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# Younger apes and human children plan their moves in a maze task

Christoph J. Völter [a,b,*], Josep Call [a,c]

[a] Max Planck Institute for Evolutionary Anthropology, Department of Developmental and Comparative Psychology, Germany
[b] University of Bielefeld, Department of Animal Behaviour, Germany
[c] University of St Andrews, School of Psychology and Neuroscience, UK

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Planning defined as the predetermination of a sequence of actions towards some goal is crucial for complex problem solving. To shed light on the evolution of executive functions, we investigated the ontogenetic and phylogenetic origins of planning. Therefore, we presented all four great apes species ($N = 12$) as well as 4- and 5-year-old human preschoolers ($N = 24$) with a vertical maze task. To gain a reward placed on the uppermost level of the maze, subjects had to move the reward to the bottom through open gaps situated at each level of the maze. In total, there were ten gaps located over three of the maze's levels, and free passage through these gaps could be flexibly blocked using multiple traps. Due to the decision tree design of the maze, the subjects had to plan their actions depending on the trap configuration up to two steps ahead to successfully retrieve the reward. We found that (1) our measure of planning was negatively correlated with age in nonhuman apes, (2) younger apes as well as 5-year-old children planned their moves up to two steps ahead whereas 4-year-olds were limited to plan one step ahead, and (3) similar performance but different underlying limitations between apes and children. Namely, while all species of nonhuman apes were limited by a lack of motor control, human children exhibited a shortage in shifting their attention across a sequence of subgoals.



## 1. Introduction

While thinking about the next move, a good chess player not only needs to envision the potential outcomes of the current move but also to conceive of the sequences of multiple upcoming moves to determine what to do next (e.g. Charness, 1981). Even more mundane activities such as getting dressed or cooking a meal entail the planning of a number of actions before the execution of the first action. Accordingly, planning has been defined as the "predetermination of a course of action aimed at achieving some goal" (Hayes-Roth & Hayes-Roth, 1979).

Such strategic planning is essential for complex problem solving. In the problem-solving literature, an important distinction has been made between forward search on the one hand and problem-reduction or "subgoaling" on the other hand (Willatts, 1989). In forward search, a sequence of actions or choices is tried out step by step, a strategy that has also been termed "generate and test" (Klahr, 1994). If an error occurs, an alternative sequence of actions or choices is tried out until eventually the goal is achieved. Remembering which sequence of actions has already been tested to avoid the previously made error can impose significant loads on memory. Willatts (1989) subdivides forward search into random and heuristic search. In random search each single decisions is made on a trial-and-error basis. In heuristic search (also termed "sighting", see Wellman, Fabricius, & Sophian, 1985), the efficiency of search is increased by the usage of fixed rules

* Corresponding author. Address: Max Planck Institute for Evolutionary Anthropology, Department of Developmental and Comparative Psychology, Deutscher Platz 6, 04103 Leipzig, Germany. Tel.: +49 341 3550 450.
*E-mail address:* christoph_voelter@eva.mpg.de (C.J. Völter).

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(i.e. heuristics like a proximity bias) that guide each single decision in a sequence.

In contrast to forward search, subgoaling involves a means-ends analysis, that includes the identification of the discrepancy between the current state and the target state and the consideration of means to reduce this discrepancy (Willatts, 1989). In the simplest version, this has been called "hill climbing" (Klahr, 1994) in which the next move (but nothing beyond the next move) is evaluated based on a goodness of fit approximation between the current state and the target state. Subgoaling goes beyond that: if the discrepancy between current state and goal state cannot be resolved immediately a sequence of subgoals is formulated. Achieving each of these subgoals in sequence will lead to the overarching goal. The key difference to forward search is that in subgoaling the sequence of subgoals is predetermined before the first step is made. Thus, subgoaling includes planning defined as the predetermination of a sequence of actions whereas forward search has been described as "planful" (Wellman et al., 1985), meaning that only the current move is taken into account.

These strategies are not mutually exclusive and might be both at work in different situations (Willatts, 1989). Indeed, in some situations forward search might be more efficient than subgoaling (no or little information on task-specific means-end relations, limited number of alternatives), whereas in other settings subgoaling might be better suited for solving the problem (information on causal structure of the task available, large number of possible alternatives).

Experimental studies on planning in children have mostly concentrated on navigation tasks (including maze and route planning tasks) and subgoaling tasks (like the Tower of Hanoi task). With regard to navigation tasks, a two-dimensional maze paradigm revealed that 4½- to 7-year-olds were able to plan the complete path through the maze before the first move (Gardner & Rogoff, 1990). Interestingly, younger children took longer pauses for planning than older ones, a finding that suggests that planning is more effortful for younger children. In route planning, children typically need to collect some items distributed in space. To find the shortest route and to avoid backtracking to locations that were previously visited the children needed to plan ahead before the first choice was made. Wellman, Somerville, Revelle, Haake, and Sophian (1984) reported that 4- and 5-year-olds but not 3-year-old children planned one step ahead. The search strategy of the 3-year-olds was best explained by a heuristic forward search strategy based on perceptual features of the search array ("sighting"). Additional experiments by Wellman and colleagues (summarized in Wellman et al. (1985)) revealed that the search behavior of preschoolers was best explained by a "mixture of sighting and planning, with planning growing in dominance over the preschool years" (Wellman et al., 1984). At the age of 5.5 years children's search behavior could be solely ascribed to planning and not sighting. Similarly, Fabricius (1988) found that 5-year-olds were considering alternative routes before the first move and were spontaneously self-correcting errors. In contrast, 4-year-olds' performance was best explained by a mixture of sighting (i.e. a proximity bias) and planning.

With regard to subgoaling tasks, Klahr and Robinson (1981, see also Klahr, 1994) showed that a majority of the 4-year-olds confronted with the Tower of Hanoi task reliably planned one step ahead (beyond the current move). Around one third of the 4-year-olds, however, did not plan ahead at all (i.e. they considered nothing beyond the current step). In contrast, all 5- and 6-year-olds planned at least one step, most of them even more steps ahead (between two and four steps).

Non-human primates face various situations in their natural habitat in which this type of planning would also be advantageous. Activities that potentially involve planning are extractive foraging including (sequential) tool use (Sanz & Morgan, 2007), locomotion (Bard, 1995), hunting (Stanford, 1996) or nest building (van Casteren et al., 2012). Sanz and Morgan (2007) reported the usage of up to three tools used in a hierarchical sequence to open a beehive and to extract honey by wild chimpanzees (*Pan troglodytes*). Planning might be implicated in this example by predetermining the appropriate sequence of tools used. However, as we do not know the learning history of these wild chimpanzees, chaining of previously established behaviors provides an alternative account here (Epstein, Kirshnit, & Lanza, 1984).

Therefore, experimental studies are needed to shed light on primates' planning abilities. Mainly two types of studies have been used to investigate planning: navigation tasks (including route planning and mazes) and serial ordering tasks. First of all, with regard to navigation tasks, Menzel (1973) pioneered the investigation of chimpanzees' route planning in three-dimensional space (also known as the traveling salesman problem) by hiding 18 food items randomly in a large outdoor enclosure and analyzing their search behavior. Menzel showed that the chimpanzees remembered the location and type of most of the food rewards, but also that their routes were close to optimum with regard to the food acquisition rate. However, whether the apes were planning their route in advance or whether they, alternatively, were relying on a forward search strategy (cf. sighting, Wellman et al., 1985) cannot be distinguished from these data alone. In vervet monkeys there is evidence that the monkeys considered two further destinations beyond the current one when deciding for a route (Cramer, 1995; see also Gallistel & Cramer, 1996). However, a recent re-analysis of Menzel's and Gallistel and Cramer's data casts doubt on the planning hypothesis (Janson, 2013). Accordingly, the existing evidence for optimal spatial foraging in primates would not require multi-step route planning but might be consistent with a forward search strategy based on a proximity bias (in combination with a risk avoidance strategy).

Considering mazes, Bingham (1929) presented chimpanzees with a three-dimensional maze apparatus and noted that the chimpanzees' behavior involved "preparation for an effect in a location remote from that where concerted activities are initiated" (p. 44). One of the earliest studies using two-dimensional mazes with great apes was conducted by Rensch and Döhl (1968) who presented Julia, a juvenile chimpanzee, with a large battery of mazes