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Orangutans (*Pongo pygmaeus pygmaeus*) and children (*Homo sapiens*) use stick tools in a puzzle box task involving semantic prospection

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This study compared three captive orangutans and a group of 5-10 year-old children in their ability to use stick tools to solve a series of mazes in a puzzle box, including three puzzles that required semantic prospection. The puzzle box had seven levels and moveable plastic inserts that created three easy, three intermediate, and three difficult maze configurations. Three wood and three plastic stick tools were presented with each maze. All 26 children immediately solved the easy and intermediate mazes. Seventy-nine percent of the children solved the difficult mazes on their first attempt, and nearly all the children solved the difficult mazes on the second attempt, which suggested a majority of children engaged in effective planning. Girls took significantly longer to solve the intermediate mazes while boys took significantly longer to solve the difficult mazes. Two of three orangutans also successfully avoided the dead ends in the difficult mazes and consistently used stick tools to move peanuts to the goal slots, and took longer to solve the intermediate or difficult mazes. Both the children and orangutans preferred to use plastic tools, although both tool types were functional. These results suggest many similarities between orangutans and children in their ability to use tools in a puzzle box task that requires planning to avoid dead ends.

Tool use can be defined as the action of using an agent to achieve a goal (Kuba, Byrne, & Burghardt, 2010). There has been a recent surge of interest in tool use abilities in both terrestrial and aquatic animals (e.g., Bird & Emery, 2009; Deecke, 2012; Furlong, Boose, & Boysen, 2007; Grindt, Meier, & Call, 2008; Grueter, Robbins, Ndagijimana, & Stoinski, 2013; Kuba et al., 2010; Mann et al., 2008; Millot et al., 2014; Mulcahy & Shubiger, 2014; Visalberghi & Mason, 2008; Wimpenny, Weir, & Kacelnik, 2011). However, few studies have examined the ability of animals to plan ahead while solving a tool use problem. Semantic prospection is the ability to think about and plan for the future without the autonoetic sense of personally experiencing the event (Raby & Clayton, 2009). Planning for the future can be vital to the survival of a species and includes both long-term planning (e.g., saving enough food to survive the winter) or temporary means-end goals (e.g., planning how to extract food from a tree or termite mound over the course of several minutes). There is a lot of research on the ability of animals to store and cache food for days, weeks, or months in the future (e.g., Clayton, Bussey, & Dickinson, 2003; Dally, Emery, & Clayton, 2006; Smith & Reichman, 1984), but less work on animals planning for short-term goals. One way of examining the ability to plan for a short-term goal is to test complex problem solving and tool use in a foraging task. The ability to carefully plan one's actions to avoid traps and dead ends shows semantic prospection. The current study examines the ability of children (*Homo sapiens*) and orangutans (*Pongo pygmaeus pygmaeus*) to use stick tools in a maze task and utilize planning to avoid dead ends in multiple mazes.

Humans show considerable cognitive abilities in the areas of tool use, language, and planning. Nine month olds readily grasp and use tools to achieve goals (Claxton, McCarty, & Keen, 2009; McCarty, Clifton, & Collard, 2001) and children have a flexibility and causal understanding of the purpose of tools in problem solving tasks (e.g., Elsner & Schellhas, 2012; Fitzpatrick, Wagman, & Schmidt, 2012; Nagell, Olguin, & Tomasello, 1993; Seed & Call, 2014). Further, children as young as 2-3 years of age can actively plan their

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actions and readily adapt to situations in order to solve a task using tools (Cox & Smitsman, 2006). Mayer, Call, Albiach-Serrano, Visalberghi, Sabbatini, and Seed (2014) tested children and primate species on a standard broken string problem as well as one where functional cues were hidden and replaced with nonfunctional cues. Results suggest that children and primates rely on abstract concepts, such as function, to solve the broken string problem. Nagell et al. (1993) demonstrated tool use in children and chimpanzees by presenting a desirable object out of their reach thereby forcing them to use a tool to reach it. They found that both species had higher performance when they watched someone demonstrate how to use a tool to reach an object than when they had to use trial and error to solve the problem. Want and Harris (2001) also examined tool use and showed that 3-year-old children can determine the most effective solution when comparing a correct and incorrect solution (unlike 2-year-olds) suggesting a causal understanding. Further, 2-year-old children could only complete part of a solution via imitating an experimenter, but 3-year-olds could easily copy the solution. This suggests that problem solving and tool use abilities develop with age (Want & Harris, 2001).

Being able to plan specific actions to solve a problem requires a certain degree of future thinking and an understanding of the task. Cox and Smitsan (2006) tested 2- and 3-year-old children on their ability to use different tools (stick tool or cane) at varying starting locations to reach a target object. They revealed that children could flexibly change the hand they were grasping the tool with depending on the demands of the task. Older children also had more dexterity in movements and Cox and Smitsan (2006) concluded that older children are better at planning on a short-term scale when they need to integrate multiple cues simultaneously. Some studies even compare tool use and problem solving when planning is required. Using a paddle-box task, Tecwyn, Thorpe, and Chappell (2014) tested children ages 4 to 10 yr in two tasks with a paddle-box task, one requiring sequential planning and one with advanced planning. They revealed that younger children had more extraneous actions than older children. Further, reducing the cognitive demands necessary to engage in inhibitory behaviors did not improve performance for any of the children in the advanced planning task. While these results suggest children can effectively plan in a sequential step-by-step manner and in advance of an action, the amount of action inhibition necessary does not reduce performance. Tecwyn et al. (2014) also demonstrated that younger children are more likely to use too many steps to solve a problem when planning out their actions compared with older children. However, the preliminary findings in Tecwyn et al. (2014) imply that children as young as 4 years of age can plan a series of simple actions to solve a problem, even if it is not the most optimal solution. What remains unclear is the extent to which non-human primates can plan their actions in avoidance of negative outcomes during a short-term problem-solving task involving tool use.

Orangutans have demonstrated the use of tools repeatedly in the wild and in captivity. Tools are used and created for foraging tasks in the wild (e.g., Galdikas, 1982; van Schaik, Fox, & Sitompul, 1996; van Schaik & Knott, 2001). In captivity, orangutans have demonstrated tool use in a wide range of contexts from selecting a key to open a box (Lethmate, 1982) to using water as a tool to raise a peanut within their reach (Mendes, Hanus, & Call, 2007). Orangutans can even modify pre-existing tools to create straws (Manrique & Call, 2011) or to extract raisins from a wood block (O'Malley & McGrew, 2000). These animals have solved various tasks also presented to chimpanzees and bonobos such as the trap tube task (e.g., Mulcahy & Call, 2006b) and can even infer functionality of tools thereby aiding in their ability to solve problems (e.g., Osvath & Osvath, 2008; Mulcahy & Schubinger, 2014; Walkup, Shumaker, & Pruetz, 2010). Osvath and Osvath's (2008) task demonstrated that the orangutans can choose a functional tool (a plastic hose), but they could plan ahead to use the hose almost 70 minutes before they were able to use the tool to retrieve the reward.

Orangutans can effectively use stick tools held in their hands or mouths. O'Malley and McGrew (2000) found that captive orangutans modified and used stick tools (made of bamboo, wood sticks, or straw) to extract raisins from a wood block. Five subjects showed a strong preference for holding the tools with their mouths (like the wild orangutans observed by van Schaik et al., 1996), one subject preferred hand-held tools, and two subjects showed an equal preference for manual and oral tool manipulation. Mulcahy and Call (2006b) presented chimpanzees, bonobos, orangutans, and a gorilla with a modified trap-tube task to push or rake a food reward using a wood dowel. All but one subject preferred to rake the food towards them, and two orangutans and one chimpanzee solved the modified trap-tube task but failed the original task (push only). Walkup et al. (2010) studied three adult orangutans and their ability to reach a food reward by using a stick tool to open a door. Walkup et al. (2010) also tested the animals' ability to understand functionality, specifically whether the tool was sturdy enough to complete the task. All three participants chose the functional tool significantly more often than the nonfunctional tool (willow branches, firehoses, PVC pipes). Mulcahy and Schubinger (2014) presented four orangutans with a task in which they had to skewer a grape reward with a stick tool. The orangutans preferred to choose a continuous tool to one that was broken when the properties could be inferred from each tool's configuration. Both Mulcahy and Schubinger's (2014) study and Walkup et al.'s (2010) study suggest that orangutans may have the ability to infer tool functionality. Further, Völter and Call (2012) demonstrated that while orangutans can solve puzzle boxes without viewing the functional mechanisms of the puzzle box, solution time decreases significantly when able to view the mechanisms.

While studies have shown both orangutans and young children have the ability to use a variety of tools (e.g., Fitzpatrick et al., 2012; Gredlein & Bjorklund, 2005; Nagell et al., 1993), very few studies (e.g., Hanus, Mendes, Tennie, & Call, 2011) have directly compared their tool use abilities using the same task. Hanus et al. (2011) used the same methodology used as Mendes et al. (2007) study that tested the ability of orangutans to solve a floating peanut problem, but tested chimpanzees, gorillas, and human children of various ages (4, 6, and 8-year-olds) in the same task. Comparing the two studies, Hanus et al. (2011) determined that both orangutans and chimpanzees performed better than 4-year-old children, but worse than 6- and 8-year-old children. Furthermore, how children and orangutans compare when they must plan their moves on a short-term basis has rarely been studied. In fact, only a few studies have shown semantic prospection in orangutans.

Orangutans have been observed creating tools in the wild for later use in foraging tasks (Seed & Byrne, 2010) and several studies have developed around this concept. Bourjade, Call, Pepe, Maumy and Dufour (2014) demonstrated that orangutans and bonobos can adjust their planning strategy based on the context. The species were trained that tokens collected in one room could be exchanged for food rewards in a different room, but only in a specific exchange condition. Both the orangutans and the bonobos could identify when they were in the exchange condition and collect more tokens than when they were in the release condition. Surprisingly, chimpanzees tested on the same task could not adjust their planning (token collection) according to the experimental condition they were in. To see what kind of strategies orangutans might be using to solve a puzzle-tube task, Tecwyn, Thorpe and Chappell (2011) manipulated the rules available for solution of the task across 64 trials. Two of three orangutans solved the task which suggests the orangutans could understand the constraints of the task and alter their behavior appropriately, suggesting they may be planning their actions. As a follow up to that study, Tecwyn, Thorpe and Chappell (2013) tested orangutans and bonobos on the same sequential versus advanced planning setup on the paddle-box task tested by Tecwyn et al. (2014) with children. The apes failed to solve the task when advanced planning was required and this failure was attributed to their inability to inhibit behaviors. However, both the orangutans and bonobos were able to solve the task when they could solve the task step-by-step. While these results definitely demonstrate some degree of planning by orangutans, none of these studies compared orangutans to children within the same task. Völter and Call (2014) saw this shortcoming of the previous research and directly compared 4- and 5-year-old children with bonobos, chimpanzees, a gorilla, and two orangutans on the same maze task. In this task, all of the subjects had to move a food reward down through the different levels of a maze while avoiding traps. Their maze only had three levels with a total of 10 gaps across the three levels. The subjects could access the levels (and thereby move the food reward down through the levels) by inserting their finger through slots in the acrylic glass. Their initial experiment contained tree traps where the subjects could get the food reward stuck. It is important to note that the placement of these traps ensured that planning was only required for the moves on each level, the animals did not need to plan all of their moves before starting a trial. Völter and Call (2014) found that when planning in advance of a level was not necessary, the children avoided the traps better than the apes. They also found an age effect within the apes, where apes less than 20 could plan ahead (just like 5-year-old children) while older apes and younger children could not plan ahead. This suggests that as age increases in apes, the planning ability in problem solving tasks declines. This age-related decline in planning was seen in all of the species of apes except the gorilla, who could not solve the task although she was under the age of 20. However, there were only two orangutans (one over 20 and one below 20) tested in Völter and Call's (2014) study. While this study presented interesting results, it needed to be replicated using different puzzle boxes and testing different animals.

To investigate semantic prospection in a tool use context, we compared the abilities of 5- to 10-year old children and orangutans (ages 9, 13, and 35) in a problem solving task requiring future planning to avoid dead ends. We tested children ages 5-10 years old because most problem solving research (e.g., Buttleman, Carpenter, Call, & Tomasello, 2008; Gredlein & Bjorklund, 2005; Völter & Call, 2014) have tested children 5 years old and younger, but there is evidence that there are differences in performance in older children especially where planning is required (e.g., Völter & Call, 2014). For example, Tecwyn et al. (2014) revealed age related differences in a problem solving tasks requiring different types of planning in children 4-10 years of age. Orangutans were tested because of their extensive tool use abilities (e.g., Buttleman et al., 2008; Galdikas, 1982; Grindt et al., 2008; Manrique & Call, 2011; Mendes et al., 2007; Mulcahy, Call, & Dunbar, 2005), and the recent findings by Bourjade et al. (2014) that demonstrated orangutans could plan to collect tokens to use in a future task based on the context of the task, but chimpanzees could not. We wanted to continue to explore the planning abilities of orangutans in a task that requires a different kind of cognitive challenge – dead ends requiring flexible planning in advance of solving the maze.

We tested nine maze configurations (three easy, three intermediate, and three difficult mazes). Easy mazes contained seven walls to navigate around, and intermediate and difficult mazes each contained 13 walls. In addition, the difficult mazes all contained two *dead ends* one which was a functional trap (which ended the trial and prevented individual from finishing the task) and the other which was not. The subjects needed to plan their moves carefully to avoid the dead ends and retrieve the marble (children) or food reward (orangutans) from specified goal slots in the maze. The subjects had to move the marble or food reward through the mazes using rigid tools. Both species were given wood and plastic stick tools to test the effect of material functionality and familiarity on tool choice and performance. While both tools were functional, the orangutans had a history of breaking wood sticks during other enrichment activities, so they may have viewed the wood sticks as less functional than other rigid tools. The wood sticks were familiar to the orangutans because they had access to wood sticks in their outdoor enclosure and used them in other problem-solving tasks, but the plastic tools were novel because they had no access to plastic dowels prior to the current study. Research also suggests that captive orangutans are more likely to seek out novelty and be exploratory than wild orangutans (e.g., Forss, Schuppli, Haiden, Zweifel, & van Shaik, 2015) so the novel plastic tools may have been more appealing to the orangutans. The children were very likely to have used wood sticks but they may not have used plastic dowels of this size prior to the study. Presumably the children, like the orangutans, had experience breaking wood sticks during play or other activities prior to the study.

This study provided an opportunity to compare children and orangutans on performance accuracy, solution time, tool preferences, and the ability to flexibly plan strategies according to feedback (i.e., hitting a dead end). Unlike Völter and Call (2014), our maze incorporated seven levels and required subjects to plan their moves in advance of a level or have their marble or peanut be trapped in a dead end. Furthermore, our maze required the use of tools to solve and incorporated both functional (trap) and non-functional (looks like a trap) dead ends. We hypothesized that all of the subjects would successfully solve the easy and intermediate mazes (that do not include dead ends), and solution time would increase with maze complexity because they needed to navigate around more visible barriers in intermediate and difficult mazes compared to easy mazes. We predicted that both the children and orangutans would succeed in solving the difficult mazes, although more than one trial may be needed so they could learn the effect of pushing the marble or peanut into a dead end and plan accordingly on the next trial. Both children and orangutans have shown the ability to plan to avoid dead ends in other tasks (e.g., Tecwyn et al., 2013, 2014). Additionally, on the difficult mazes we predicted that younger children would hit more dead ends on their first attempt to solve the maze and have more unnecessary movements than older children (i.e., Tecwyn et al., 2014). Although previous research suggests an age effect on animals' abilities to solve a task (Völter & Call, 2014), we do not expect an age effect as the older orangutan, Kumang, has extensive experience solving similar upright maze puzzles. We also predict that the children and the orangutans would take the longest time to complete the difficult mazes compared to the intermediate and easy mazes because they had to negotiate dead ends in the difficult mazes.

Experiment 1

Experiment 1 compared the tool use abilities of 26 children ages ranging in age from 5-10 years of age. Children had to move a marble down through the levels of a maze apparatus using a tool for nine different mazes. The mazes were separated into easy (3), intermediate (3), and difficult mazes (3) and were presented in sequential order. The difficult mazes tested involved both a functional (trap) and a nonfunctional (no trap) dead ends. In order to solve the difficult mazes, the children had to appropriately plan their moves to avoid the functional dead ends. If unsuccessful, children were given a second attempt to solve the difficult mazes.

Method

Participants

Twenty-six children (13 girls, 13 boys) enrolled in a summer program at Margaret's House Early Childhood Center at Rochester Institute of Technology were tested. Participants included three 5-year olds, nine 6-year olds, four 7-year olds, five 8-year olds, two 9-year olds, and three 10-year olds (*M* = 7.1 yrs, *SD* = 1.6 yrs). Forty-six percent were entering 1st grade, 11.5% were entering 2nd grade, 23.1% were entering 3rd grade, 7.7% were entering 4th grade, and 11.5% were entering 5th grade in the fall. As incentive for participation, the children were given the choice between three food rewards; Craisins (chosen by 11.5% of the participants), plain M&Ms (57.7%), and organic gummy fruit snacks (30.8%). The children consumed one packet of snacks during the experiment, and were allowed to choose a second packet of snacks and a sticker following the completion of the study. This experiment was approved by the Rochester Institute of Technology Institutional Review Board.

Apparatus

The mazes were presented via a 30.5 cm × 15.2 cm × 5.1 cm polycarbonate box (Puzzle-Feeder Product #1EPF00, Primate Products, Inc.; Figure 1a). The goal of the seven-level maze apparatus was to move a flat-bottomed marble (2.0 cm in diameter and 0.5 cm high) placed in the top level through the different levels down to the seventh level where the marble could be extracted. The top six levels contained four slots (4.0 cm × 1.5 cm) which allowed a tool or a finger to move a food reward or object horizontally across a level. The upper-level slots could be accessed by either a tool or finger by design, so we could assess whether the participant chose to use a tool on instead inserted a finger. The seventh (bottom) level contained two larger slots (4.3 cm × 3.0 cm) that allowed the reward or object to be easily removed by manual gripping. We defined a successful solution as moving a marble with a stick tool (not a finger) from the starting box down to one of the goal slots (slot 7b or 7c), followed by removing the marble from a goal slot using either fingers or a tool.

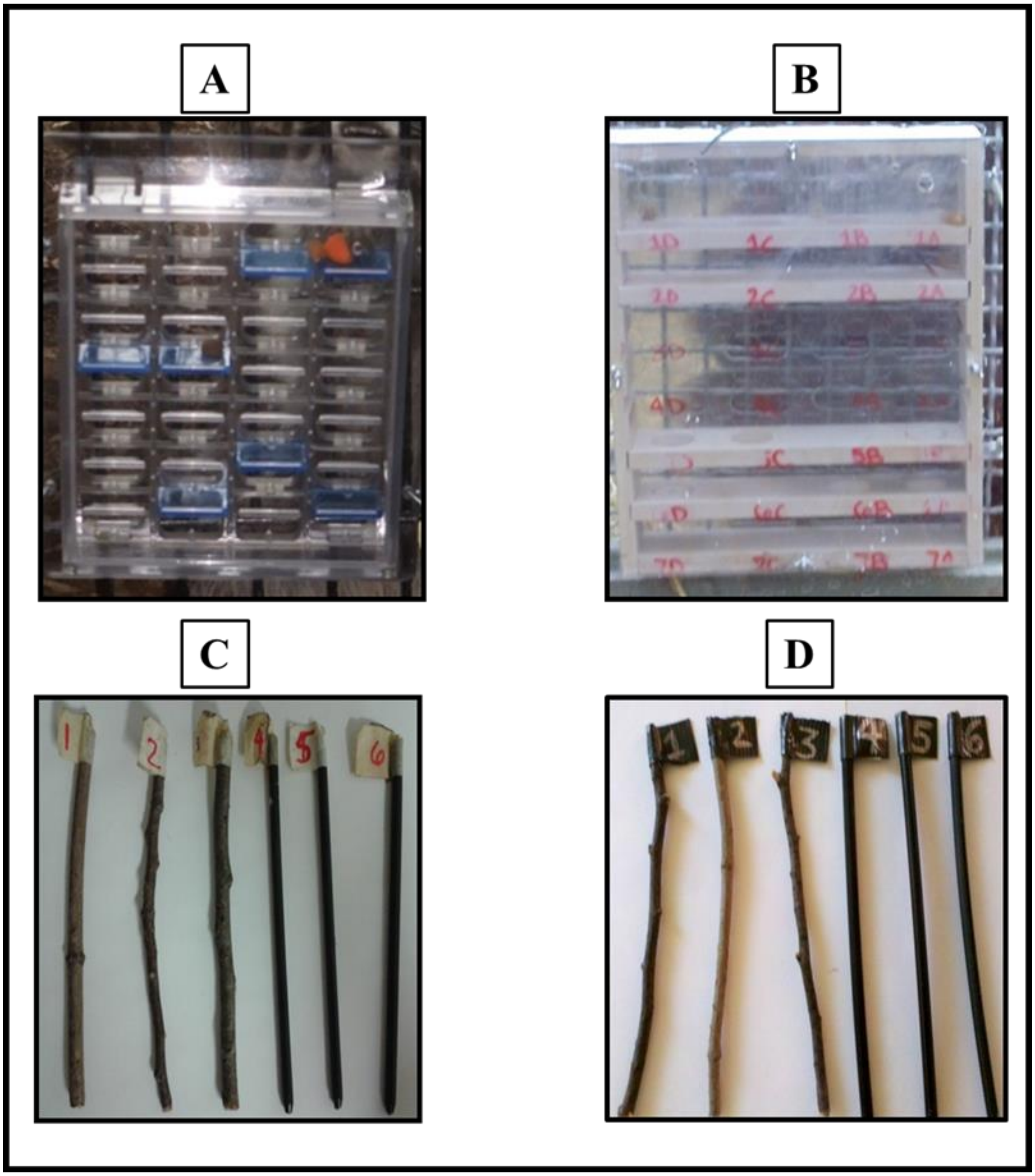

Figure 1. **Apparatus and tools for the two experiments.** Figure 1a depicts the puzzle box apparatus which was used in Experiment 1 with children. Figure 1b depicts the custom-built puzzle box which was used for Experiment 2 with the orangutans. Figure 1c shows the 15.2 cm tools used in Experiment 1. Figure 1d shows the 22.9 cm tools used in Experiment 2.

Three maze configurations were used for each level of complexity: easy, intermediate, and difficult for a total of nine maze configurations (see Figure 2). The maze configuration could be altered using blue plastic pieces (4.75 cm wide × 2.54 cm long × 0.32 cm thick) to create horizontal barriers and red plastic pieces (2.86 cm wide × 2.86 cm long × 0.32 cm thick) to create vertical barriers. Easy level mazes were configured using a total of seven blue plastic pieces, while the intermediate and difficult mazes were configured using a total of 13 blue plastic pieces. Thus, the easy mazes contained more open space, which required the children to maneuver the

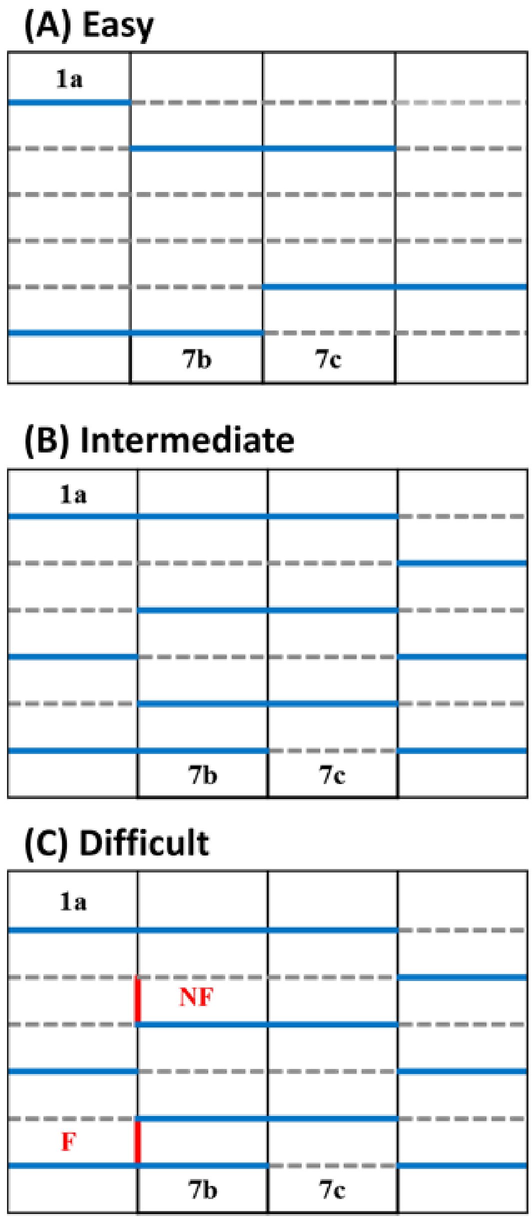

Figure 2. **Examples of maze configurations for all three maze complexity levels.** A successful solution involved moving the marble or food item with a stick tool, starting at slot 1a, down through the levels until it could be removed from slots 7b or 7c. Dotted lines indicate where an opening in a level of the maze. Figure 2a depicts an easy maze with only seven blue plastic pieces. Figure 2b depicts an intermediate maze with 13 blue pieces. Figure 2c depicts a difficult maze with the same number of blue pieces as an intermediate maze (13), but with two additional red plastic pieces, one that led to a dead end. The non-functional dead end is indicated by **NF** and the functional dead end is indicated by **F**.

stick tool into fewer maze slots to reach the goal box. The intermediate and difficult mazes contained the same number and configuration of blue pieces, but the difficult mazes additionally contained two vertical red pieces. The red pieces were used to create *dead ends*, locations from which the goal box could not be reached, which required participants to plan their path. The maze apparatus was presented upright, resting on a table (see Figure 1A) with six tools (0.64 cm diameter × 12.7 cm long), numbered 1-6, on each trial. The tools were either wood (prepared tree branches) or plastic (identical solid, black, plastic dowels) as seen in Figure 1C. The tools were numbered 1 through 6 and were displayed in increasing numerical order with 1 on the far left and 6 on the far right.

Procedure

Participants were tested individually in the afternoon by a single experimenter in the library at RIT's Margaret House over a two week period. The children received verbal instructions explaining the goal of the puzzle and how to use the tools. Before the first maze, the experimenter explained how to hold the tools and how to use the tool to move the flat marble between the levels in the maze apparatus, but did not show the children a particular path to take to solve the first maze. Children were told to select a tool and to use the tool to move the marble down through the levels in order to remove the marble through one of the goal slots (7b or 7a). They were told that they could insert the tools in any of the slots. If they did not like the tool they chose, they could choose a new tool. Each child received the nine mazes in order starting with maze 1 (easy) and finishing with maze 9 (difficult). For each of the nine mazes, after the children maneuvered the flat-bottomed marble from the starting slot to one of the goal slots and extracted the marble with their fingers, they were allowed to eat one piece of their chosen food reward. If the child pushed the marble into a dead end the experimenter would say, "Uh oh! The marble is stuck. Would you like to try this maze again?" After the child agreed, the experimenter removed the marble and re-inserted it in the starting slot. The participants were only offered two attempts to solve each of the nine mazes.

After the completion of each maze, the experimenter asked the child why they had selected the particular tool(s) utilized on that maze. An inter-trial interval (approx. 2 min.) followed while the experimenter set up the next maze. During this time, the child read their choice of age-appropriate books. After the completion of all nine mazes, the experimenter verbally asked each participant items from a questionnaire. The questionnaire included demographic information and questions about why they chose specific tools overall and how they solved mazes with dead ends. The participants had the opportunity to solve all nine mazes in one experimental session which lasted between 22 and 35 min (M = 31.4, SD = 6.0).

Results

Accuracy

We defined a successful solution as moving a marble with a stick tool from the starting box down to one of the goal slots (slot 7b or 7c), followed by removing the marble from a goal slot using either fingers or a tool. Figure 3 shows the number of participants who solved each maze on their first attempt. All children solved both the easy (mazes 1, 2, 3) and intermediate mazes (mazes 4, 5, 6) on their first attempt. We expected ceiling effects, since there were no dead ends and the children simply needed to persevere to complete the mazes. Therefore, we only analyzed accuracy for the difficult mazes (mazes 7, 8, 9) because children could hit a dead end if they did not plan their moves (or through chance). The majority of the girls (M = 87%) and boys (M = 69%) solved the difficult mazes (mazes 7, 8, 9) on their first attempt. The children who did not solve the difficult mazes on their first attempt solved them on their second attempt (8 males ages 6, 8, and 9; 4 females ages 5, 6, and 8) except for one 6-year-old girl on maze 7 and one 6-year-old boy on maze 8 who both failed on their second attempt.

A 2 (gender) x 3 (maze number: 7, 8, 9) repeated measures analysis of variance (ANOVA) was conducted on the number of participants who solved each difficult maze on their first attempt (age was not used as a variable in any of the analyses since there were unequal numbers of children in each age category). There were no significant effects of gender, $F(1, 24) = 2.83$, $p = 0.11$, maze number, $F(2, 48) = 1.75$, $p = 0.18$, or an interaction between gender and maze number, $F(2, 48) = 0.65$, $p = 0.53$.

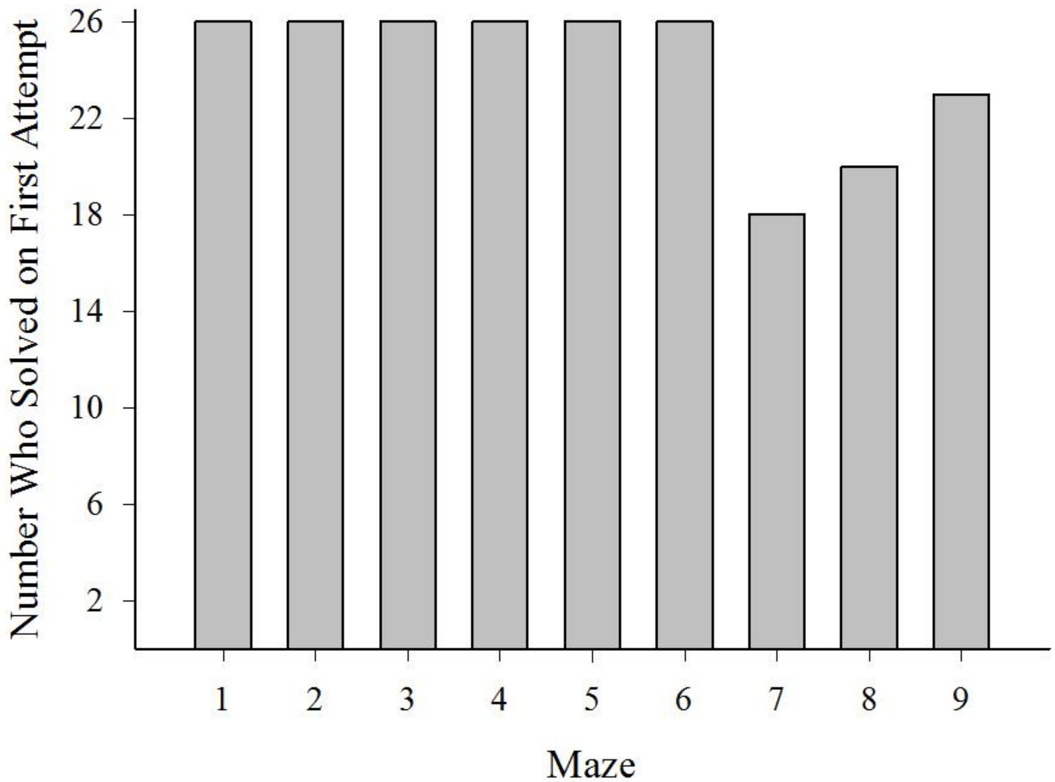

Figure 3. **Number of children who solved each maze on the first attempt (out of 26 children).** A correct or successful solution was when a child used a stick tool to move the marble down through the levels and remove it from one of the goal slots (7b or 7c). Mazes 1-3 were easy, mazes 4-6 were intermediate, and mazes 7-9 were difficult.

Error Analysis

We conducted an error analysis to see where the children made errors on the difficult mazes. The errors made by the children that took two attempts to solve each maze, or who never solved a maze, can be seen in Table 1. A fatal error was defined as a movement of the marble in a direction that ultimately resulted in the marble getting stuck in a functional dead end. For Maze 7 (the first difficult maze), eight children got stuck in the functional dead end on their first attempt and further analysis revealed six of those children seemed to make their fatal error on level 3 of the maze near the nonfunctional dead end. However, on their second attempt all except one child (female, age 6) were able to solve the maze, but that girl did not solve any of the difficult mazes.There was no consistent pattern in fatal errors for Maze 8. Two of the children never successfully solved maze 8 including the same female who did not solve any difficult mazes and a 6 year old boy. For Maze 9, all three participants made their fatal error in slot 2c (four levels above the functional dead end) and the marble proceeded to make its way down the other levels into the dead end.

Table 1

Fatal Errors on Difficult Mazes in Experiment 1

	Solved on 2nd Attempt		Never Solved		Location of Fatal Error				
Maze	# of Children	Mean Age	# of Children	Mean Age	Level 1	Level 2	Level 3	Level 4	Level 5
7	7.0	6.4	1.0*	6.0	1.0	2.0	2.0	2.0	0.0
8	5.0	7.4	2.0*	6.0	2.0	1.0	2.0	2.0	0.0
9	2.0	7.0	1.0*	6.0	0.0	1.0	1.0	1.0	0.0

Note. Numbers are out of 26 participants. An asterisk (*) next to a number indicates that the same female participant (age 6) failed to solve all three difficult mazes. The locations of functional dead ends were at slots 6a, 6d, and 6b for Mazes 7, 8, and 9, respectively. The nonfunctional dead ends were located at slots 3b, 2c, and 3b for Mazes 7, 8, and 9, respectively. The functional dead end trapped the marble, but the nonfunctional dead end did not.

Solution Time

Solution time was calculated from when the child first inserted a tool into the starting slot until they removed the marble from a goal slot, but if a child could not solve a maze the trial was stopped as soon as the marble hit a dead end. Solution time was only analyzed and presented for the children who solved the maze correctly on their first attempt. Figure 4a displays average solution times shown by gender for all nine mazes.

A 2 (gender) x 3 (maze level: easy, intermediate, difficult) x 3 (maze number: three mazes at each level of difficulty) repeated-measures ANOVA was conducted on the time it took for participants to solve each maze, with the last two factors as within-subjects variables. There was a significant interaction effect of difficulty exposure and gender, $F(2, 44) = 6.80$, $p < 0.01$, $\eta^2 = 0.021$. Girls took significantly longer to solve the intermediate mazes ($M = 22.07$ s; $SD = 10.95$) than the easy mazes ($M = 18.18$ s; $SD = 10.63$) and the difficult mazes ($M = 18.44$ s; $SD = 9.86$; *Newman*-Keuls tests, $p < 0.05$). For girls, there was no significant difference in solution time for easy versus difficult mazes. Boys took significantly longer to solve the difficult mazes ($M = 19.13$ s; $SD = 8.39$) than the easy ($M = 15.40$ s; $SD = 6.93$) and the intermediate mazes ($M = 17.21$s; $SD = 9.49$; Newman-Keuls tests, $p < 0.05$). For boys, there was no significant difference in solution time for easy and intermediate mazes.

There was a main effect of maze number, $F(2, 44) = 9.01$, $p < 0.001$, $\eta^2 = 0.041$. Participants took significantly less time to solve the second maze in each complexity level (mazes 2, 5, 8; $M = 16.03$ s; $SD = 8.22$) compared to the first maze in each complexity level (mazes 1, 4, 7; $M = 20.71$ s; $SD = 10.93$) and the third maze in each complexity level (mazes 3, 6, 9; $M = 18.78$ s; $SD = 18.92$; Newman-Keuls tests, $p < 0.05$). There was no significant difference between the first and third mazes at each complexity level (Newman-Keuls tests, $p < 0.05$). There was also a significant interaction effect of maze level and number, $F(4, 88) = 6.41$, $p < 0.001$, $\eta^2 = 0.049$. For the easy mazes, maze 1 ($M = 22.80$ s; $SD = 10.81$) took participants significantly longer than mazes 2 ($M = 13.57$ s; $SD = 6.55$) and 3 ($M = 14.95$ s; $SD = 6.53$), but there was no significant difference between mazes 2 and 3 (Newman-Keuls tests, $p < 0.05$). For the intermediate mazes, maze 5 ($M = 17.67$ s; $SD = 9.62$) took significantly less time than maze 6 ($M = 21.73$ s; $SD = 10.91$), but there was no significant difference between mazes 4 ($M = 19.53$ s; $SD = 10.83$) and 5 or between mazes 4 and 6 (Newman-Keuls tests, $p < 0.05$). For the difficult mazes, there were no significant differences between mazes 7 ($M = 19.76$ s; $SD = 11.26$), 8 ($M = 16.90$ s; $SD = 7.83$), or 9 ($M = 19.65$ s; $SD = 7.90$;Newman-Keuls tests, $p < 0.05$).

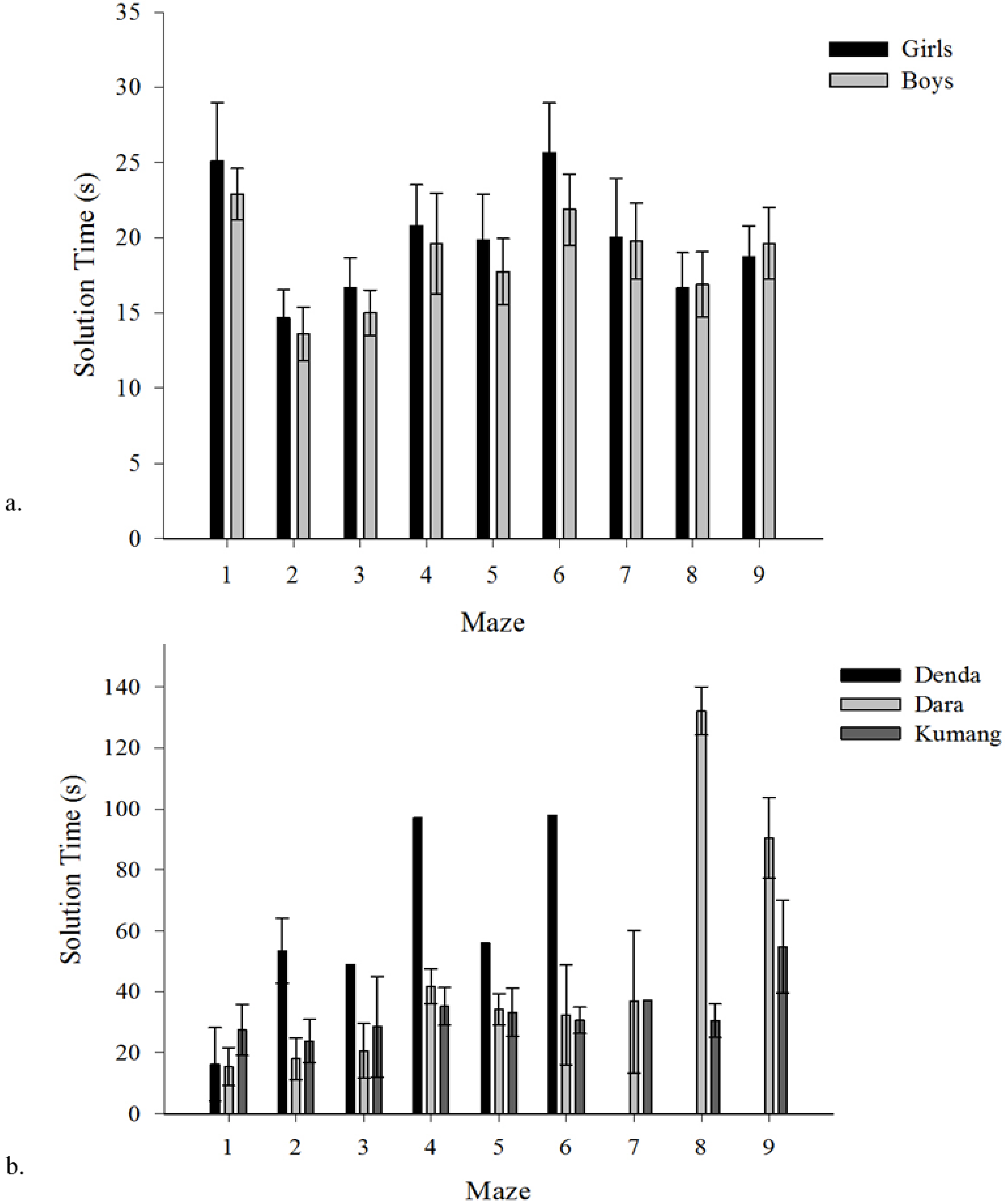

Figure 4. **Solution time shown by species.** Mazes 1-3 were easy, mazes 4-6 were intermediate difficulty, and mazes 7-9 were difficult. A successful solution was limited to instances where an orangutan used a stick tool to move the peanuts down through the levels and then removed the peanut from either slot 7b or 7c. Figure 4a depicts the solution time for children shown by gender. Figure 4b shows the solution time for each orangutan. Note that Denda did not solve the three difficult mazes, but he did eat all five peanuts on every test session. Also note that bars without error bars indicate an orangutan only solved the maze correctly on one of five attempts. Error bars show *SEM*.

Tool Use

Table 2 shows the proportion of children who selected each tool on each of the nine mazes. Overall, plastic tools were chosen more often (M = 59.9%) than wood tools (M = 40.1%). Plastic tools 4 and 6 were the most popular choices. Wood tool 2 was chosen least often overall. The children preferred plastic tools for seven of the nine mazes.

Table 2

Tool Choices by Children for Each Maze

	Wood			Plastic			Total	
Maze	1	2	3	4	5	6	Wood	Plastic
1	0.19	0.04	0.00	0.19	0.08	**0.50**	0.23	**0.77**
2	0.19	0.04	0.15	0.15	0.15	**0.32**	0.38	**0.62**
3	0.15	0.12	0.12	**0.27**	0.19	0.15	0.39	**0.61**
4	0.15	0.08	**0.27**	0.20	0.15	0.15	0.50	0.50
5	0.08	**0.27**	0.19	0.19	0.08	0.19	**0.54**	0.46
6	0.23	0.12	0.08	**0.31**	0.12	0.15	0.51	**0.58**
7	0.19	0.08	0.15	0.19	0.08	**0.31**	0.42	**0.58**
8	0.23	0.04	0.12	**0.38**	0.08	0.15	0.39	**0.61**
9	0.12	0.12	0.08	**0.35**	0.23	0.11	0.32	**0.69**

Note. Numbers shown are proportion of participants who selected each tool by maze. Bolded numbers indicate the tool selected by the highest proportion of children on each maze or material type (wood vs. plastic). Children could select more than one tool per maze. Children preferred plastic tools in 7 of 9 mazes.

Questionnaire

The questionnaire included items about how familiar the children were with puzzles and mazes prior to the experiment and their experience and choices during the experiment. The results of the questionnaire can be found in Table 3. Ninety-six percent of the children reported that they had solved at least one kind of puzzle prior to the experiment with 57.7% of children solving them frequently (i.e., once a day, 2-3 times a week, or once a week). All of the children reported that they had solved at least one kind of maze prior to the experiment. Overall, this group of children was highly experienced with solving typical puzzles and mazes; however, we did not ask about their experience using stick tools.

When asked about the mazes they completed in this experiment, 96% of the children said that the first few mazes were easy, but only 57.7% said that the mazes became harder. When asked if the food reward made them want to solve the maze, three participants did not answer and 78.3% of the remaining children agreed. These results suggest the children appeared to be motivated to solve the mazes. Children were also asked about the difficult mazes and how they were able to avoid dead ends. As seen in Table 3, the responses about tool use and their strategy for the difficult mazes were varied. The majority (54.2%) of children reported looking ahead at the different levels and planning how to move the marble, but 16.7% reported not noticing the dead ends. When asked why they chose certain tools, 44.4% of the children cited a quality of the tool, such as “It was easier to move” or “They are thinner than wood”, and 37.0% didn’t know why they had selected a tool. The reasons for selecting certain tools over others did not suggest a knowledge about the functional differences between tool types as we predicted. Additionally, none of the children specifically referenced novelty (e.g., “I have never used a tool like this before”) or functionality (e.g., “This tool works better than that tool” or “this tool might break”).

Table 3

Children’s Responses to the Questionnaire

Questions	Percent Response				
			General Survey Questions		
What kind of puzzles do you solve?	*Word Finds*	*Mazes*	*Jigsaw Puzzles*	*Other*	*None*
	73.1	96.2	73.1	23.1	3.8
How often do you solve puzzles?	*Frequently*	*Rarely*			
	57.7	42.3			
What kind of mazes have you done?	*Corn Maze*	*Maze on Paper*	*Other*	*None*	
	61.5	100.0	3.8	0.0	
			Experiment Specific Questions		
% Yes Response	*Like the apparatus?*	*First mazes easy?*	*Mazes become harder?*	*Using a tool hard?*	*Snack motivate you?*
	100.0	96.2	57.7	3.8	73.8 *
Why did you choose specific tools?	*Related to # of Tool*	*Quality of the Tool*	*Ambiguous Response*	*Don't Know Why*	
	14.8	44.4	80.0	37.0	
How did you avoid dead ends?	*Planned their moves.*	*Didn't notice dead ends.*	*Practiced until they got it.*	*Don't Know*	
	54.2	16.7	16.7	12.5	

Note. The asterisk (*) indicates that three children did not answer this question and the percentage is out of 23 children, not 26 children.

Discussion

As predicted, the children were able to solve all nine mazes (with the exception of two children on two of the difficult mazes), with 79% of the children solving the difficult mazes on their first attempt. The boys took the longest time to complete the three difficult mazes compared to the intermediate and easy mazes. The girls took longer to solve the intermediate mazes than the easy or difficult mazes. This could be in part because the girls recognized the similarity between the intermediate and difficult maze configurations (i.e., the difficult mazes were the same configuration as the intermediate mazes, but with two red pieces added to create dead ends). Boys took significantly longer to solve difficult mazes than easy or intermediate mazes. This may be due to the boys speeding through the easy and intermediate mazes and then slowing down to avoid the dead ends in the difficult mazes. Children applied different strategies to move the marble through the maze. One strategy involved looking ahead and planning where to place the marble, whereas another “brute force” approach involved pushing the marble with as much force as possible to maximize the movement of the marble. On average 43.6% of the time the boys employed this brute force approach to moving the marble through the maze while girls applied the brute force strategy only 12.8% of the time. The girls were more likely to plan the placement of the marble.

We also predicted that younger children would hit more dead ends than older children. Unfortunately, due to our small sample size we were unable to find any differences based on age, especially when looking specifically at children who did not solve on their first attempt. There was a difference in the percentage of children solved each difficult maze on their first attempt with the fewest children solving maze 7 (69%). When compared to the percentage of children who solved maze 9 (88%), there was a trend towards significance. These results may suggest that the difficult mazes required varying levels of planning or that the order the mazes were presented impacted the ability of the children to solve the difficult mazes. The children may have used mazes 7 and 8 to develop their planning abilities so that when maze 9 was presented more children were able to develop a plan to avoid the dead ends. Furthermore, the results of Tecwyn et al. (2014) suggested that younger children (4-5 year olds) would have more unnecessary movements than older children, but we did not see any differences across age. The number of total movements and the number of unnecessary movements did not change as a result of age contrary to the results of Tecwyn et al. (2014).

Although there was a gender effect for solution time, we found no significant differences between the girls and boys in likelihood to solve the problem. This contrasts with the results of Gredlein and Bjorklund's (2005) study in which participants had to select a tool to retrieve an out-of-reach toy with a 30-s limit. In two experiments, the 3-year old boys were significantly more likely to use the correct tool to retrieve a toy on a shelf than 3-year old girls. Other studies on tool use in young children (age range 2-6) have not reported gender differences (Elsner & Schellhas, 2012; Fitzpatrick et al., 2012; Nagell et al., 1993; Seed & Call, 2014). This suggests that some methodologies may lead to gender differences but not others. While boys may be more likely identify a functional tool (Gredlein & Bjorklund, 2005), our study suggests that boys can also solve mazes faster than girls. Further experiments are necessary to determine whether boys are better equipped to solve problems involving tools or whether it depends on the type of problem and the age of the child.

In the current study the children preferred the plastic tools more than the wood tools. Fifty percent of the children said they chose specific tools based on the characteristics of the tool (e.g., "It was easy to move"). In fact, both the plastic and wood sticks were functional in that they were rigid enough to efficiently move the marble. The participants may have used artificial, man-made tools (e.g., plastic or wood pens or pencils) to solve problems in the past, although they may not have handled plastic dowels prior to the study. They are likely to have used natural stick tools in the past, and may have discovered they can break which may have led them to prefer to the plastic tools in this task (although the children did not state this directly). Many participants (38.5%) stated no conscious reasons why they chose a tool, but may have selected a tool based on past experiences. A future study could explore children's ability to select a functional tool as opposed to a non-functional tool in a planning task, or further explore the effect of novelty or past experience on tool preference.

Experiment 2

Experiment 2 tested three orangutans with the same series of nine mazes as in Experiment 1. However, the maze apparatus and tools used were scaled to the larger size of the orangutans and built to withstand their strength. Testing the orangutans served two purposes. It allowed us to expand the recent research surrounding the ability of orangutans to plan in problem solving tasks (i.e., Bourjade et al., 2014), as well as directly compare the performance of the orangutans to the children.

Method

Animal Subjects

Three orangutans (*Pongo pygmaeus pygmaeus*) housed at the Seneca Park Zoo in Rochester, NY were tested. There was one male orangutan, Denda (age 9) and two female orangutans, Kumang and Dara (ages 35 and 13, respectively). Dara is Kumang's daughter. All three orangutans were born in captivity and housed together in the same set of enclosures. Their habitat consisted of three separate concrete enclosures, one larger main enclosure and two smaller enclosures, which had connecting doors that could be either open or closed by the zookeeper to allow the animals to interact with one another. The walls dividing the enclosures were made of concrete, but the walls facing the public and the ceiling were composed of metal grating which allowed the orangutans to climb. Their daily diet consisted of a mixture of Purina® Monkey Chow, legumes, assorted vegetables (e.g., carrots, lettuce, etc.), and the occasional piece of fruit. During testing, the orangutans were fed five shelled peanuts per session as reward. The two female orangutans were on a low calorie diet which prevented consumption of peanuts at any time other than testing and the male orangutan only received peanuts during testing sessions throughout the duration of the experiment, so they were highly motivated to obtain the peanuts. These three orangutans had no prior experience participating in psychology research studies. Although all three had previous experience interacting with a different puzzle boxes and stick tools that were similar to the one used in the present study, Kumang began interacting with these types of puzzle boxes about 20 years prior to the current study whereas the other orangutans had far less exposure. Other enrichment devices simulating foraging experiences were added to the enclosure on a weekly basis (e.g., extract Jello from a bowl using a stick tool). The orangutans were tested over a period of nine weeks once or twice per week. All test sessions occurred at 2:00 pm in the afternoon prior to the subjects' afternoon meal. All methods with the orangutans were approved by both the Rochester Institute of Technology's Institutional Animal Care and Use Committee and Seneca Park Zoo's Institutional Animal Care and Use Committee.

Apparatus

A scaled-up version of the Primate Puzzle Feeder apparatus used in Experiment 1 was built to better accommodate the orangutans and the enclosure (Figure 1). The orangutans were accustomed to manipulating longer stick tools with bigger and sturdier puzzle boxes than the one used in Experiment 1. The maze apparatus for the orangutans was a 60.96 cm × 35.56 cm × 7.62 cm plastic framed-box with Plexiglas enclosing either side of the apparatus. The apparatus was affixed to the enclosure via metal bolts originally and then later zip ties when one of the orangutans broke the bolts off the maze apparatus. The maze apparatus was placed in such a way that the bars of the enclosure did not occlude the slots of the apparatus. Coarse wire mesh was placed across the front of the puzzle box to discourage the animals from picking the food out of the slots with fingers instead of using the tools, although using fingers was still possible (wire mesh had been used on previous puzzle boxes used by these orangutans). Instead of plastic pieces, there were removable white plastic boards with circular 1" diameter holes to allow the peanuts to pass through to the next level. The holes were equivalent to slots without a blue piece in the child apparatus. For difficult mazes, there were opaque red, plastic blocks 7.30 cm x 5.08 cm x 2.54 cm that served as potential dead ends just like the clear red pieces in the previous apparatus. There were eight white boards with different numbers of openings in different locations which could be placed on the different levels to make the same maze configurations used in Experiment 1.

The tools were three wood sticks and three plastic dowels 0.64 cm in width as in Experiment 1; however, in Experiment 2 the sticks were 22.9 cm in length instead of 12.7 cm in length to better accommodate the larger hands of the orangutans. During the first three test sessions the zookeeper presented the array of six tools (in order from 1 on the far left to 6 on the far right), to the orangutans when they entered the testing enclosure to ensure the orangutans noticed the tools. In the remaining sessions the tools were placed in the same array on top of the maze apparatus for the orangutans to choose from.

Procedure

A test session began by gating all three orangutans out of the main enclosure to set up the apparatus. In the main enclosure, the maze apparatus was affixed to the outside of the enclosure on the metal grating The position of the apparatus was marked on the metal grating so that the position remained the same for all animals and all sessions. For every maze presented, five peanuts were inserted into slot 1a of the maze. Once setup was complete one orangutan was allowed to move to the main enclosure while the other two remained in the side enclosures. The zookeepers used red grapes, a rare sugary treat, as incentive for moving or staying in a specific enclosure.

The test session began after the orangutan picked up their first tool and inserted it into the maze apparatus. Each test session consisted of the chance to solve one maze configuration for five trials. The opportunity to remove one peanut from the maze constituted one trial, and there were five peanuts placed in the maze prior to the onset of the session. The session ended once an orangutan had extracted all of the peanuts from the maze apparatus with a tool or finger, whether they were removed from the goal slots (7b and 7c) or another slot. After an orangutan had completed a test session, they were moved back to the far enclosure and the next orangutan was moved into the main enclosure while the zookeeper re-baited the apparatus with five new peanuts. Each test session took 1-12 min (M = 4.10; SD = 2.35) for each orangutan. Each orangutan was tested on each of the nine maze configurations in one test session each, for a total of nine test sessions for each orangutan.

Results

Accuracy

A correct solution was defined as the orangutan moving a single peanut all the way down to the goal slot using a stick tool and extracting it from one of the goal slots (7b and 7c in Figure 1B). From this point the peanut could be removed with either their finger or a tool of their choosing. This distinction was made to make the orangutan results as comparable to the children's results as possible. Figure 5 shows the number of orangutans who solved each maze by correctly extracting the first peanut from the goal slot (first trial performance). Both Dara and Kumang correctly solved all nine mazes at least once during their nine sessions, but Denda discovered how to extract the peanuts from slots other than the goal slots after maze 6 and from then on did not move the peanuts to the goal box. Instead, Denda would move the peanuts partially through the maze and remove them from any of the other slots. Therefore, we did not include Denda's data for the mazes he did not correctly solve with a stick tool. Dara solved eight of the nine mazes on her first trial by extracting the first of the five peanuts from the goal box, but in maze 5 she removed her first peanut from a location in the maze other than slots 7b or 7c (the other four peanuts were removed from the goal slots). Kumang also solved eight of the nine mazes on her first trial and extracted the peanut from the goal box, but in maze 8 she also extracted her first peanut from a location other than 7b or 7c. Denda only solved five of the nine mazes on his first trial. On most trials, Denda preferred to extract the peanuts from any location other than slots 7b or 7c, even if he successfully removed one of the peanuts from a goal slot (e.g., the first trial).

Error Analysis

By the time the difficult mazes had been presented, Denda was removing at least one peanut per test session from a location other than a goal slot. However, the other two orangutans (Dara and Kumang) both solved all three difficult mazes at least once. Dara had a 100% success rate on the difficult mazes, she never hit a dead end. Kumang hit the functional dead end between slots 6c and 6d in maze 8 with her first peanut, but was able to avoid the dead end for the remainder of the peanuts. On maze 8 (like other mazes), Kumang moved the peanuts down the levels of the maze together. As a result, when Kumang pushed the first peanut to the right in slot 5c it fell into the dead end in slot 6d and she readily adjusted to pushing the other four peanuts toward the left of slot 5c (away from the dead end).

Solution Time

The solution time was calculated by averaging the time it took each orangutan to extract each of the five peanuts. The average solution time for each maze for all the orangutans is shown in Figure 4b. It was calculated using only the solution times for the mazes that were successfully completed. The average solution time for all three orangutans across all easy mazes was 27.91 s (SD = 14.07). The average solution time for intermediate mazes was 50.94 s (SD = 27.49). The average solution time for the difficult mazes was 63.61 s (SD=40.08). Denda did not correctly solve any of the difficult mazes; however, he did solve all of the easy and intermediate mazes during at least one of his attempts.

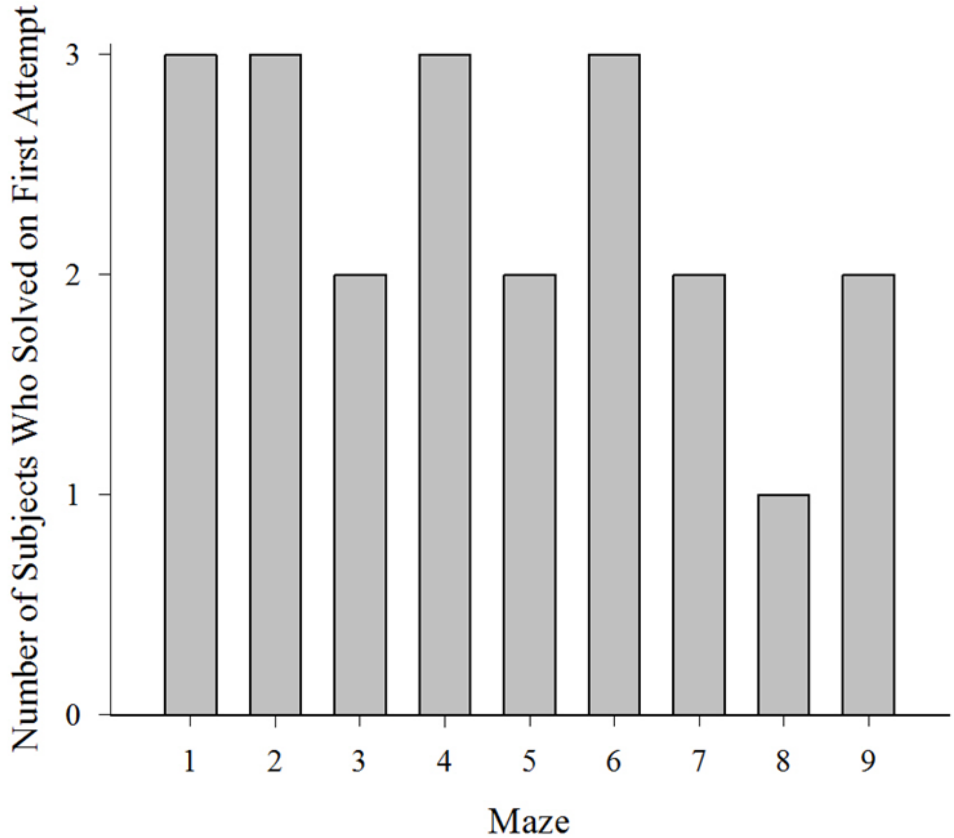

Figure 5. **Number of orangutans who solved each maze on their first attempt.** An attempt was the removal of the first peanut from one of the goal boxes via the use of a stick tool to move the peanut down through the various levels and extract it at a goal slot. Mazes 1-3 were easy, mazes 4-6 were intermediate, and mazes 7-9 were difficult.

Tool Use

The tool selection by each orangutan across each session can be seen in Table 4. Subjects often chose more than one tool per maze (they could use a different tool for each of the five trials) and the results are averaged across all three orangutans. All three orangutans chose plastic tools more often than wood tools. Plastic tools 4 and 5 were the tools chosen most often overall. Wood tools 2 and 3 were chosen least often overall.

Table 4

Tool Choices by Orangutans for Each Maze

	Wood			Plastic			Total	
Maze	1	2	3	4	5	6	Wood	Plastic
1	-	De	-	Da, K	-	De	0.25	**0.75**
2	-	-	-	-	De, Da, K	De	0.00	**1.0**
3	-	-	De	K	Da	-	0.33	**0.67**
4	De	-	De	De, Da, K	-	De	0.33	**0.67**
5	De	-	-	De, Da, K	De	-	0.20	**0.80**
6	-	De	-	De	Da, K	-	0..25	**0.75**
7	De	-	-	De	K	De, Da	0.20	**0.80**
8	Da	K	-	Da	De, K	De	0.33	**0.67**
9	De, Da	-	Da	De, K	Da	-	0.5	0.5

Note. Individual tool choice by orangutan can be seen for each of the nine mazes. For each maze, orangutans could select multiple tools because there were five trials per maze. The proportion of the time each tool type was selected for each maze is depicted in the last two columns. Bolded values indicate the preferred tool type for each maze. When collapsed across orangutan, plastic tools were preferred to wood tools on all mazes except maze 9.

Discussion

The orangutans were capable of using stick tools to solve the mazes, although there were individual differences between the animals. The two female orangutans solved all nine mazes using stick tools, but the young male never maneuvered the peanuts all the way to the goal box on the difficult mazes using a stick tool. Of the two females, Dara (the younger female) showed an increase in solution time on the last two difficult mazes, but Kumang (the older female more experienced with puzzle box mazes) had a relatively consistent solution time for all nine mazes. Denda showed an increase in solution time on the intermediate mazes compared to the easy mazes. Each orangutan adopted a different strategy for achieving the goal of extracting the peanuts from the apparatus. Kumang preferred to push the peanuts one at a time through the maze while Dara and Denda tried to move all five peanuts at once through the maze. As a result, the solution time metric was highly variable depending on the technique(s) each orangutan utilized. Additionally, Denda, after discovering he could remove the peanuts from other locations other than the goal slots, would spend considerable time attempting to use his fingers and/or the tools to remove the peanuts. If he was not successful in one slot of the maze he would move all five peanuts to a new slot before trying to remove them again. He was never successful when using his fingers. Denda also used his mouth to store extra tools so that he had one hand free to use his fingers.

All three orangutans readily handled the stick tools and used them to propel the peanuts through the maze. The orangutans chose plastic tools more often than wood tools, just like the children in Experiment 1. The two females almost exclusively chose plastic tools. It is important to note that Denda broke at least one tool during every test session and all but one of the tools he broke were wood tools (on maze 7, he broke plastic tool 5), but Denda also preferred to use multiple tools in one test session. Kumang also broke a tool on maze 8 (plastic tool 5) after which she switched to a wood tool (wood tool 2; the only time she used a wood tool). This suggests, at least for Kumang, that there was a win-stay, lose-shift method to how she used tools where if the tool was working she continued to use it, but if it broke she switched to a tool with different properties. The orangutans' prior experience with similar wood stick tools for their daily enrichment (which often broke while completing tasks) may have biased them toward the novel plastic tools from the beginning. The wood tools breaking may have led them to consider the wood tools "non-functional"; thus, making the plastic tools more desirable. Further, the orangutans could have seen the plastic tools as novel thereby making them more desirable or they could have preferred to choose tools from the right side of the tool array. There may have been a spatial bias to their preference of tool. With the tools always presented in increasing order from 1-6, the tools on the right side of the configuration (i.e., the plastic tools) may have coincided with their preference to hold the tools with their right hand. The orangutans also interacted with the tools differently than the children. While the children only interacted with one tool at a time and typically only used one tool per maze, the orangutans often used multiple tools per maze and used their mouths to store extra tools. Denda would place a tool in his mouth when he was inserting his fingers into the puzzle box slots to extract a peanut. Kumang would take extra tools and place them in her mouth if she decided to discard the current tool in her hand and try a new tool. Dara rarely placed tools in her mouth or switched tools while completing a maze.

Second, the cognitive difficulty of the mazes served as a form of enrichment for the orangutans. Clark and Smith (2013) demonstrated that chimpanzees benefitted from access to a cognitive challenge device (CCD) by increasing social play between individuals. The CCD was left in the enclosure for two hours at a time and it was suggested that less time would be beneficial to reduce habituation. Therefore, each orangutan receiving a maximum of 12 minutes with the maze apparatus once a week would continue stimulating the orangutans and should have led to more social play.

Experiment 3

The intention of this experiment was to compare tool use abilities across children and orangutans using the same task and the same tools. However, the maze apparatus used in Experiment 2 with the orangutans was larger and sturdier than the maze apparatus used in Experiment 1. This change in size may have affected the solution times of the orangutans (i.e., they may have been longer than the children because the orangutans had to traverse a slightly longer distance between the middle of the start slot to the middle of the first goal slot) (19.0 cm vs. 37.6 cm) or it may have affected the results in other unpredictable ways. Additionally, the need to move five peanuts through the maze versus a single marble may have resulted in different strategies. Therefore, we tested children from Experiment 1 on the orangutan apparatus to provide a direct comparison to their results in Experiment 1 and also compare with the orangutans' results from Experiment 2.

Method

Participants

Approximately one year after completion of Experiment 1, two of the children previously tested in Experiment 1 (a 9-year-old male and a 6-year-old female) were re-tested on the same nine mazes with the orangutan apparatus and orangutan-sized tools from Experiment 2 (no other children from Experiment 1 were accessible one year later). The children received the same selection of awards (i.e., Craisins, Organic Fruit Snacks, or M&Ms) as well as stickers for their participation.

Materials and Procedure

The procedure from Experiment 1 was used with two exceptions. First, the children moved five peanuts through each maze (like the orangutans) instead of the single flat-bottomed marble. Second, the six tools were placed in a random order in front of the apparatus instead of in numerical order from 1-6.

Results and Discussion

Both participants were able to successfully remove the five peanuts for each of the nine mazes with one exception. On maze 9, the girl pushed her first peanut into a dead end (between slots 6b and 6c), but was able to successfully extract the remaining four peanuts from a goal slot. On that first trial, the girl pushed the first peanut to the left in slot 4c causing it to fall two levels into slot 6b (the dead end). If she moved the peanut to the right (as she did for the remaining peanuts) she would have successfully avoided the dead end. The boy successfully extracted all five peanuts from all nine mazes. In Experiment 1, both children were able to successfully avoid the dead ends. On 29 out of 30 difficult trials (five peanuts per difficult maze for each child) in Experiment 3 both children were able to effectively plan to avoid the dead ends. Therefore, the size of the maze likely did not affect the children's ability to successfully plan ahead and solve the problem.

Solution time for Experiment 1 was measured by how long it took a participant to remove one marble from the maze whereas solution time in this task was measured by how long it took a participant to remove all five peanuts from the maze. In Experiment 1, the female participant averaged 23 s on the easy mazes, 25 s on the intermediate mazes, and 74 s on the difficult mazes. With the larger apparatus, the same participant averaged 143 s on the easy mazes, 151 s on the intermediate mazes, and 141 s on the difficult mazes. In Experiment 1 the male participant averaged 9 s on the easy mazes, 8 s on the intermediate mazes, and 14 s the difficult mazes in Experiment 1. With the larger apparatus, the male participant averaged 125, 144, and 163 s on the easy, intermediate, and difficult mazes. Overall, the average time to solve the puzzle box increased with the larger apparatus. However, in Experiment 1 the participants had to remove one item from the puzzle, and in the current task solution time was based on how long it took to remove five items. By dividing the solution times for Experiment 3 by five to get an approximate average solution time per peanut, the solution times for Experiment 3 were about 30 s for both children.

The children's times can also be compared to the amount of time it took each orangutan to extract all five peanuts (adding all five trials together) in Experiment 2. Averaging across all mazes, the children took more time than two of the orangutans but less time than one of the orangutans (girl = 145 s, *SD* = 157.31; boy = 144 s, *SD* = 134.56; Denda = 115 s, *SD* = 79.54; Kumang = 125 s, *SD* = 61.79; Dara = 216 s; *SD* = 187.51). It does not appear that using a slightly larger apparatus for the orangutans caused them to have greatly increased solution times compared to the children on the same apparatus. Similarly to Dara and Denda, both the girl and boy typically moved all five peanuts together and extracted them at the same time. Kumang was the only subject, orangutan or human, that moved the peanuts one at a time in the larger apparatus. When using the larger apparatus, the children continued to prefer plastic tools, similar to the results of Experiment 1 and consistent with the preferences of the orangutans. The boy chose plastic tool 6 for all nine of the mazes. The girl chose plastic tool 5 for every maze except maze 7 on which she chose plastic tool 6. Overall, the children behaved similarly to the orangutans using the larger puzzle box suggesting that differences between the results of Experiment 1 and Experiment 2 could be due to the different apparatuses used and not major differences in strategy or tool use abilities between children and orangutans on this task. Importantly, these results should be considered with caution because only two subjects from Experiment 1 were available to test.

General Discussion

Twenty-four of the twenty-six children and two of the three orangutans solved all nine mazes using tools at least once. These children and orangutans were challenged by the dead ends in the difficult mazes, as seen by an increase in solution times and a decrease in the percentage of individuals who solved the difficult mazes on their first attempt. However, both the children and orangutans were capable of semantic prospection that would allow them to succeed in solving the difficult mazes, even though some failed on their first attempt. Previous research supports the ability of both the children and the orangutans to plan within the context of a short task. Both Tecwyn et al. (2013, 2014) studies revealed that children and orangutans (among other apes) can use sequential planning to solve a paddle-box task, but they could not use advanced planning. Our study suggests that a children and orangutans may be able to solve mazes using advanced planning of several minutes (and may draw on their immediate experiences with the previous difficult maze). If the animals were only using sequential planning like Tecwyn et al.'s (2013, 2014) subjects, all of our subjects would have hit dead ends across all the difficult mazes unless by chance. Most of the children were also able to adapt their strategy following hitting a dead end and so was Kumang. This flexibility in their action plans is similar to the orangutans tested in Bourjade et al. (2014) who planned their actions according to the condition they were in. Tecwyn et al. (2011) also showed that orangutans can change their solution path in a puzzle-tube task using tools based on changing rules. This can be compared to our results when we introduced a dead end into the maze configurations.

All of the children and orangutans were willing and able to use the stick tools, although the orangutans chose to remove peanuts with their fingers as well as remove the peanuts from slots other than the goal slots. The children only used their fingers to remove the marble from the goal slot after using the tool to move the marble all the way to the bottom (and never placed tools in their mouths). Interestingly, the orangutans did manipulate the tools with their mouths occasionally like other captive orangutans (O'Malley & McGrew, 2000) and wild orangutans (van Schaik et al., 1996). When the orangutans were inserting a stick tool into the puzzle box they would manipulate them with their hands. However, they would place tools in their mouths as a means of storing extra tools.

Both species showed a preference for the artificial plastic tools to the natural wood tools. The plastic tools were novel for the orangutans, but they had prior experience using (and breaking) wood sticks in enrichment tasks at the zoo. The one child who broke a tool (a female on maze 2) broke a wood tool and proceeded to use plastic tools for the remainder of the test session. Although both tools were rigid, the material types were not functionally equivalent as plastic tools were arguably less breakable than the wood tools because they never broke in the context of moving the food through the maze. Therefore, the children and orangutans may have identified the functional superiority of the plastic tools and preferred them to the wood tools. The male orangutan, Denda, may have demonstrated a choice to switch from wood tools to plastic tools on Maze 4. After breaking two wood tools, Denda switched to using only plastic tools for the rest of that maze. It is possible that in addition to recognizing the functional difference between the tool materials, the novelty of the plastic tools aroused their curiosity. Alternatively, the orangutans may have also seen the plastic tools as more functional because they had previous experience with similar wood tools which broke. Several other studies show orangutans' ability to detect functionality (Mendes et al., 2007; Mulcahy & Call, 2006a; Mulcahy & Schubiger, 2014) possibly even before using either of the tool types (Manrique & Call, 2011). If the subjects thought the plastic tools were more continuous than the wood tools (e.g., the bumps in the wood disrupted the tool), then the plastic tools may have appeared more functional (Mulcahy & Schubiger, 2014). Unfortunately, we cannot be sure why the subjects chose their tools, and as Visalberghi, Fragaszy and Savage-Rumbaugh (1995) point out, there is no way to know whether the subjects actually comprehend that the tool will be effective when they use it.

Our study found similar results as other studies on tool use in orangutans (e.g., Lethmate, 1982; Mendes et al., 2007; Mulachy & Call, 2006b), that although no formal training or direction were provided, the orangutans could still solve the task. The three orangutans in this study were all able to extract all five peanuts on a given session (although not necessarily the way we intended). Similar to O'Malley and McGrew (2000), the orangutans in our study also utilized their mouths to store extra tools while they solved the mazes, especially Denda, possibly due to the need for their hands to travel between trees in the wild. Gruber, Clay and Zuberbühler (2010) demonstrated that female bonobos and chimpanzees were more avid tool users than males of their species. These results are consistent with Denda's preference to solve the mazes with his fingers instead of tools, but are not necessarily representative of all male orangutans. Further, these results do not explain why he did not solve the mazes in the same way (i.e., removal from slot 1c or 1d) for each maze.

The error analyses from Experiments 1, 2, and 3 revealed that a majority of the children and at least one of the orangutans could solve the difficult mazes on their first attempt. With regard to errors, there was no clear pattern that resulted in children or orangutans hitting dead ends. It is possible that there were inter-maze differences, at least for the children. Six of the eight children who failed to solve maze 7 (either completely or on the first attempt) seemed to make their fatal error on level 3 of the maze near the nonfunctional dead end. While the children had a similar solution path that resulted in hitting a dead end in maze 7, the other two mazes had no clear path. All three participants in Experiment 1 who did not solve on their first attempt made their fatal error on level 1 of the maze. This suggests that they may not have been able to plan their moves in advance of moving between levels. On the other hand, only one orangutan (excluding Denda) was unable to solve a maze on their first attempt (Kumang on maze 8) and Kumang quickly recovered to extract the remaining four peanuts. More surprising, even with hitting the dead end, Kumang was faster to solve maze 8 than either of the other two difficult mazes. This could be attributed to novelty of the dead ends in maze 7 and an attempt to avoid the dead ends in maze 9. Since Kumang preferred to move all five peanuts at one time, the four remaining peanuts were in a position that she could easily switch the direction of movement prior to hitting the dead end. Völter and Call's (2014) revealed an age effect in Experiment 1 with any subject (human or nonhuman primate) under the age of 20 years learning to avoid the traps. They revealed that although the subjects could solve the task by only paying attention to the current level, the successful subjects actually attended to all three levels. The majority of our subjects, children and orangutans, were also able to successfully solve our task which did require them to attend to all seven levels at the start of the task. This supports the evidence previously seen by Völter and Call (2014) and suggests that planning is not limited to three levels of a maze, but can be extended up to seven levels of a maze. While we only had one subject over the age of 20, we saw no age effect for accuracy although Völter and Call (2014) saw this effect for all subjects over the age of 20. This may suggest a methodological or task difference that inhibited learning in Völter and Call (2014) and enabled learning in Kumang, or it could be because of Kumang's twenty years of experience with similar (but not identical) upright mazes. It is possible that by allowing a level by level solution, the older subjects in Völter and Call (2014) could not see the bigger picture which resulted in no learning. However, our maze required planning several levels in advance of a dead end and did not allow a level by level solution which may have actually facilitated Kumang's solution.

The children solved the mazes in approximately 15 to 25 s in Experiment 1 and about 30 s (per peanut) in Experiment 3, which is faster than the averages for the two younger orangutans (Denda: 69 s; Dara: 49 s) but close to Kumang's average time of 33 s. Those differences may be due to the the manual dexterity of the children versus the orangutans, the tool use ability of individuals, or and the experience of the individuals in solving mazes. Kumang had extensive experience with puzzle boxes of this type compared to the younger orangutans, which may have led to her skill, speed, and use of a different strategy. She methodically pushed each peanut to the bottom individually instead of manipulating all the peanuts at once. Overall, the orangutans in this study solved the mazes on our puzzle boxes very quickly compared to the monkeys in Bloom and Cook's (1989) study. The monkeys took on average 10-15 min to remove and eat 10 peanuts from the apparatus (compared to 2-4 min for five peanuts in the current study). However, the specifics of the maze configurations used in the Bloom and Cook (1989) study are unknown – they may have used more difficult maze configurations.

There were some limitations of this study. The absolute size of the puzzle boxes used for the children and orangutans was different, although the puzzle box design and the maze configurations were identical. The orangutans needed and larger and sturdier apparatus because they have been known to break or damage problem-solving devices. Experiment 3 addressed questions about how the children would perform using the orangutan puzzle box, and results were not substantially different for Experiment 1 versus Experiment 3 (except for solution time). In addition, the human participants were given verbal directions while the orangutan subjects received no directions. However, slight differences in procedure between human and non-human animals are common in comparative cognition studies. A possibility for future research is to train a participant from each group to model the behavior for their counterparts (or have an adult model perform the task). This would explore the effect of observational learning on tool use. Preliminary data from our lab suggests that 2 to 4 year-old children are more successful when they observe someone solve the difficult mazes than when they try to solve the difficult mazes by trial and error (O'Leary & DeLong, 2016). Several studies have compared social learning and tool use between children and great apes and the results suggest that both children and great apes can copy the actions of a human demonstrator at least to some degree (e.g., Buttleman et al., 2008; McGuigan, Whiten, Flynn, Horner, 2007; Nagell et al., 1993). However, the results of Buttleman et al. (2008) suggest that not only can children and orangutans understand the choices a demonstrator makes to solve the task, but other great apes could not (i.e., chimpanzees, bonobos, and gorillas). We have yet to conduct a study on observational learning versus trial and error learning in orangutans, but our current results (O'Leary & DeLong, 2016) support previous research on observational learning in children (i.e., Buttleman et al., 2008; Nagell et al., 1993) demonstrating that children perform better when a solution is demonstrated for them than when trying to solve by trial and error. Further, the results of Nagell et al. (1993) suggest that testing observational learning with orangutans will result in higher performance than trial and error solutions similar to the previously tested chimpanzees.

The present study compared the use of tools by children and orangutans in a problem solving task that required semantic prospection. Our present results suggest that both children and orangutans can plan their moves to avoid dead ends when using a tool to move an item through a maze. The errors that resulted in children and orangutans hitting dead ends did not seem systematic across species or maze suggesting that there is not only one way to reach a dead end. More research in this area with similar methodologies between species will illuminate the similarities in prospective cognition as it relates to problem solving in these two species.

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