstances subjects spontaneously looked into one or more of the tubes before choosing one.

We were interested in two aspects of subjects' looking behavior: (1) whether subjects looked when it was appropriate to do so (i.e., looked when the baiting was done behind a screen but did not look when they had watched the baiting), and (2) the search strategies subjects used. That is, the efficiency of subjects' searches provides information about how directly and flexibly subjects can access and use their knowledge of their perceptual knowledge (or lack thereof). For instance, if subjects keep looking into all possible locations even after they have already seen the piece of food in one of them, this does not suggest privileged access to perceived information; instead, these subjects may simply be using a fixed strategy of looking in all

locations. In contrast, if subjects vary their strategies depending on the information gathered, this would indicate greater flexibility and suggest a more privileged access to visual information. The most convincing example of this would be if subjects terminate their search and select the correct location *before* seeing the food, that is, if with minimal perceptual information they can infer the logical location of the food. Thus, an important question in this study concerned what types of reasoning subjects used in their searches.

Experiment 1

In this experiment we presented chimpanzees and orangutans with two tubes and varied two factors systematically: visual access to the baiting procedure and delay between baiting and presentation of the platform for the subject's choice. We made two predictions. First, we predicted that subjects would be more successful and look less often into the tubes when the baiting was conducted in full view of the subjects than when it was conducted behind a screen. Second, we predicted that subjects would be more successful and look more often into the tubes in the delayed condition than the immediate condition because in the former condition subjects would not need to refrain from making an uninformed choice, and could use the delay period to gather information about the location of the reward.

Subjects

Three chimpanzees (*Pan troglodytes*; two adult females and one subadult male) and three orangutans (*Pongo pygmaeus*; two adult males and one subadult male) served as subjects. All six individuals were housed at the Yerkes Regional Primate Research Center. Previously these apes had participated in a number of other experiments (see Table 1 for further information about subjects' ages and rearing and experimental histories). Subjects were tested in their indoor cages, separated from the rest of the group, and were fed according to their normal daily routine (i.e., twice a day on a diet of fruit, vegetables, and monkey chow). Water was available ad libitum, and subjects were not deprived of food or water during testing.

Materials

The apparatus consisted of four rectangular "tubes" made of opaque, white PVC (5 cm×5 cm×30 cm). Two of these tubes (the "closed" tubes) had a square piece of cardboard inside at about 5 cm from one of the ends; this prevented subjects from seeing through them. The position of the cardboard piece created a 5-cm compartment that permitted us to hide a piece of food in the interior of the tube. The remaining two tubes (the "open" tubes) lacked any

Table 1 Chimpanzees and orangutans who participated in experiments 1 and 2 (experimental history: *1* gaze following, *2* tool use and social learning, *3* comprehension of communicative signs, *4* distinguishing intentional from accidental actions, *5* false belief task, *6* language acquisition, *7* Piagetian conservation, *8* object permanence, *9* quantity discrimination)

Subject	Species	Age (years)	Sex	Birth-place	Parti-cipation in study	Rearing history	Experimental history
Anja	Chimpanzee	18	Female	Captivity	2	Mother	1
Barbara	Chimpanzee	26	Female	Captivity	2	Mother	1,8
Chantek	Orangutan	18	Male	Captivity	1	Mother-home	2,3,4,5,6,7,8,9
Cissie	Chimpanzee	22	Female	Captivity	1,2	Nursery	1,3,4,5,8
Dona	Chimpanzee	8	Female	Captivity	2	Mother	
Ericka	Chimpanzee	25	Female	Captivity	2	Home	1,3,4,5,8,
Jesse	Chimpanzee	16	Female	Captivity	1,2	Nursery	1,3,4,5,8
Peony	Chimpanzee	30	Female	Wild	2	Nursery	1,6,
Renette	Chimpanzee	11	Female	Captivity	2	Mother	
Rita	Chimpanzee	11	Female	Captivity	2	Mother	1
Solok	Orangutan	11	Male	Captivity	1	Mother	2,4,8,9
Sonia	Chimpanzee	39	Female	Wild	2	Unknown	1,4,5,8
Tai	Chimpanzee	31	Female	Wild	2	Mother	1,3,4,8
Teriang	Orangutan	23	Male	Captivity	1	Mother	2,4,5,7,8,9
Travis	Chimpanzee	9	Male	Captivity	1,2	Mother	3,4,5,8

form of blockage, thus allowing subjects to see through the middle. Different combinations of pairs of tubes (i.e., open-open, open-closed, closed-closed) were placed on a wooden platform (70 cm×40 cm×35 cm in height) and a cardboard screen was used to occlude the hiding process from the subject. Orange pieces were used as rewards. See Figure 1 for a depiction of testing setting.

Procedure

Before testing began, subjects were given the opportunity to explore and manipulate the tubes through the fence. Subjects explored the tubes in various ways such as looking through them, touching them, and poking at the cardboard blockage in the closed tubes. Testing began shortly after the exploratory interest decreased (this never lasted more than 5 min). The general procedure consisted of

three basic steps. First, the experimenter (E) placed two tubes on the platform approximately 40 cm apart and perpendicularly oriented toward the fence. The platform itself was situated in front of the cage just outside the subject's reach (approximately 30 cm away from the fence). Second, E showed the subject a piece of food and then baited one of the tubes. Finally, E pushed the platform against the fence so that subjects would be able to choose (by touching) one of the two tubes. Once the subject had chosen one of the tubes (only one choice was allowed), E pulled back the platform from the fence and gave the food reward to the subject if she chose the baited tube.

The following three factors (and their combinations) determined the various experimental conditions: the type of tube pair, the baiting procedure, and the delay between the baiting and the presentation of the platform for the subject's choice. First, there were three types of tube pairs: (1) two open tubes (open-open condition), (2) two closed tubes (closed-closed condition), and (3) one open and one closed tube (open-closed condition). Second, there were two baiting procedures: (1) E baited one of the

Fig. 1 The test setting (*E* experimenter, *S* subject)
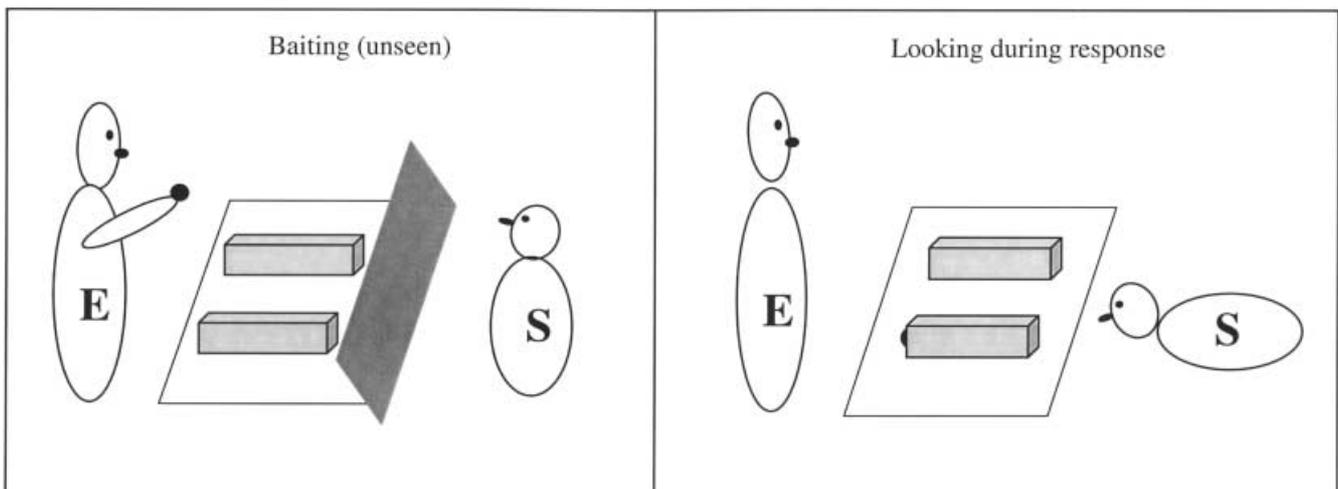
tubes in full view of the subject (seen condition), or (2) E placed the screen in front of the tubes (between the tubes and the subject) while baiting so subjects could not see (unseen condition). In every unseen trial, E introduced his hand into both tubes but left the reward inside only one of them to prevent the possibility of subjects using noises or body movements to determine where he had deposited the food. Finally, there were two types of delay for the presentation of the platform for subjects' choice. After baiting (and removing the screen if necessary), (1) E pushed the platform against the fence without delay (immediate condition), or (2) E waited for 5 s before pushing the platform against the fence (delayed condition). During these 5 s, E looked at the subject with a neutral facial expression.

Each subject received a total of 128 trials administered in four 32-trial blocks. Subjects received 96 unseen and 32 seen trials. In unseen trials, subjects received 32 trials in each of the three type of tube conditions. In half of those 32 trials in each condition, subjects' choice was immediate and in the other half it was delayed. In the seen trials, subjects received 16 trials in both the open-open and the closed-closed condition, and no trials in the open-closed condition. It was deemed unnecessary to include open-closed trials because it was thought that they would not produce any information different from the other types of trials. In half of those 16 trials in each condition, subjects' choice was immediate and in half it was delayed. Food location was randomly varied among the two tubes with the only constraint that the reward was never placed in the same side for more than two consecutive trials. The position (left or right) of the open tube in the open-closed condition was counterbalanced across trials and food was placed an equal number of times in the open and in the closed tube.

Data analysis

We used two behaviors as dependent measures: choosing and looking. Choosing consisted of touching one of the two tubes and it was unequivocal. Looking consisted of bending the head or body down and gazing into any of the tubes. The platform was low enough that a clear head or body movement was required in order to see into the tubes. Of the sessions 20% were coded live by a second coder to assess the inter-observer reliability of the subjects' looking behavior. Inter-observer reliability was excellent (Cohen's κ=0.89). All statistics on these two measures were one-tailed, based on our predictions, unless indicated otherwise.

Another measure we obtained for each trial was the subject's search (i.e., looking) pattern. With each look, subjects could encounter three different tube configurations: closed, empty (i.e., open with no food), or visible food (i.e., open with food inside). Three strategies were identified. An *efficient* strategy was one in which subjects continued looking into different tubes until they saw (1) the food, (2) a closed tube and an empty tube, or (3) two

closed tubes (note that an example of a particularly efficient search is seeing an empty tube and then choosing the other tube without looking inside it first). An *excessive* strategy was one in which subjects continued looking even after seeing one of these three sights. An *insufficient* strategy was one in which subjects stopped looking before they saw or could logically infer the location of the food. All statistics on search analyses were two-tailed because we did not have predictions regarding the use of each of the search patterns.

Results

There were no differences between chimpanzees and orangutans on any measure so for all analyses these two groups were collapsed.

Choosing behavior

All subjects chose a tube in every trial. As a group, subjects obtained more food than expected by chance (50%) in all experimental conditions (t>3.39, df=5, P<0.05; mean percent trials: seen-delayed=100%, seen-immediate=100%, unseen-delayed=80.6%, unseen-immediate=66.7%). A 2×2 repeated-measures ANOVA (baiting: seen, unseen; delay: immediate, delayed) on the percentage of correct responses revealed significant effects of baiting, $F_{(1,5)}$=182.78, P<0.001, delay, $F_{(1,5)}$=5.10, P<0.05, and baiting×delay, $F_{(1,5)}$=5.10, P<0.05. As predicted, there were significant differences between the two types of delay for the unseen condition (t=2.26, df=5, P<0.05) but not for the seen condition (t=0). Individual analyses indicated that all subjects performed above chance (50%) in all conditions (binomial test: P<0.05) except Cissie who failed to do so in the unseen immediate condition.

Looking behavior

Figure 2 presents the percentage of trials in which subjects looked into the tube(s) as a function of the baiting procedure and the delay. A 2×2 repeated measures ANOVA on these percentages revealed a significant effect of baiting, $F_{(1,5)}$=4.98, P<0.05, and delay, $F_{(1,5)}$=23.11, P<0.01, and no interaction effect of baiting×delay, $F_{(1,5)}$= 0.53, P=0.50. Subjects looked more often when E did not show the food's location (unseen condition) and when he delayed the subject's choice (delayed condition). This was as expected because subjects did not need to look into the tube to succeed in the seen condition. All subjects looked inside the tubes in the first unseen trial except Cissie who looked for the first time in the third unseen trial. Thereafter all subjects except Cissie and Teriang continued looking regularly when they had not witnessed the baiting procedure.

For the unseen condition, we did two sets of analyses to relate the percentage of correct responses with the per-
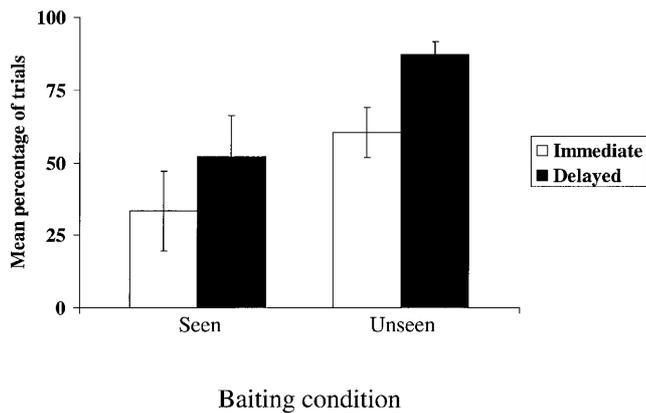
Fig. 2 Experiment 1: the percentage of trials in which subjects looked into the tube(s) as a function of baiting procedure and delay

centage of trials in which subjects looked into the tubes. First, we correlated these two measures within each of the delay conditions. There was a significant relation between these two measures for the immediate condition ($r=0.88$, $P<0.05$, $n=6$) but not for the delayed condition ($r=-0.04$, $P=1.0$, $n=6$). Second, we analyzed the percentage of correct responses as a function of whether subjects looked into the tube(s). Subjects were significantly more successful ($t=6.02$, $df=5$, $P<0.01$) when they looked (mean= 82.9%, SEM=1.5) than when they did not (mean=45.1%, SEM=5.1) for immediate and delayed trials pooled together.

Search patterns

Figure 3 presents the percentage of trials in which each of the search patterns was used by subjects during unseen trials. Only those trials in which subjects looked at least once were included in this analysis. A repeated-measures ANOVA indicated significant differences between search patterns, $F_{(2,10)}=18.72$, $P<0.001$. Subjects used the efficient search strategy significantly more often than either
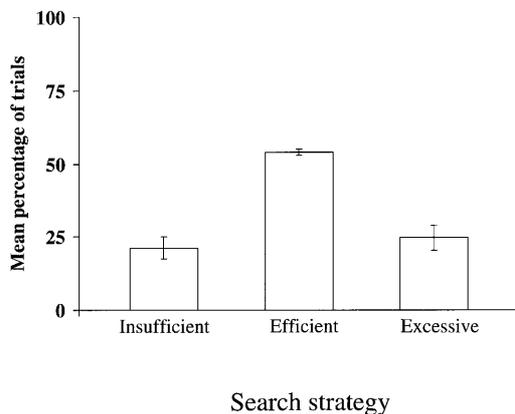
the insufficient ($t=8.91$, $df=5$, $P<0.001$) or the excessive ($t=5.93$, $df=5$, $P<0.01$) search strategy. There were no significant differences between the insufficient and excessive search patterns ($t=0.43$, $df=5$, $P=0.69$). Whereas all subjects used the efficient strategy about half of the time, there were individual differences in the use of the two other strategies. Three individuals (Cissie, Teriang, and Jesse) used both strategies equally often, another individual (Chantek) mostly relied on the insufficient strategy, and the remaining two subjects (Travis and Solok) relied more on the excessive strategy.

Although searching too much is not the most efficient way to find food, a more detailed analysis of the excessive searches may still be of interest because it may show that subjects carried them out in an exhaustive and systematic way. That is, subjects may check all the locations where food may be found (exhaustive search), and they may check each location only once (systematic search). Subjects employed exhaustive and systematic (e.g., Empty-Closed) searches in 86.7% (SEM=6.5) of the trials. They employed exhaustive and non-systematic (e.g., Empty-Closed-Empty) searches in 4.9% (SEM=2.5) of trials and non-exhaustive and non-systematic (e.g., Closed-Closed-Closed) searches in 8.9% (SEM=4.3) of trials. These non-systematic searches involved re-inspecting a previously inspected tube.

Another aspect of the searches besides whether or not they were efficient, exhaustive, or systematic is what determined the termination of the search and led subjects to select one of the tubes. Subjects could encounter three different tube configurations: empty, closed, and visible food. Figure 4 presents the percentage of trials in which subjects made a selection (i.e., did not look again) as a function of the type of tube configuration encountered in their first look. A repeated-measures ANOVA indicated significant differences across configurations, $F_{(2,10)}=16.02$, $P<0.01$. Subjects were more likely to terminate their search after they encountered a tube with visible food compared to either a closed ($t=4.80$, $df=5$, $P<0.01$) or an empty tube ($t=4.25$, $df=5$, $P<0.01$). There was no signifi-

Search strategy

Fig. 3 Experiment 1: the percentage of trials in which each search pattern was used during unseen trials
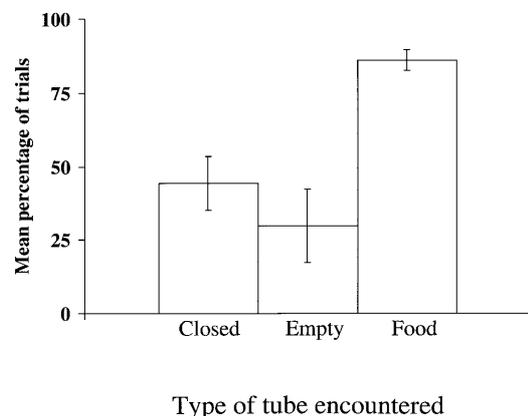

Type of tube encountered

Fig. 4 Experiment 1: the percentage of trials in which subjects chose a tube as a function of the tube configuration encountered with their first look
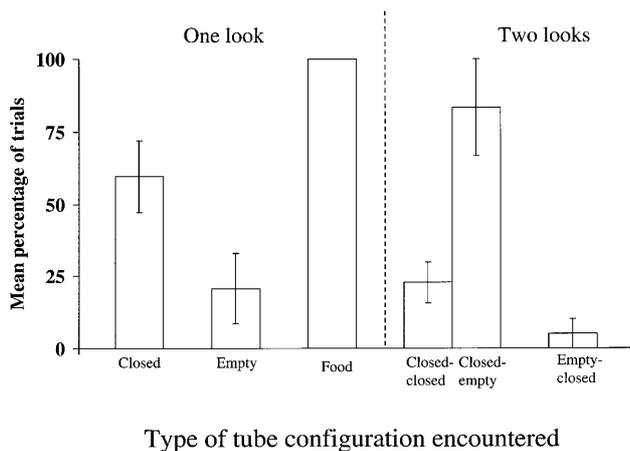
Fig. 5 Experiment 1: the percentage of trials in which subjects selected the same tube they had looked into (with one look) or the first of the two (with two looks)

cant difference between the closed and empty configurations ($t=1.75$, $df=5$, $P=0.14$). Whereas all subjects usually stopped after finding the food, there were marked individual differences upon encountering the other two configurations. Whereas Chantek always stopped regardless of what he found after his first look, Travis and Solok continued searching regardless of what they found. Cissie and Jesse continued searching after finding an empty tube but stopped in half of the trials after finding a closed tube. Finally, Teriang stopped in half of the trials regardless of whether he found an empty or a closed tube.

Finally, we investigated which location subjects selected as a function of the type of tube configuration encountered. Figure 5 presents the percentage of trials in which subjects selected the *same* tube they had looked into or the *first* of the two (if they looked into both). Focusing on those trials with a single look, which represented 50.5% (range: 23–83% depending on the subjects) of the trials with looks, there were significant differences across tube configurations, $F_{(2,8)}=16.95$, $P<0.01$. Subjects always selected the same tube they had looked into if it was baited but rarely did so if it was empty ($t=6.49$, $df=4$, $P<0.01$), selecting the other tube instead without looking. Upon finding a closed tube, subjects selected it on approximately half of the trials, which was still significantly less than for the baited tube ($t=3.26$, $df=5$, $P<0.05$). With regard to individual differences, when they found a baited tube, all subjects chose that tube, and when they found an empty tube, all subjects except Solok usually chose the other tube. Upon encountering a closed tube, three subjects (Cissie, Solok, and Jesse) chose it, one subject (Travis) selected the other one, and two subjects (Chantek and Teriang) selected it in half of the trials.

Focusing on those trials with two looks (in which food was not visible) confirmed our previous results. If subjects found two closed tubes, they usually selected the last one they had inspected. In contrast, if they found a closed tube and then an empty tube, they significantly chose the first one that they had inspected ($t=2.82$, $df=5$, $P<0.05$).

Moreover, if they found an empty tube and then a closed one, they chose the last one they had inspected.

We were particularly interested in evidence that subjects could infer the location of the food, that is, correctly find it without having seen it. We thus looked at trials in which subjects saw an empty tube with their first look and calculated the percentage of these trials in which subjects chose the other (correct) tube without looking into it first. Subjects did this in 26.8% of these trials (five of the six individuals did this at least once).

Discussion

Our two predictions were confirmed. First, subjects looked more often into the tubes when they had not seen the baiting, which translated into a greater percentage of success. Second, they also looked more often when there was a delay between presentation and choice, presumably because they did not need to refrain from choosing one of the tubes and could use the extra time to investigate the contents of the tubes.

Efficient searches (as opposed to insufficient or excessive searches) predominated. When searches were excessive, they were usually exhaustive and non-repetitive (systematic). In general, subjects stopped their search after finding a tube with visible food and continued searching otherwise. They often continued searching even in those cases in which continued searching was not strictly necessary, such as after finding an empty tube, although in 27% of trials they correctly chose the other tube without inspecting it. This is important because it shows that subjects were making inferences about the possible food locations even without directly perceiving the food.

Subjects also stopped quite often (40% of the trials) upon finding a closed tube, but their choice patterns were very different from those observed after finding an empty tube. In particular, upon finding a closed tube, subjects selected it on approximately 60% of the trials compared to 20% after finding an empty tube. Stopping after finding a closed tube is in itself a deficient strategy because subjects could have obtained useful information about the food location by looking into the remaining tube in a number of trials.

In general, the apes' strategy in this task can be summarized as follows. They gathered information about the food's location when they did not possess this information (i.e., they had not witnessed the baiting). They stopped gathering information upon finding the food, but continued gathering information otherwise. The way they gathered information was systematic and exhaustive. They selected a container if it had food inside, avoided it if it was empty, and selected it half of the time if it was closed.

This experiment has some limitations. First, given that there was little effort involved in checking two containers, and that excessive checking was not penalized in any way, it is perhaps not surprising that we did not find more evidence of inferential reasoning such as selecting the alternative tube after seeing an empty one. Furthermore, since

subjects often found the food with their first look into the tubes, this may have prevented them from developing more advanced search strategies. Second, it can be argued that finding closed tubes may have confused the apes. For instance, upon finding a closed tube, subjects may have thought that all of them may be closed and, therefore, it was futile to continue searching. Our relatively small sample (3 individuals per species) makes broader generalizations about species-specific skills problematic. We conducted the next experiment to solve these potential problems.

Experiment 2

In this experiment we used the same basic procedure as before with some modifications. In particular, we increased the number of tubes available to make searching more costly and to allow subjects more room to develop strategies. We eliminated the closed tubes to avoid the potential confusion in regard to the types of tubes available in each trial. Finally, we increased our sample size and focused on chimpanzees to obtain a more accurate estimate of the ability of one of the species to solve our task.

Subjects

Eleven adult and sub-adult chimpanzees (*Pan troglodytes*) housed at the Yerkes Regional Primate Research Center Field Station participated in the study. Three of the chimpanzees (Cissie, Jesse, Travis) had participated in the previous experiment. See Table 1 for further information about the subjects.

Materials

The apparatus consisted of three open tubes identical to those used in experiment 1. All three tubes were placed on a platform separated by 25 cm and a cardboard screen was used to occlude the hiding process from the subject. Banana and apple pieces were used as rewards.

Procedure

The general procedure of the previous experiment was used, with some modifications. First, three tubes, all open, were used (i.e., there were no closed tubes). Second, the presentation of the platform to subjects for their choice was delayed by 5 s for all subjects (i.e., there was no immediate condition). For each subject, there was a total of 48 trials administered in two 24-trial sessions. Each session consisted of 8 seen and 16 unseen trials presented in a randomized fashion. Food location was randomly varied among the three tubes with the only constraint that the reward was never placed in the same tube for more than two consecutive trials.

Results

Choosing behavior

All subjects chose a tube in every trial. Subjects performed above chance (33.3%) in both experimental conditions ($t>2.43$, $df=10$, $P<0.05$), although they were significantly more successful in the seen compared to the unseen condition ($t=4.67$, $df=10$, $P<0.01$; seen mean=97.2%, SEM=1.8, unseen mean=56.0%, SEM=9.3). Individual analyses revealed that all subjects performed above chance in the seen condition (binomial test: $P<0.01$) but only 45% of them (Anja, Travis, Jesse, Renette, and Barbara) did so in the unseen condition (binomial test: $P<0.01$).

Looking behavior

Subjects looked into the tube(s) significantly more often in the unseen condition compared to the seen condition ($t=2.39$, $df=10$, $P<0.05$; see Fig. 6). The frequency of looking behavior was related to the percentage of correct trials in the unseen condition ($r=0.96$, $P<0.001$, $n=11$) but not in the seen condition ($r=0.17$, $P=0.31$, $n=11$). Of the eight subjects who looked inside the tubes in the unseen trials, four did so for the first time in the 1st unseen trial, one in the 2nd unseen trial, another in the 6th unseen trial, and two others in unseen trials 17 and 25, respectively. Thereafter five subjects (Ericka, Travis, Jesse, Renette, Barbara) continued looking regularly when they had not witnessed the baiting procedure. Two other subjects (Dona and Anja) looked regularly at first and then stopped looking while the remaining subject (Rita) looked inconsistently throughout.

The relation between looking and succeeding was further confirmed by studying the percentage of correct responses as a function of whether subjects looked into the tube(s) in the unseen condition. Subjects were significantly more successful ($t=3.06$, $df=6$, $P<0.05$) when they
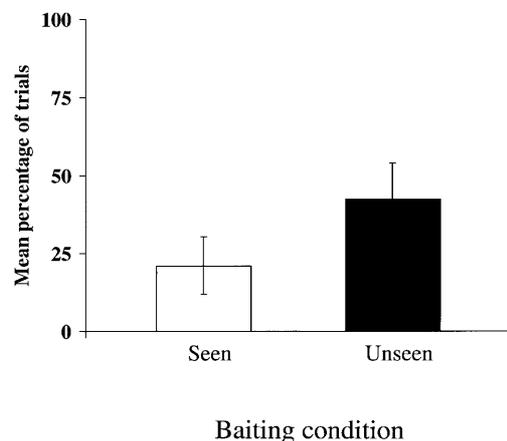

Fig. 6 Experiment 2: the percentage of trials in which subjects looked into the tube(s) as a function of baiting procedure

looked (mean=81.6%, SEM=9.7) than when they did not (mean=45.8%, SEM=11.1).

Search patterns

Figure 7 presents the percentage of trials in which each of the search patterns was used by subjects during unseen trials. Only those trials in which subjects looked were included in this analysis. A repeated measures ANOVA indicated significant differences between search patterns, $F_{(2,14)}=4.13$, $P<0.05$. Subjects used insufficient searches significantly less often than efficient searches ($t=2.55$, $df=7$, $P<0.05$). The differences between insufficient and excessive ($t=2.25$, $df=7$, $p=0.06$) and efficient and excessive ($t=0.40$, $df=7$, $P=0.70$) searches did not reach significance. Three chimpanzees (Jesse, Dona, and Anja) mostly used an efficient strategy whereas three others (Ericka, Travis, and Renette) mainly relied on an excessive search strategy. Another subject (Barbara) used both of these strategies equally often while the other three did not look at all.
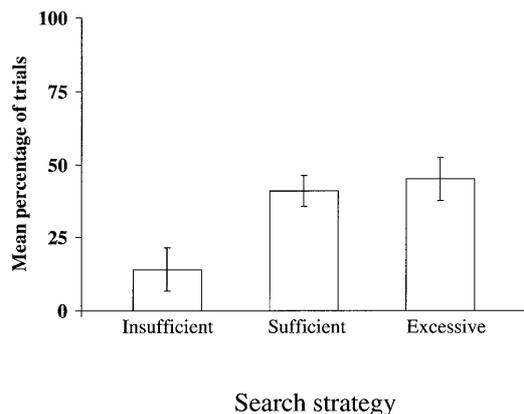

Fig. 7 Experiment 2: the percentage of trials in which each search pattern was used during unseen trials
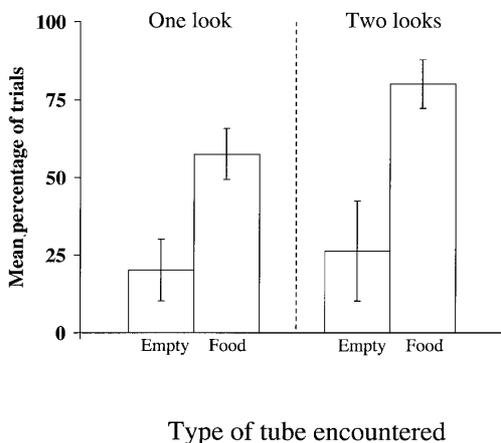

Fig. 8 Experiment 2: the percentage of trials in which subjects chose a tube as a function of the tube configuration encountered with their first looks

We also investigated to what extent excessive searches were exhaustive and systematic. Subjects used exhaustive and systematic searches in 36.6% (SEM=10.2) of the excessive trials (mostly represented by searches of the type Empty-Empty′-Food, EE′F). In addition, 27.4% (SEM= 10.2) of the trials were exhaustive and non-systematic (e.g., EE′EF), 15.9% (SEM=4.7) of the trials were non-exhaustive and systematic (e.g., FE), and 20.1% (SEM= 9.6) of the trials were non-exhaustive and non-systematic searches (e.g., FEF).

Another aspect of the searches besides whether or not they were efficient, exhaustive, or systematic is what determined the termination of the search and led subjects to select one of the tubes. Subjects could encounter two different tube configurations: empty or baited. Figure 8 presents the percentage of trials in which subjects made a selection as a function of the type of tube configuration encountered. After their first look, subjects terminated their search significantly more often upon encountering a baited tube compared to an empty one ($t=4.46$, $df=7$, $P<0.01$). An analysis of the individual strategies indicated that only Rita and Jesse reliably terminated their search upon finding food. Most of the remaining subjects terminated their search after finding food in half of the trials, with the exception of Travis and Renette who continued searching even after finding the baited tube. In contrast, only Rita and Dona (in half of the trials) terminated their search upon finding an empty tube whereas all other subjects continued their search.

Similarly, after encountering an empty tube after their first look and then looking again, subjects terminated their search significantly more often upon encountering a baited tube with their second look than upon encountering a second empty tube ($t=5.60$, $df=7$, $P<0.001$). Individual strategies revealed that no subjects except Rita terminated their search upon finding a second empty tube. In contrast, all subjects waited to terminate their search until finding the baited tube, except Ericka, Renette, and Anja who only stopped searching at this point in half of their trials.

Finally, we investigated which location was selected by subjects as a function of the type of tube configuration encountered in trials with one and two looks. Figure 9 presents the percentage of trials in which subjects selected the *same* tube they had looked into or the *first* of the two (if they looked into two). Trials in which subjects looked into all tubes were not used in this analysis because they did not offer much information about possible inferences about the location of hidden food. In trials with single looks, subjects preferentially selected the same tube they had looked into if it was baited but rarely did so if it was empty, selecting one of the other tubes without looking into them instead ($t=4.47$, $df=4$, $P<0.05$). With regard to individual differences, all subjects chose the baited tube except Dona (who chose baited and empty equally often), and all subjects except Rita chose another tube when they found an empty one (Rita usually chose the empty tube in this situation).

Focusing on those trials in which subjects found an empty tube with their first look and then looked again
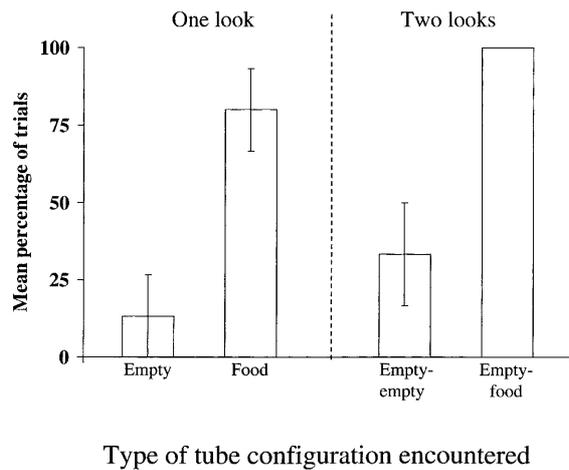
Fig. 9 Experiment 2: the percentage of trials in which subjects selected the same tube they had looked into (with one look) or the first of the two (with two looks)

confirmed our previous results. Namely, upon finding a baited tube on their second look, subjects always selected it whereas they rarely did so upon finding another empty tube ($t=4.0$, $df=4$, $P<0.05$). With regard to individual differences, if they found a baited tube, all subjects always chose it and if they found an empty tube, all subjects except Rita chose the other, still uninspected tube when they found an empty one.

We then looked at those trials in which subjects inferred the location of the food without having seen it. In trials in which subjects saw empty tubes with their first two looks, subjects chose the baited tube without looking into it first in 13.9% of trials (two of the eight individuals who encountered this situation did this at least once).

Discussion

In general, we found the same pattern of results as in the previous experiment. Chimpanzees looked into the tubes more often when they had not seen the food's location during baiting, and they were more successful if they looked. However, we found a greater percentage of excessive looks (although still systematic and exhaustive) than in the previous study: after finding food with their first look, subjects continued looking in 50% of the trials (although this percentage decreased to less than 25% after the second look). This difference between studies cannot be solely attributed to the fact that we only used chimpanzees in the current experiments because chimpanzees were not different from orangutans in our previous experiment. Upon finding an empty tube, subjects continued looking. They often continued looking even after finding two consecutive empty tubes even though this was not necessary. Indeed, only two subjects chose the baited tube without looking after finding two consecutive empty tubes. Instead they usually waited until they had seen the food to choose. Perhaps the increase in excessive searches and the decrease in extra-efficient searches was a result of

the added tube, which may have taxed subjects' ability to make inferences in this situation. Alternatively, chimpanzees may have preferred to look through open tubes and since there were more open tubes in this experiment than in the previous one this could explain the increase in excessive searches. Any preference for looking through open tubes, however, was overcome once subjects found the baited tube. In this case, subjects simply stopped their search and selected that tube.

We detected important individual differences in looking and searching behavior. While some chimpanzees always looked into the containers when they had not witnessed the food placement, others never did so. Still a third group of chimpanzees who did not initially look quickly "learned" to look after some trials. The acquisition of this looking behavior was sudden, lacking a gradual acquisition curve of the type observed in cases of trial-and-error learning.

In summary, this study produced results similar to those of experiment 1. Therefore, our two main procedural modifications (three tubes and no closed tubes) did not alter our previous findings. The only two main differences were that we found some subjects who never looked inside the tubes, and that subjects continued to search in a substantial number of trials even after spying the food inside a particular tube. In our next experiment we investigated how human children responded to the same setup of the current experiment.

Experiment 3: children

In this experiment we tested children with the same basic procedure that we used in experiment 2, with the re-addition of the immediate and delayed conditions. We expected that children, too, would do better in the seen and delayed conditions, and we were interested in whether children would make the same inferences as those made by apes.

Subjects

Twelve children (*Homo sapiens*) from the Atlanta (Georgia) area participated in the study. Children's mean age was 29.7 (range: 27–32 months). There were eight males and four females. Children were recruited from their day care centers.

Materials

A different set of three open tubes, a platform, and a screen identical to those used in experiment 2 were used. Stickers or small toys were used as rewards. Stickers were placed inside a small purple cup for easier visibility in the tubes.

Procedure

Children were tested individually in a quiet room in their day care center. Children sat on the floor; the platform

was placed on top of a short stack of books (approximately 9 cm high). Before testing began, a brief warm-up procedure was used to teach children to touch the container they wanted. Two overturned, opaque bowls were placed on the platform and E hid a sticker under one of them (note that there was no way children could look into the bowls before choosing). E asked the child to touch the bowl the child thought contained the sticker. This procedure was repeated until the child was correct twice in a row. Then the same procedure was repeated but E placed the screen between the child and the bowls while baiting. Finally, a third bowl and a progressively longer delay (maximum 5 s) were added in three final warm-up trials.

Then children were given the opportunity to explore and manipulate the tubes. For testing, E placed the platform in front of the child but out of easy reaching distance. The tubes were placed on the platform approximately 25 cm apart and perpendicularly oriented toward the child, as in the previous two experiments. Three of the previous conditions (with the same baiting procedures) were used: seen immediate, unseen immediate, and unseen delayed (with a 5-s delay).

After baiting, once the tubes were within children's reach, children were allowed to choose one (and only one) of the tubes. E always looked at the child's face and maintained a neutral facial expression during the presentation and choice. Once the child had chosen one of the tubes, E pulled back the platform and gave the contents (if any) of the chosen tube to the child (and showed children where the reward was if they were unsuccessful). The test consisted of a total of 18 trials administered in one session. A session consisted of six seen, six unseen immediate, and six unseen delayed trials presented in a randomized fashion. Reward location was randomly varied among the three tubes with the only constraint that it was never the same tube for more than two consecutive trials.

Data analysis

The same choosing and looking measures were obtained. A research assistant coded 20% of the sessions live to assess the inter-observer reliability of the children's looking behavior. Inter-observer reliability was excellent (Cohen's $\kappa=0.95$).

Results

Choosing behavior

All children chose a tube in every trial. Children performed above chance (33.3%) in all experimental conditions ($t>3.49$, $df=11$, $P<0.01$ in all cases, mean percent correct: seen=97.4%, unseen-immediate=68.3%, unseen-delayed=76.4%). A repeated-measures ANOVA on the percentage of correct responses revealed significant dif-

ferences across conditions, $F_{(2, 22)}=6.41$, $P<0.01$. As predicted, children were significantly more successful in the seen condition compared to either the unseen immediate ($t=2.89$, $df=11$, $P<0.01$) or the unseen delayed conditions ($t=2.21$, $df=11$, $P<0.05$). Moreover, children were also significantly more successful in the delayed compared to the immediate condition ($t=1.83$, $df=11$, $P<0.05$). Individual analyses showed that 12, 6, and 9 children performed above chance (33.3%, binomial tests: $P<0.05$) in the seen, unseen immediate, and unseen delayed conditions, respectively.

Looking behavior

Figure 10 presents the percentage of trials in which children looked into the tube(s) in each of the three experimental conditions. There were significant differences across conditions, $F_{(2, 22)}=6.86$, $P<0.01$. As predicted, children looked significantly less often in the seen condition compared to the unseen immediate ($t=2.60$, $df=11$, $P<0.05$) or the unseen delayed condition ($t=2.93$, $df=11$, $P<0.01$). There was no significant difference between the immediate and the delayed conditions ($t=1.04$, $df=11$, $P=0.16$). Seven of the ten children who looked inside the tubes in the unseen condition did so in the 1st unseen trial. Three other children looked for the first time in unseen trials 2, 3, and 8, respectively. Thereafter seven subjects continued to look regularly into the tubes when they had not witnessed the baiting procedure.

As expected, the frequency of looking behavior was related to the percentage of correct trials in both the unseen immediate ($r=0.73$, $P<0.01$, $n=12$) and the unseen delayed condition ($r=0.78$, $P<0.01$, $n=12$) but not in the seen condition ($r=-0.32$, $P=1.0$, $n=12$). The relation between looking and succeeding was further confirmed by investigating the trials in the unseen condition. Children were significantly more successful ($t=2.97$, $df=5$, $P<0.05$) when they looked (mean success=97.3%, SEM=2.7) than when they did not (mean success=30.2%, SEM=12.8).
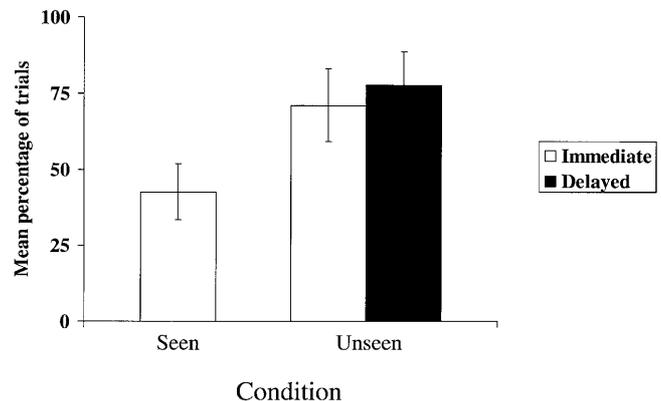

Fig. 10 Experiment 3: the percentage of trials in which subjects looked into the tube(s) as a function of baiting procedure and delay
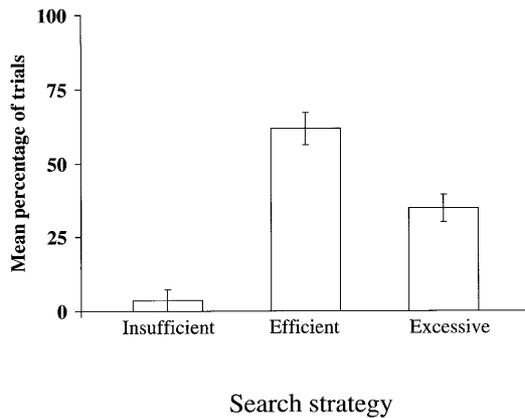
Fig. 11 Experiment 3: the percentage of trials in which each search pattern was used during unseen trials

Type of tube configuration encountered

Fig. 12 Experiment 3: the percentage of trials in which subjects chose a tube as a function of the tube configuration encountered with their first looks

Search patterns

Figure 11 presents the percentage of trials in which each of the search patterns was used by children during unseen trials. Only those trials in which children looked at least once were included in this analysis. There were significant differences in the percentage of trials for each search pattern, $F_{(2, 18)}$=40.20, p <0.001. Children used efficient (t=12.9, df=9, P<0.001) and excessive (t=4.65, df=9, P<0.01) searches significantly more often than insufficient ones. Moreover, children used efficient searches significantly more often than excessive searches (t=3.45, df=9, P<0.01). Seven children mostly used an efficient strategy whereas three used the efficient and excessive strategies equally often.

We also investigated to what extent excessive searches were exhaustive and systematic. Children used exhaustive and systematic searches in 91.7% (SEM=4.3) of the trials (mostly represented by searches of the type Empty-Empty′-Reward). Of the remaining trials 5% (SEM=3.3) were exhaustive and non-systematic (e.g., EE′ER), and 3.3% (SEM=3.3) of the trials were non-exhaustive and non-systematic (e.g., RER).

Another aspect of the searches besides whether or not they were efficient, exhaustive, or systematic is what determined the termination of the search and led children to select one of the tubes. Children could encounter two different tube configurations: empty and baited. Figure 12 presents the percentage of trials in which children made a selection as a function of the type of tube configuration encountered. After their first look, children terminated their search significantly more often upon encountering a baited tube compared to an empty one (t=20.4, df=9, P<0.001). An analysis of the individual strategies indicated that all children except one on one occasion always terminated their search upon finding the reward but continued searching upon finding an empty tube. This one child terminated her search upon finding the reward, but after finding an empty tube she continued to search in only half of the trials, otherwise choosing one of the other tubes.
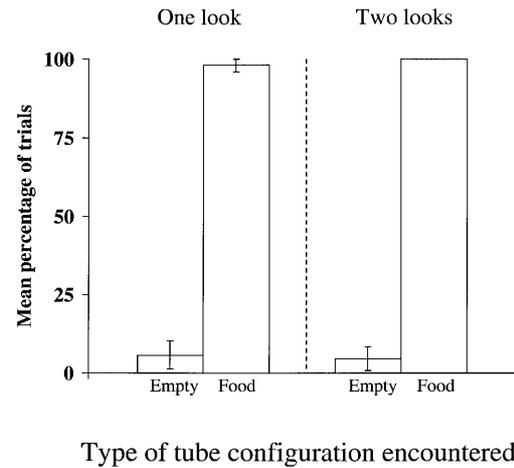
Similarly, after encountering an empty tube after their first look and then looking again, children terminated their search significantly more often upon encountering a baited tube with their second look than upon encountering a second empty tube (t=25.0, df=8, P<0.001). There were not enough trials to investigate which location was selected by children as a function of the type of tube configuration encountered since children rarely made a choice after only finding empty tubes. Instead, they continued to search until they found the baited tube.

Finally, we looked at those trials in which subjects inferred the location of the food without having seen it. In trials in which subjects saw empty tubes with their first two looks, subjects chose the baited tube without looking into it first in 4.6% of trials (two of the ten individuals who encountered this situation did this at least once).

Discussion

Children looked more when they had not witnessed the placement of the sticker and obtained more rewards if they looked into the tubes before choosing. Adding a delay between the baiting and selection phases increased their looking behavior slightly, but not significantly. Most children's searches were efficient and were guided by locating the reward. Upon finding the sticker, children stopped; otherwise they continued searching. Most excessive searches resulted from searching the third tube after having found two empty ones. Children were less likely than apes to stop searching after finding one or two empty tubes. Therefore, we found little evidence that children at this age inferred the location of the reward after finding two empty containers, although, like apes, they engaged in exhaustive and systematic searches.

General discussion

We placed apes and children in a situation of uncertainty by asking them to choose the location of a reward when they did not know where it was (in unseen trials). There is an extensive literature on metacognition that shows that humans respond to uncertainty by either escaping from those situations or seeking information. The only studies of this in nonhuman animals are those of Smith et al. (1995, 1997) who used escape responses to study metacognition. These researchers tested dolphins and rhesus monkeys on a discrimination task in which animals could choose one of two discrimination responses or an "escape" response that terminated the current trial and started a new, easier one. They found that dolphins and monkeys, like adult humans, used this escape response on trials in which the discrimination was very difficult, suggesting that they knew when they were uncertain.

In the current study we showed that apes (and 2-year-old children) could also seek information when they were uncertain. All subjects except three chimpanzees and two children spontaneously looked into the tubes before choosing one in at least some trials, especially in those trials when they had not seen where the reward was hidden. Moreover, some subjects who did not initially look into the tubes acquired this response suddenly, and once they started looking into the tubes they continued to do so (at least occasionally) for the remaining trials. The sudden appearance of this looking response is consistent with insight learning, which has been observed in other problem-solving situations (Köhler 1925; Sternberg and Davidson 1995). Alternatively, this sudden appearance may have been the result of rapid associative learning. At this point, we cannot determine which one of these two alternatives is correct. Nevertheless, this pattern of acquisition is inconsistent with trial-and-error learning because there was not a gradual shift in performance.

The results of this study are consistent with the hypothesis that subjects knew when they did not know where the reward was, and that, when necessary, they could act to obtain this knowledge. However, there are at least two alternative explanations of the results. One is that perhaps subjects did not have any metacognitive knowledge at all but instead learned associations that allowed them to make the correct choices.[1] That is, either during the course of the experiment or by generalizing from past experiences subjects learned to look or learned to choose without looking when it was appropriate to do so. For instance, it is possible that subjects had simply learned that the bait would be in the last tube if the first tube(s) were empty. In this case, however, this would be a very difficult association to learn because it involves both a compound conditional cue (i.e., if the first two tubes are empty then the third tube is baited) and a spatially incompatible response (i.e., choose the tube that is not associated with the cue).

Another possible interpretation of these results is that subjects knew not what they knew but instead what they had seen. This, by the way, is a possible alternative explanation of many previous seeing-knowing studies (e.g., Povinelli et al. 1990; Call et al. 2000; Hare et al. 2000). That is, an understanding of others' *knowledge* is not needed to solve these problems. Instead, subjects can use an understanding just of others' seeing, a much less demanding mental state. In the current study, one indication that at least some apes' understanding may go beyond seeing is their use of the extra-efficient search pattern. We found that 7 apes (47%) sometimes correctly chose the tube with food in it without looking into that tube first – that is, they were able correctly to infer the location of the food based on the contents of the first tube(s) they looked into. If apes can choose the correct tube without having seen its contents, perhaps this is an indication that they are using more than what they have seen – instead, what they know – to find the food. This type of inference is reminiscent of the ability of apes and children to solve invisible displacements in object permanence tasks (Natale et al. 1986; de Blois et al. 1998; Call, in press). In those studies subjects have to infer the location of a reward based on the trajectory followed by a container in which the reward has been deposited.

It is true that the use of this extra-efficient strategy was relatively uncommon. However, this probably was not an ideal situation for finding these inferences because apes and children incurred few costs associated with looking into extra tubes. Even adult humans occasionally engage in this type of illogical, unnecessary behavior, yet most researchers would credit them with metacognition. For example, when packing for a trip, one packs one's plane ticket and passport but then before leaving for the airport one usually double-checks to make sure one has both items, even though logically one knows that they must still be in the place where one left them. In this situation and in the current study, we think a cost-benefit analysis is probably involved – the costs of checking are low and the benefits are potentially high. Future studies in which the costs of searching all available locations are increased (e.g., by increasing the distance between the tubes) would be helpful as this may encourage subjects to make some inferences. On the other hand it would also be interesting to see whether subjects increase their unnecessary looks when the benefits are increased (e.g., by increasing the amount of food) and the costs of looking remain low.

The current results give rise to other questions as well. The most interesting of these questions involves the development of the ability to spontaneously look into the tubes. This question has implications for theories of the development of mental attribution. One influential theory, the simulation theory, posits that children (or animals) understand their own mental states before those of others. Another influential theory, the theory theory, posits that mental states are understood in self and other at the same time, once a theory of the given mental state is constructed (see, e.g., Davies and Stone 1995, for more discussion of both these theories). If children (and apes)

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[1] We thank an anonymous reviewer for this suggestion.

show evidence of an understanding of the seeing-knowing link in themselves before they show evidence of an understanding of this link in others, that would support the simulation view, whereas if they show each type of understanding at the same time, that would support the theory theory view. There is one previous study that found that children were better at assessing their own knowledge than that of others (Wimmer et al. 1988). This would support the simulation view that this understanding in the self may be a precursor – and a trigger – for this understanding in others. More systematic studies of seeing and knowing in self and other are needed within the same subjects.

We would also predict an interesting developmental pattern of success and failure on this task with children (but not with apes). It is possible that young infants do not look into the tubes (because they do not understand the link between seeing and knowing, and/or because they do not have privileged access to their knowledge states), older infants do look into the tubes (because they have this understanding and/or access), and then there comes a point when children stop looking. We expect that older children would be aware of social prohibitions against "cheating" and would not dare to peek into the tubes.

Another interesting finding in the current study was the finding of increased looking in the delayed as compared with the immediate conditions. For apes (but not to the same extent for children), we found that preventing subjects from immediately choosing one of the alternatives enhanced their looking behavior, and hence, their success. It is likely that apes were more successful in the delayed situation because they did not have to inhibit the powerful responses elicited by the prospect of getting the reward (Boysen and Berntson 1995; Boysen et al. 1996). It is interesting that children did not have much of a problem with this type of inhibition.

In conclusion, children and apes sought information about the location of a reward to reduce uncertainty, and they did so preferentially when they were prevented from visual access to the baiting procedure. Moreover, there was some evidence that some subjects were capable of extra-efficient search strategies, which consisted of selecting a tube without inspecting it after having found the alternative tube(s) empty. This suggests that subjects were capable of inferring the location of the food after having found an empty tube, and may indicate evidence of meta-knowledge in apes. Finally, the procedure that we used in this study to investigate metacognition in nonhuman animals complements the escape method used by Smith et al. (1995, 1997) with dolphins and rhesus monkeys. These two complementary procedures can be viewed as possible alternatives to the mirror self-recognition tasks that currently dominate the research on self concept in primates and other animals (see Parker et al. 1994). While mirror self-recognition tasks may merely involve some form of understanding of one own's body, these other tasks may involve understanding of at least one's own perception, and perhaps one's own knowledge.

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