Report

Current Biology

Children's and Apes' Preparatory Responses to Two Mutually Exclusive Possibilities

Highlights

- Representing alternative future events is an important facet of effective foresight
- Children and apes had the chance to catch a target falling from one of two locations
- 2-year-olds and apes prepared for the target's emergence from only one location
- Many 3- to 4-year-olds simultaneously and consistently prepared for both possibilities

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In Brief

Redshaw and Suddendorf gave children and apes the chance to catch a target dropped into an inverted Y-shaped tube. Many 3- to 4-year-olds, but no 2-year-olds or apes, spontaneously and consistently covered both exits from which the target could fall. This is a nonverbal demonstration of the potent capacity to prepare for alternative future events.

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Children's and Apes' Preparatory Responses to Two Mutually Exclusive Possibilities

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SUMMARY

Animal brains have evolved to predict outcomes of events in the immediate environment [1–5]. Adult humans are particularly adept at dealing with environmental uncertainty, being able to mentally represent multiple, even mutually exclusive versions of the future and prepare accordingly. This capacity is fundamental to many complex future-oriented behaviors [6, 7], yet little is known about when it develops in children [8] and whether it is shared with non-human animals [9]. Here we show that children become able to insightfully prepare for two mutually exclusive versions of an undetermined future event during the middle preschool years, whereas we find no evidence for such a capacity in a sample of chimpanzees and orangutans. We gave 90 preschool children and 8 great apes the opportunity to catch an item dropped into a forked tube with two bottom openings. Children's performance improved linearly across age groups (2, 2.5, 3, 3.5, and 4 years), with none of the youngest group but most of the oldest group spontaneously covering both openings the first time they prepared to catch the item. The apes performed like 2-year-olds on the first trial, with none of them covering both openings. Some apes and 2-year-olds eventually passed the task, but only in a manner consistent with trial-and-error learning. Our results reveal the developmental trajectory of a critical cognitive ability that allows humans to prepare for future uncertainty, and they also raise the possibility that this ability is not shared with other hominids.

RESULTS AND DISCUSSION

To investigate the capacity to represent and prepare for future uncertainty, we constructed a minimalist forked tube apparatus that had one opening at the top but two openings at the bottom (see Figures 1, S1, and S2). The experimenter could drop a ball or grape into the top of the tube and surreptitiously control which bottom opening it would fall from (in a pseudorandom order). After six observation trials—in which the subject could see the item fall but not catch it—children (n = 90; 18 each from age groups 2, 2.5, 3, 3.5, and 4 years; see Table S1 for details) and great apes (n = 8; 3 chimpanzees, *Pan troglodytes*, and 5 orangutans, *Pongo abelii*) were given the opportunity to catch the item for 12 test trials, and each time they failed to do so, it fell on a ramp and rolled out of reach. We were interested in whether the children and apes would cover one or both bottom openings with their hands when preparing to catch the item. Covering two holes would suggest an understanding that immediate future events can have more than one possible outcome. Of particular interest was first-trial performance, because over the experience of multiple trials, success may be shaped through simple trial-and-error learning.

Figure 2 shows the cumulative percentage of children (by age group) and great apes that covered both bottom openings of the tube for the first time over 12 trials. None of the 2-year-olds, few 2.5-year-olds, many 3- and 3.5-year-olds, and most 4-year-olds passed the first trial. A significant Cochran-Armitage χ^2 test revealed that children were more likely to cover both openings on the first trial as they increased in age, χ^2 (1) = 25.74, p < 0.001. Post hoc Pearson's χ^2 tests revealed that 4-year-olds were significantly more likely to cover both openings on the first trial than 3- and 3.5-year-olds combined, χ^2 (1) = 4.58, p = 0.032, who in turn were significantly more likely to cover both openings on the first trial than 2- and 2.5-year-olds combined, χ^2 (1) = 13.57, p < 0.001. This pattern of first-trial results suggests that the ability to prepare insightfully for mutually exclusive outcomes of a single future event emerges during the third and fourth years.

Despite their poor spontaneous performance on the first trial, however, many 2- and 2.5-year-olds covered both bottom openings at least once over the later trials, and nearly all 3-, 3.5- and 4-year-olds had done so by the end of the experiment (see Figure 2). Yet interestingly, not all of the children who showed this behavior maintained it across all subsequent trials. Figure 3 (cf. yellow segments) shows that many 2- to 3.5-year-olds (but no 4-year-olds) regressed to covering only one opening on at least one later trial. Of the children who covered both openings at least once (n = 67), regressing to covering one opening was significantly less likely among the 4-year-olds (0 out of 17) than among the younger children combined (19 out of 50), post hoc Pearson's χ^2 (1) = 9.02, p = 0.003, even though the 4-year-olds tended to cover both openings much earlier. This pattern of results substantiates the claim that most 4-year-olds and some 3-year-olds were solving the problem by accounting for future uncertainty, whereas many of the younger children were perhaps weakly conditioned into using the optimal response through trial-and-error learning and thus remained susceptible to covering only one opening on some trials.

Like the 2-year-old children, none of the great apes spontaneously prepared for two potential outcomes on their first trial (see

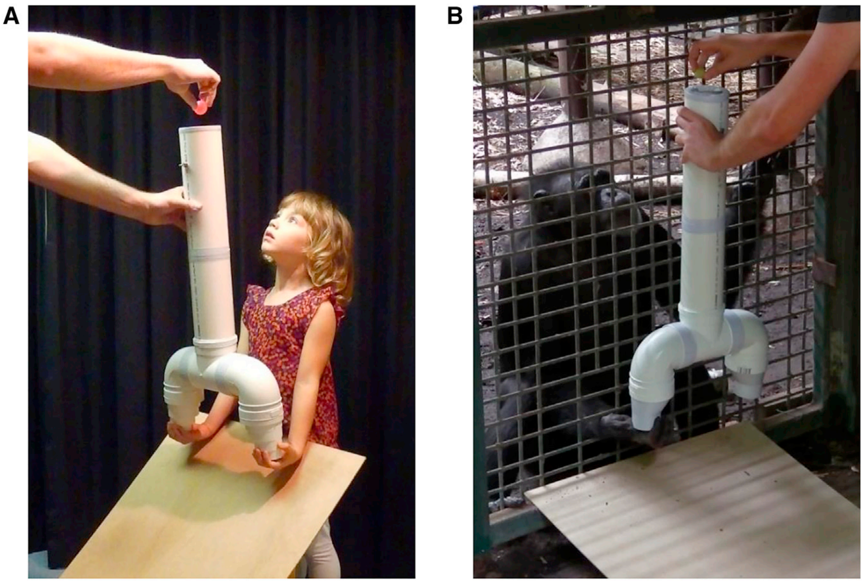

Figure 1. Depiction of the Forked-Tube Task Given to Children and Great Apes

Participants had the opportunity to cover one or both bottom openings of the forked tube when preparing to catch a ball or grape that would be dropped into the top opening. See also Figures S1 and S2.

(A) The child is spontaneously covering both bottom openings.

(B) The ape is covering only one opening.

Figure 2). Only one ape, the chimpanzee Holly, covered both bottom openings at all during the 12 trials. She did so on trials 9 and 11 but regressed to covering only one opening on trials 10 and 12, much like many of the younger children (cf. yellow segments in Figure 3).

Because of the apes' poor performance over these first 12 trials, we were interested in whether they could eventually learn to consistently cover both bottom openings over extra trial blocks (see Table 1). Of the five subjects (three chimpanzees and two orangutans) that were given extra trials, one chimpanzee (Samantha) and one orangutan (Dinar) learned to pass at least six trials in a row (see Figure S3, Table S2, and Supplemental Experimental Procedures for more details). Like the younger children, however, both subjects regressed to covering only one bottom opening at least once after first covering both openings. Such a response pattern—an initial appearance of the target behavior after many unsuccessful trials, followed by brief regression, then reappearance of the behavior and eventual maintenance—is consistent with simple operant conditioning principles rather than insightful behavior. Nonetheless, these results do show that great apes (like 2-year-old children) can learn to pass the task consistently, and so their lack of spontaneous and sustained success cannot be attributed to a basic limitation in the ability to synchronize the actions of two hands through mesh to solve the problem.

The results of the current study show that, by the middle preschool years, many children have the capacity to spontaneously and consistently prepare for two mutually exclusive versions of an immediate future event. We found limited evidence for this capacity in children younger than 3 years and no evidence in a sample of great apes. Interestingly, our results contrast with those of the only two previous studies of children's ability to prepare for alternative future event outcomes, which found strong positive evidence for the behavior only during the fifth year [10, 11]. Unlike our minimalist task, however, the tasks used in these previous studies relied heavily on language comprehension and included complex intermediate steps between the preparatory behavior and the future outcome. Our results more comfortably place the capacity to prepare for immediate alternative futures on a similar developmental trajectory to other future-oriented behaviors [8, 12], such as the abilities to delay gratification [13, 14], to select an appropriate object to solve a future problem [15, 16], and to save resources for the future [17].

The improvements on our task with increasing age may have been driven by developments in various cognitive components of foresight that typically occur around the third and fourth years [8]. One fundamental component is the capacity to form metarepresentations, which allow an agent to reflect on the relationship between their representation of a given event and the event itself [9, 18, 19]. An effective way to solve our task, for instance, would be to reflect on a representation of the item coming out of one bottom opening of the tube, to recognize that this representation could be incorrect (i.e., to metarepresent), and thus to simultaneously prepare for this possibility as well as for the alternative by covering both openings. This interpretation is consistent with the overall pattern of results from various domains suggesting that a fundamental shift in the representational mind occurs during the middle preschool years [18, 20]. Nevertheless, nonverbal behavioral patterns can often be explained in rich and lean manners [20], and future research may examine

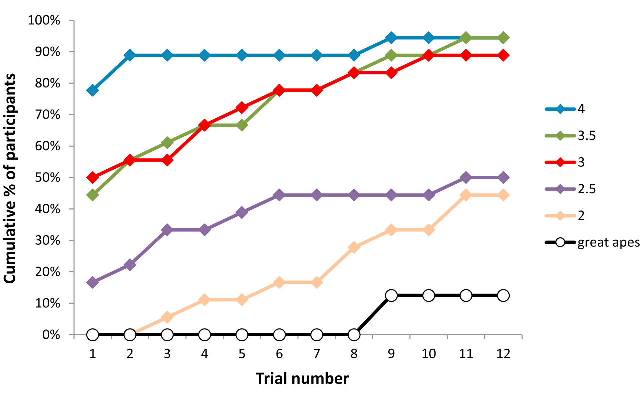

Figure 2. Cumulative Percentage of Children by Age Group and Great Apes that Covered Both Bottom Openings of the Forked Tube for the First Time across the Twelve Trials

Each increment represents a unique participant covering both bottom openings for the first time.

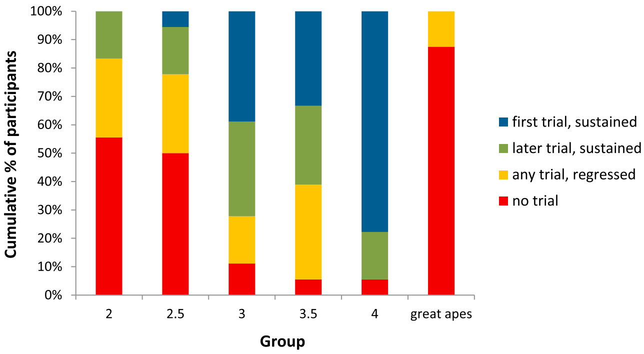

Figure 3. Grouping of Children by Age Group and Great Apes According to When They Covered Both Bottom Openings of the Forked Tube across Twelve Trials

Blue segments: covered both bottom openings on the first trial and all subsequent trials. Green segments: did not cover both openings on the first trial, but eventually covered both openings and sustained that response across all subsequent trials. Yellow segments: covered both openings on at least one trial and subsequently regressed to covering one opening on at least one trial. Red segments: did not cover both openings on any trial.

the feasibility of leaner accounts of the older children's performance.

Whatever the cognitive underpinnings, our results clearly show that 4-year-olds and some 3-year-olds have the capacity to spontaneously and consistently prepare for mutually exclusive future event outcomes. The 2-year-olds and apes, on the other hand, did not provide such evidence. As in other developmental and comparative studies, these negative results have to be interpreted cautiously, as performance may be affected by factors other than the capacity of interest. One may, for instance, be concerned about the role of children's and apes' gravity bias, whereby they expect a dropped item to fall perpendicularly to the ground [21]. Our subjects' performance appeared largely unaffected by this bias, however, as nearly all of them covered at least one bottom opening of the tube on all trials and none of them placed their hands directly underneath the top opening (see Supplemental Experimental Procedures). Another concern may be that the younger children and apes expected the experimenter to cooperate at the beginning of the task (and force the ball/grape to come out of the single covered opening), or that these subjects simply lacked the behavioral flexibility required to switch to using two hands after the experience of using one hand during the practice trials (see Experimental Procedures). Neither of these possibilities, however, can explain why all three of the apes and most of the 2-year-olds that eventually covered two openings on any trial subsequently switched back to covering only one opening (see Figure 3 and Table 1). We also note that most apes and 2-year-olds switched between covering the left and right sides of the forked tube (see Table S2 and Supplemental Experimental Procedures), indicating that they were genuinely considering the contingencies of the task rather than simply perseverating with a single, sub-optimal response that was reinforced 50% of the time.

There may still be reasons other than lack of an ability to spontaneously and consistently prepare for alternative futures that account for why the 2-year-olds and great apes failed our task. One can only provide subjects with opportunities to demonstrate capacities, and although we devised our minimalist paradigm with the aim of giving young children and apes the best possible chance to pass, we acknowledge that future studies with other subjects and/or paradigms may discover some competence. For now, however, we only have compelling evidence for prudent preparatory responses to two mutually exclusive possibilities in 3- to 4-year-old children. Our pattern of results thus points to a gradual development of this capacity over the middle preschool years. The results also raise the possibility that humans' closest extant relatives lack the capacity altogether, despite being capable of responding flexibly to new risks [22] and possibly solving problems with some foresight [23–25]. This would suggest that a new cognitive ability for dealing with environmental uncertainty evolved after the split of the human and chimpanzee lineages approximately 6–8 million years ago [26]. Our study therefore contributes a new perspective to the ongoing debate about what, if anything, is unique to human foresight [7, 9, 27–30] and cognition more generally [20, 31].

The capacity to consider and prepare for multiple, even mutually exclusive versions of future events is central to human adaptability and prudent decision making. Here we have introduced a new minimalist paradigm to chart the ontogeny of this ability and

Table 1. Summary of Great Apes' Performance across All Trials of the Forked-Tube Task

Subject	Species	Sex	Age	Total Number of Trials	First Trial Success?	Any Trial Success?	First Trial Passed	Passed All Subsequent Trials?	Learned to Pass Consistently?
Holly	*Pan troglodytes*	F	25	96	no	yes	9	no	no
Samantha	*Pan troglodytes*	F	30	84	no	yes	15	no	yes
Cassie	*Pan troglodytes*	M	42	48	no	no	–	–	–
Sekara	*Pongo abelii*	F	25	12	no	no	–	–	–
Dinar	*Pongo abelii*	M	28	24	no	yes	16	no	yes
Hsing Hsing	*Pongo abelii*	M	40	24	no	no	–	–	–
Teliti	*Pongo abelii*	F	5	12	no	no	–	–	–
Pulang	*Pongo abelii*	F	21	12	no	no	–	–	–

Subjects received different total numbers of trials because of time constraints and varying levels of cooperativeness. Passing consistently was defined as passing at least six trials in a row. See also Figure S3 and Table S2.

commence investigating its phylogeny. Our findings augur well for future research. Variations of the paradigm may prove valuable not only for establishing the capacities and limits of children and animals, but also for nonverbally examining basic prospection difficulties in certain clinical populations [32].

EXPERIMENTAL PROCEDURES

Subjects

Participants included 90 children (18 each from age groups 2, 2.5, 3, 3.5, and 4 years), three common chimpanzees (*Pan troglodytes*), and five Sumatran orangutans (*Pongo abelii*; mean age of all apes = 27 years, range = 5–42 years). All parents and/or guardians gave informed consent for their children to participate, as approved by the ethics board of the School of Psychology at the University of Queensland. The ape study was approved by the relevant animal ethics boards of the University of Queensland, Rockhampton Zoo, and Perth Zoo.

Materials and Procedure

Participants were first taught how to catch a ball or grape from a basic tube that contained only one opening at the top and one opening at the bottom, and were considered to pass this practice phase after catching three consecutive items. Subjects were then introduced to the forked tube and given six observation trials (in which they could not catch the item), with the item coming out of the bottom openings in the following pseudorandom order: right, left, left, right, left, right (from the experimenter's perspective). Twelve test trials immediately followed, with the subjects given the opportunity to catch the item as it exited the bottom openings in the following pseudorandom order: right, left, left, right, left, right, right, left, right, left, left, right (from the experimenter's perspective). Participants were scored for whether they covered one or two bottom openings when preparing to catch the item on each trial. Further methodological details are described in the Supplemental Experimental Procedures.

SUPPLEMENTAL INFORMATION

Supplemental Information includes three figures, two tables, and Supplemental Experimental Procedures and can be found with this article online at http://dx.doi.org/10.1016/j.cub.2016.04.062.

AUTHOR CONTRIBUTIONS

J.R. conceptualized, designed, and carried out the experiment, and also conducted the statistical analyses and wrote the manuscript. T.S. assisted in designing the experiment, testing the chimpanzees, and writing the manuscript.

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