Wayfinding Behavior and Spatial Knowledge of Adults and Children in a Virtual Environment

The Role of Landmarks

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Abstract. This study investigated the effect of different organizations of landmark-location pairings as fine-space information on wayfinding behavior and spatial knowledge on a total of 90participants: 30 second graders, 30 sixth graders, and 30 adults. All participants had to find their way to a goal in a virtual environment with either randomized or categorical landmarks, or without any landmarks. Thereafter, they had to find the shortest way from the start position to the goal in two consecutive trials (wayfinding performance), and they had to solve a number of spatial knowledge tasks. The results showed that independent of their categorical function, the existence of landmarks influenced the wayfinding performance of adults and children in the same way. Whereas the presence of landmarks had no effect on spatial survey knowledge, landmark knowledge itself was influenced by the categorical function of the landmarks presented. Moreover, second graders showed limited achievement compared to adults independent of the existence of landmarks. The main results implicate firstly that children at school age indeed are able to use landmark-location pairings as fine-space information like adults during learning an unknown environmental space, and secondly that a dissociation between wayfinding behavior and spatial knowledge might exist.

Keywords: spatial cognition, wayfinding performance and behavior, spatial knowledge, landmark knowledge, children, development, virtual environments

For a long time, spatial cognition research was concerned with, on the one hand, the ability to find a way through a large-scale environment or environmental space and, on the other hand, the acquisition of spatial knowledge of this large-scale environment (see, for example, Canter & Craig, 1981). In reality, however, both aspects are obviously not independent: Humans may acquire spatial knowledge of a new environmental space by traveling through this environment. This wayfinding behavior can be subdivided into the performance to find a way (the wayfinding performance) as well as the strategies used (the orientation behavior). The acquired spatial knowledge as a result of the wayfinding behavior in a new environment has been detailed in the literature as landmark knowledge, route or procedural knowledge, and survey knowledge (Cousins, Siegel, & Maxwell, 1983; Golledge, 1987; Siegel & White, 1975; Thorndyke, 1981), which refer to the hierarchical organization of spatial knowledge (Hirtle & Jonides, 1985; McNamara, 1986; Stevens & Coupe, 1978; see for comprehensive studies McNamara, 1986; McNamara, Hardy, & Hirtle, 1989; McNamara & LeSueur, 1989; McNamara, Ratcliff, & McKoon, 1984).

In contrast to the well-documented hierarchical organization of spatial knowledge, only very few studies investigated these organizational aspects during wayfinding *behavior* (e.g., Bailenson, Shum, & Uttal, 1998) and in navigation experiments in a virtual environment (Wiener & Mallot, 2003; Wiener, Schnee, & Mallot, 2004). Thereby, the focus was on the influence of the hierarchical presentation of different levels of information that were perceived and stored during navigation. Wiener and Mallot (2003) concluded that wayfinders use fine-space information for close locations (place-connectivity) and coarse-space information for distant ones (region-connectivity) so that human wayfinding is a fine-to-coarse process, which results in the hierarchical representation of spatial knowledge. Both in artificial intelligence and in cognitive science, this hierarchy was expressed in graphlike spatial representations in which locations defined by landmarks are interconnected without exact metrical relations, grouped together forming superordinate nodes in the form of "regions" (e.g., Kuipers, 1978, 2000; Leiser & Zilbershatz, 1989; Schölkopf & Mallot, 1995). This wayfinding process model is, in fact, in line with the category-adjustment model of Huttenlocher, Hedges, and Duncan (1991) applied to situations where subjects estimate locations. The authors assume the existence of a fine-grained information level about the location to be remembered and coarse-grained information about the category to which the location belongs.

The main focus of this study lies in the investigation of the influence of fine-space information on wayfinding behavior and the resulting spatial knowledge. This fine-space information was defined as the pairing of landmarks to locations and their possible connections. The definitions of landmarks range from visual objects that are perceived and

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remembered due to their strategic function (Lynch, 1960), their shape and structure (Presson & Montello, 1988) or their sociocultural significance (Appleyard, 1969), to reference points (Sadalla, Burroughs, & Staplin, 1980) and prototype locations (Newcombe & Huttenlocher, 2000). The differentiation into global landmarks, meaning more distant landmarks (i.e., a hilltop or a skyline), and local landmarks, such as a sign (i.e., Gillner & Mallot, 1998; Steck & Mallot, 2000), emphasizes exactly the fine-to coarse process. A topic that was recently investigated in spatial knowledge and spatial memory research, concerns the importance of the semantic value of that fine-space information: According to Hund and Plumert (2003), the categorical information of landmarks, which means the classification of these landmarks into categories, affected the memory of spatial constellations. Participants were presented landmarks in four quadrants, and following the removal of the landmarks, their task was to recall the positions of the landmarks without the aid of the grid. Children and adults placed semantically related landmarks in the same quadrant closer together than unrelated ones. Landmarks' semantic information therefore led to systematic biases in location memory, which decreased with increasing age. But besides this single study, no other study exists until now that investigates in a systematic manner the influence of the semantic value of fine-space information on wayfinding behavior and the resulting spatial knowledge.

It seems to be quite astonishing at first glance that no studies exist that explicitly investigate the semantic value of fine-space information on wayfinding behavior *from a developmental point of view*. Even very young children (under 1 year) are already able to use fine-space information (Newcombe & Huttenlocher, 2000), have expectations regarding the location of objects (Newcombe, Sluzenski, & Huttenlocher, 2005), and can use information of indirect locations (Lew, Foster, Crowther, & Green, 2004). Significant developmental changes in spatial coding, reasoning, and spatial symbol systems are not, in fact, completed with infancy but continue through school-age (Allen, Kirasic, Siegel, & Herman, 1979; Newcombe & Huttenlocher, 2000). Concerning the wayfinding behavior process, we can assume a development from the use of fine-space to coarse-space information: Cornell, Heth, and Broda (1989) demonstrated that advising 6- and 12-year-old children to pay attention to landmarks near the route helped both age-groups to retrace the route successfully, but only the older children were able to profit from being told to notice distant landmarks. Thus, not only nature but also nurture plays an important role in spatial cognition development, in that neither nativism nor empiricism as extreme possibilities are viable (Newcombe, 2002).

Until now, there has been only one prominent study investigating in detail and from a developmental point of view the role of the coupling of landmark-location pairings for wayfinding behavior in an environmental space (i.e., Cohen & Schuepfer, 1980). In their study, three experimental groups of different grades (grade 2, grade 6, and adults) had to learn a route through a system of corridors, which contained landmarks (18 toy animals) with different functions (adjacent to a correct, an incorrect, or no wayfinding decision), by a slide presentation. The differentiation of landmarks due to their course-maintaining function is an important concept, because Janzen and van Turennout (2004) showed recently that the brain, especially the parahippocampal gyrus, automatically distinguishes between objects adjacent to a correct and an irrelevant turn. After learning, slides of the maze were shown without landmarks, and participants were asked to indicate the correct wayfinding decision in each case. Whereas both children and adults needed the same amount of time to learn the route, second graders made significantly more incorrect wayfinding decisions than sixth graders, who, in turn, made more errors than adults. After a second learning phase, a recall test showed that landmarks adjacent to a correct wayfinding decision were significantly better remembered and localized than those that were adjacent to an incorrect or no turn. Younger children recalled fewer landmarks than older children and adults. The study by Cohen and Schuepfer (1980) was replicated recently in a desktop virtual environment (Jansen-Osmann & Wiedenbauer, 2004a).

What does follow from the results of Cornell et al. (1989) and Cohen and Schuepfer (1980)? The relevance of fine-space information related to the landmark-location pairings especially for younger children is not completely evident as might have been expected at first glance. On the one hand, the data suggest that younger children do use this information in a way qualitatively similar to adults to improve their wayfinding behavior. On the other hand, it seems that children rely much more on the place connectivity induced by the landmarks than adults, given that children seem to suffer to a much higher degree if these landmarks are removed. These conclusions, in fact, have to remain pretty speculative as long as no control condition is realized where wayfinding behavior and spatial knowledge are observed in the same maze without landmarks. Therefore, one goal of the present study is to investigate the developmental aspects of the influence of the presence versus absence of landmarks on wayfinding behavior and spatial cognition. Moreover, in addition to a condition with landmarks and one without, we realized a third one where the course-maintaining function of landmarks was emphasized by its semantic value. We have already mentioned the influence of the semantic value for spatial knowledge and the fact that a systematic study concerning wayfinding behavior is missing. Therefore, in our study, landmarks adjacent to a correct, an incorrect, or no wayfinding decision belonged to one of three separate semantic categories (animals vs. music instruments vs. fruits), whereas no such structure was provided in the randomized landmark condition.

We were interested in whether the different age-groups would profit from this emphasis differently. It is well known that children spontaneously organize items when the members of one category are highly associated, as was the case for the category *animal* and the members *cat* and *dog* in a study by Frankel and Rollins (1985). The spontaneous classification of items can be found reliably at the age of 10 to 12 (Plumert, 1994). Hund, Plumert, and Benney (2002) showed that experiencing nearby locations together in time increases the weight 9- and 11-year-olds assign to categorical information in their estimates of locations in a small-scale space. Finally, we have also already mentioned the influence of the categorical information of objects on spatial memory (Hund & Plumert, 2003).

The study was conducted in a virtual environment of sufficient complexity so that this environment could be explored in a self-determined way. Besides the lack of a control group in the study by Cohen and Schuepfer (1980), the realization of *wayfinding behavior* and spatial knowledge by way of a discontinuous presentation of six scenes as separate slides during the learning phase constitutes an additional objection to their study. When a slide was presented, subjects had to name the correct decision, and when their answer was incorrect, they had to try again. In the end, subjects had to learn the following sequence of (verbal) decisions: right, right, left, left, right, left. Wayfinding behavior as the ability to find a new way in an unknown environment was not inevitably involved at all, but instead, one might suggest that performance was based on a simple verbal cued recall condition in which the landmarks served as cues. Whether this criticism is valid is not the scope of the present paper. What should have become obvious, however, is that wayfinding behavior and spatial knowledge should be investigated either in real or in virtual environments of sufficient complexity.

We differentiated aspects of spatial cognition as follows: Wayfinding behavior was understood as the wayfinding performance (number of trials needed to reach a learning criterion) and the orientation behavior (the strategies used) in the wayfinding phase. Spatial knowledge acquisition was retrieved by direction estimations, by two detour tasks, and by a map task, whereas landmark knowledge was measured by means of a landmark recall and localization task. For our experiment, a desktop virtual environment solution was used in which the environment was displayed on a computer monitor. A virtual environment was chosen because it allows for economically varying the structure of the environment and registering the wayfinding behavior online. In this way, a large environmental space was simulated adequately (for a comprehensive discussion of the advantages and drawbacks of desktop virtual environments in spatial cognition research with children see Jansen-Osmann, 2005; Jansen-Osmann & Wiedenbauer, 2004a, 2004b, 2004c). Contrary to most other studies, participants were allowed to explore the virtual environment in a self-determined way. Although this has the disadvantage that exposure to the environment was not strictly controlled, this method seems to be closer to reality and especially helpful for children when acquiring knowledge (Feldman & Acredolo, 1979).

To summarize, based on the two assumptions of (a) a fine-to-coarse development where the fine-space aspect of cognition should already be fully developed for second graders, at least at a qualitative level, and (b) the idea that landmarks increase the fine-space aspects of place connectivity, one would expect that landmarks should improve wayfinding behavior of both children and adults in the same way. However, it is not obvious why the presence or absence of landmarks should influence spatial knowledge at a survey level. Due to the study by Hund and Plumert (2003), we assumed that the categorical accentuation might influence spatial knowledge for both children and adults in the same way.

Method

Participants

Sixty children from two grade levels (second grade and sixth grade) and 30 adults participated in the study. The mean age of the participants was 7.83 years for the second graders, 11.23 years for the sixth graders, and 25.9 years for the adults. Gender was balanced, with 15 females and 15 males in each age-group. Children were recruited through advertisements in local newspapers; adults were recruited by postings, through a general participants' list, and personally at the Heinrich-Heine-University of Düsseldorf. Prior to testing, all parents and participating adults gave their informed written consent for participation in the study. The local ethics committee approved the experimental procedure.

Materials

The experiment was conducted in a virtual world using the software 3D GameStudio A5. The main structure of the symmetrical virtual maze was formed by six main routes, which were connected (see Figure 1 and 2). The inner section of the virtual maze was formed by four hexagons, which were located inside the room. At decision points it was possible to choose between routes that branched off at an angle of either 0° (straight ahead), 45°, 90°, or 135°. Three versions of the identical maze existed: two mazes with landmarks and one without landmarks. Each maze with landmarks contained 12 two-dimensional visual cues. There were four landmarks each from one of the following three categories: fruits (apple, banana, pear, strawberry), animals (cat, dog, parrot, rabbit), and musical instruments (drum, guitar, trumpet, violin). All landmarks were comparable with respect to coloring and brightness. In the categorical landmark condition, the function of all landmarks regarding the task to find the shortest route to the goal object was organized by categories: All landmarks belonging to the category *animal* were located adjacent to a correct wayfinding decision. The landmarks of the category *musical instrument* were located adjacent to an incorrect wayfinding decision, while those of the category *fruit* were not associated with the task to find the shortest route to the goal. Within this experimental design, the assignment of a specific landmark category was confounded with a special wayfinding decision. Assuming that the semantic value of the landmarks did not differ between the three categories, however, a possible influence might be denied. In the randomized condition, the same objects and locations were used, but the category of the objects did not have a course-maintaining function (see Figure 1).

The virtual world was projected onto a 17-inch flatscreen monitor. The distance between the monitor and the

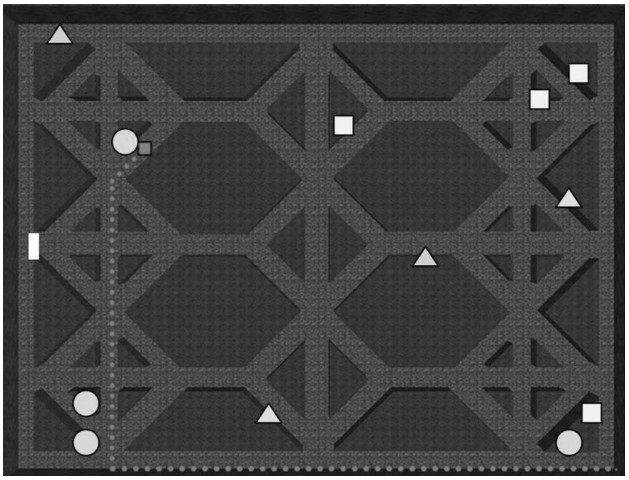


Figure 1. An overview of the maze with categorical landmarks. The shortest route to reach the target figure was marked. The circles describe the items of the category *animal*, the triangles describe items of the category *fruits*, and the squares symbolize items of the category *musical instruments*. The rectangle describes the invisible, impermeable wall.

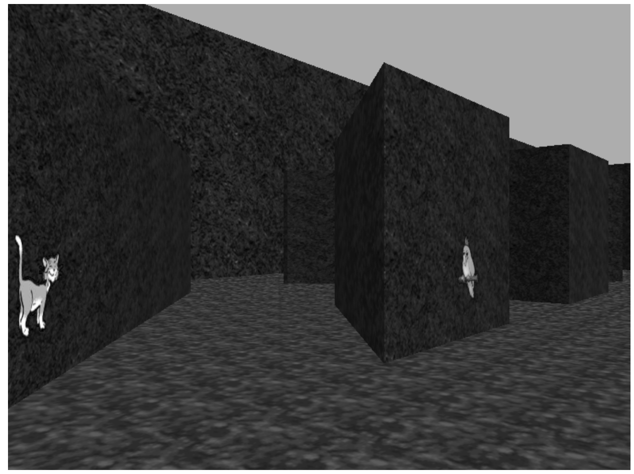


Figure 2. A snapshot into the maze with landmarks.

participant was 0.5 meters. Participants explored the simulated maze by using a joystick. The start position was marked by the green-red written word start and was always located in the lower right corner. Therefore, the start position was identifiable during each walk through the virtual world. All walls and the ground in the maze were green. One object (a virtual fish) served as the target figure. Figure 2 shows a snapshot into the maze with categorical landmarks.

Procedure

Individual test sessions lasted about 30 to 60 minutes and took place in a laboratory at the Heinrich-Heine-University of Duesseldorf. First, the computer utilization behavior was registered: Children and adults were asked how often they play computer games (in hours per week), which games they play (if they were games with wayfinding or maze elements, or more strategic games), and which input device they use for playing.

Second, all participants were given the opportunity to practice handling the joystick by navigating through another—nonexperimental—maze. In this "learning maze" as well as in the following experimental maze, the walking speed approximated a real-life walking speed. The joystick had to be pushed until dead-stop so that velocity was constant at 0.9 m per second; rotation was 10° per second. There were three experimental phases: an exploration phase, a wayfinding phase, and a spatial knowledge phase.

Exploration Phase

Participants received the following instruction: "Now, you have to explore an unknown virtual environment. Please push the joystick until dead-stop. Just try to get an impression of the structure of the virtual environment. This phase will be ended after 3 minutes." Neither the target object nor any of the landmarks were visible while participants were exploring the maze. Because this kind of instruction did not predetermine navigation behavior, this first phase varied between participants.

Wayfinding Phase

Subsequent to the exploration phase, participants were told that they now had to solve another task in the same virtual maze, which—depending on the condition—now potentially contained landmarks. They received the following instruction: "Now, you have to find the shortest route from the start position to a target figure (the virtual fish). This route is defined as the one with the shortest distance to be walked *and* which has only two turns. But you do not have to consider the first turn directly adjacent to the start position. Surely, you are free to walk around as much as you like, but try to find the shortest route as soon as possible." There was no instruction given about going back to the start position. The wayfinding phase was finished when subjects took the shortest route in two consecutive trials (learning criterion). Because two parallel routes fulfilled this requirement, the route lying farther away from the start position was blocked by an invisible, impermeable wall at the second turn. At this position, the target object could be seen but not reached. Therefore, only one correct route was possible: After turning left at the start position, the participants had to turn right at the third intersection and right again five decision points later. In contrast to the exploration phase, this wayfinding phase consisted of a problem-solving task, because the wayfinding behavior now was specified. The target figure had to be reached by choosing—beginning from the start position—two turns only. To shorten the experimental procedure, only one learning route was used. Furthermore, previous studies showed that the results did not differ depending on the number of routes to be learned (Jansen-Osmann & Schmid, 2005).

In this wayfinding phase, the wayfinding performance and the orientation behavior were analyzed. First, the number of trials needed to reach the learning criterion was computed (wayfinding performance). Each walk from the start position to the target figure was defined as one trial. Second, the orientation behavior was measured by means of (a) the number of turns back to the start point (*start*), (b) the number of turnarounds at an angle of 180° (*turnaround*), and (c) the number of segments taken twice (*twice*). These variables were computed for the last trial before reaching the criterion. The last trial was considered especially important because it could be taken for granted that all participants had formed a considerable wayfinding performance by then. Cronbach's alpha of .71 showed a sufficiently high internal consistency of these three measurements of orientation behavior. The wayfinding phase had to be distinguished from the spatial knowledge phase because the learning process of the route had not been finished yet at this point.

Spatial Knowledge Phase

In this phase, spatial knowledge was retrieved by a direction estimation task, two detour tasks, and a map task. To get a more reliable measurement of spatial knowledge, four different tasks were used. Furthermore, a landmark recall and localization task was conducted.

Direction Estimation Task

This task began when participants found the target figure by using the correct route twice in a row. Participants were instructed to estimate the direction from the target to the start position by first rotating the joystick in the correct direction and then pressing a special joystick button. The absolute error between the estimated and the correct angle was computed. After pressing the button, a virtual barrier appeared blocking the shortest route from the target to the start position for the subsequent detour task.

Detour Tasks

After the direction estimation, participants were instructed to find the shortest alternate route from the target object to the start position (*detour task 1*). Having arrived at the start position, they then had to find the shortest alternate route from the start position to the target (*detour task 2*), with the shortest route again blocked by an additional visual barrier. The distance walked to reach the start position from the goal object and vice versa was registered.

Map Task

All participants were given a ready-made overview of the maze and were asked to mark the position of the target figure. This task was not time limited. To analyze the precision of the acquired survey knowledge, the linear distance (in mm) from the marked to the correct position of the target figure in the overview was computed. A good performance, thus, was indicated by a small distance.

Landmark Task

All participants who learned the maze with landmarks had to name all the landmarks they could remember (*recall task*), and afterward, they had to mark the landmarks' positions in an overview of the maze (*localization task*). Because all participants had to pass the landmarks adjacent to a correct wayfinding decision in order to reach the learning criterion in the wayfinding phase, we concentrated on the performance of *recall* and *localization* of only those landmarks.

Experimental Design

The factors *age-group* (second graders, sixth graders, and adults) and *type of maze* (without landmarks, with randomized landmarks, with categorical landmarks) were varied between subjects. In addition, the factor *kind of detour task* (detour 1: from the goal to the start; detour 2: from the start to the goal) and the factor *kind of landmark task* (recall task, location task) were analyzed where appropriate.

Results

Gender Differences

Gender differences were not the main focus of the study. However, as differences between females and males are often found in spatial cognition research (Devlin & Bernstein, 1995; Lawton, 1994), they will be reported for the sake of completeness. Gender differences were found only in the linear distance measure of the map task, $F(1, 72) = 4.74$, $p < .05$, whereby males ($\bar{x} = 36.96$, $SESE = 6.34$) outperformed females ($\bar{x} = 44.0$, $SESE = 7.5$). In addition, there was one three-way interaction (factor *age-group*, *sex*, and *type of maze*) for the recall of the landmarks adjacent to a correct turn, $F(2, 48) = 4.45$, $p < .05$. This interaction, however, was not regarded any further because it did not reveal any systematic pattern.

Computer Experience

A univariate analysis of variance revealed a significant difference in computer experience (hours per week) for the factor *age-group*, $F(2, 81) = 6.26$, $p < .01$. Older children played computer games more often ($\bar{x} = 4.25$, $SE = 0.8$) than younger children ($\bar{x} = 2.26$, $SE = 0.41$) and adults ($\bar{x} = 1.57$, $SE = 0.35$). Most importantly, however, no significant correlations existed at all between computer experience and the spatial cognition measurements obtained here.

1. Wayfinding Phase

Wayfinding Performance

Concerning the total number of trials needed to reach the learning criterion, a univariate analysis of variance revealed a significant influence of the factor *age-group*, *F*(2,

81) = 13.52, p <.001; and the factor *type of maze*, F(2, 81) = 7.33, p <.001. Adults ($\bar{x}$ = 3.43, SE = 0.36) and older children ($\bar{x}$ = 3.13, SE = 0.5) needed fewer trials to reach the learning criterion than younger children ($\bar{x}$ = 6.53, SE = 0.75), Bonferroni adjusted. In the maze without landmarks ($\bar{x}$ = 5.97, SE = 0.85) participants needed more learning trials than in the maze with randomized ($\bar{x}$ = 3.83, SE = 0.39) as well as categorical landmarks ($\bar{x}$ = 3.30, SE = 0.40, Bonferroni adjusted. Figure 3 shows the influence of age-group and type of maze on wayfinding performance. There was no significant interaction between both factors, F(4, 81) = 1.01, *n.s.*

Orientation Behavior

A multivariate analysis of variance with the dependent variables *start*, *turnaround*, and *twice* revealed a significant effect of age-group for the variables *start*, F(2, 81) = 4.23, p <. 05; *turnaround*, F(2, 81) = 4.19, p <. 05; and *twice*, F(2, 81) = 3.37, p <. 05.

Younger children ($\bar{x}$ = 2.63, SE = 0.75) went back to the start position more frequently than adults ($\bar{x}$ = 0.57, SE = 0.19). The difference between the older children ($\bar{x}$ = 1.8, SE = 0.37) and adults was not significant (Bonferroni adjusted). Adults ($\bar{x}$ = 2.93, SE = 1.55) went fewer segments twice than older children ($\bar{x}$ = 7.03, SE = 1.4). No statistical significant difference between the younger children ($\bar{x}$ = 6.27, SE = 1.24) and the other two age-groups existed (Bonferroni adjusted). In addition, younger children ($\bar{x}$ = 6.50, SE = 1.88) turned around more often than adults ($\bar{x}$ = 1.67, SE = 0.57). No difference between the older children ($\bar{x}$ = 4.87, SE = 0.86) and the other age-groups was found (Bonferroni adjusted). No effect of type of maze was found, either as a main effect for the variables *start* F(2, 81) = 0.32, *n.s.*; *turnaround* F(2, 81) = 1.35, *n.s.*; and *twice* F(2, 81) = 2.57, *n.s.* or as an interaction for the variables *start* F(4, 81) = 0.78, *n.s.*; *turnaround* F(4, 81) = 1.69, *n.s.*; and *twice* F(4, 81) = 0.47, *n.s.*

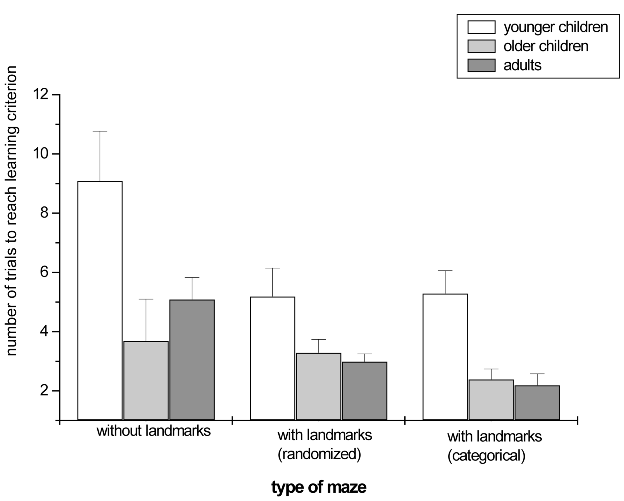


Figure 3. Number of trials needed to reach the learning criterion as a function of *age-group* and *type of maze*. (Error bars indicate standard errors.)

2. Spatial Knowledge Phase

Direction Estimation Task

A univariate analysis of variance for the estimation from the goal object to the start position revealed a significant main effect of the factor *age-group*, F(2, 81) = 12.84, p <.001. The estimation of the younger children ($\bar{x}$ = 61.57°, SE = 8.80) was less precise than the estimation of adults ($\bar{x}$ = 8.5°, SE = 6.0) or older children ($\bar{x}$ = 20.03°, SE = 8.65), whereas the latter two groups did not differ from each other (Bonferroni adjusted). No effect of type of maze was found, either as a main effect, F(2, 81) = 2.13, *n.s.*, or as an interaction, F(4, 81) = 1.14.

Detour Tasks

Detour Tasks 1 and 2 (From the Goal to the Start Point and Vice Versa)

A repeated analysis of variance revealed only a significant interaction between the factors *age-group* and *type of maze*, F(4, 81) = 3.77, p <.01, and a main effect of the factor *age-group*, F(2,81) = 7.58, p = .001. The significant interaction (see Figure 4) is due to the significant influence of the factor *type of maze* for the older children, F(2, 27) = 3.57, p <.05. Older children walked significantly longer in the maze with randomized landmarks ($\bar{x}$ = 4,723.2, SE = 511.64; for comparison, adults $\bar{x}$ = 4,283.15, SE = 459.64, and younger children $\bar{x}$ = 4,054.8, SE = 395.99) than in the maze without any ($\bar{x}$ = 3,378.3, SE = 247.91; for comparison, adults $\bar{x}$ = 3,442.7, SE = 182.39, and younger children $\bar{x}$ = 5,775.6, SE = 602.25) and with categorical landmarks ($\bar{x}$ = 3,837, SE = 263.26; for comparison, adults $\bar{x}$ = 3,532.8, SE = 371.81, and younger children $\bar{x}$ = 5,366.1, SE = 677.1), Bonferroni adjusted. There was no influence of type of maze for the younger children, F(2, 27) = 2.47, *n.s.*, and the adults, F(2, 27) = 1.67, *n.s.* Moreover, there was no difference between the distances walked in both detour tasks F(1, 81) = 1.28, *n.s.*

Map Task

Linear Distance

The univariate analysis of variance on the straight line distance between the marked and the correct position of the goal revealed only a significant influence of the factor *age-group*, F(2, 81) = 6.48, p <.01. Bonferroni adjusted post hoc testing revealed that the registered straight line distance was significantly shorter for adults ($\bar{x}$ = 18.20, SE = 4.53) than for the younger children ($\bar{x}$ = 50.87, SE = 8.20) and the older children ($\bar{x}$ = 39.53, SE = 6.55), whereby the difference between the older and younger children and the older children and adults was not statistically significant. No effect of type of maze was found, either as a main effect F(2, 81) = 1.58, *n.s.*, or as an interaction F(4, 81) = 1.28, *n.s.*

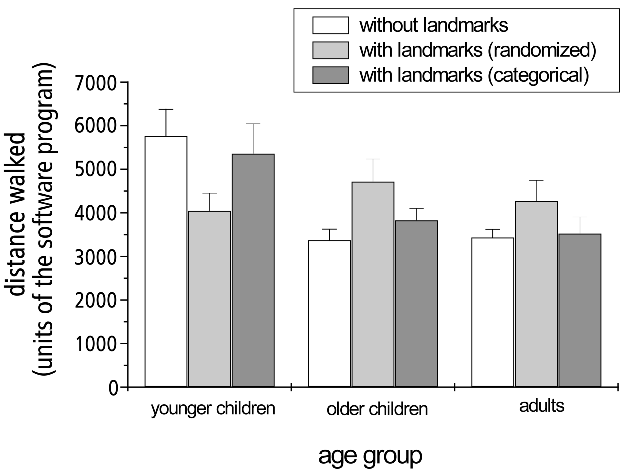


Figure 4. Means of the distance walked in both detour tasks as a function of *age-group* and *type of maze*. (Error bars indicate standard errors.)

Landmark Task

Recall and Localization of Landmarks Adjacent to a Correct Turn

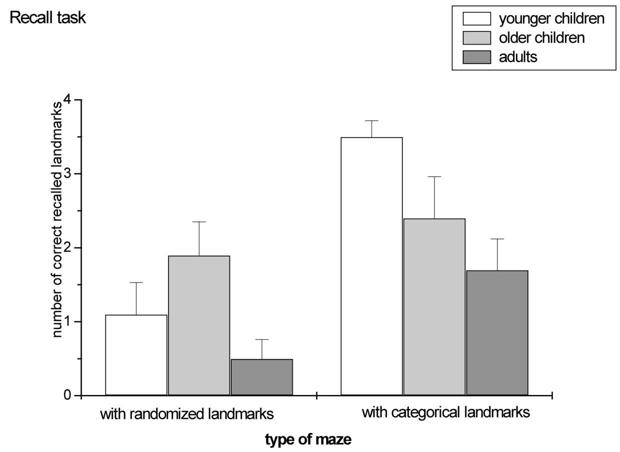
A repeated analysis of variance on the recall and localization of landmarks adjacent to a correct turn showed a three-way interaction between age-group, type of maze, and kind of landmark task, $F(2, 54) = 4.59$, $p < .05$; a two-way interaction between age-group and kind of landmark task, $F(2, 54) = 13.01$, $p < .01$, and between age-group and type of maze $F(1, 54) = 10.49$, $p < .01$; and a main effect of type of maze, $F(1, 54) = 10.49$, $p < .01$. Figure 5 shows that the recall and localization of the categorical landmarks differed between adults and younger children dependent on the kind of task. Whereas adults ($\bar{x} = 1.7$, $SE = 0.42$) recalled fewer categorical landmarks than younger children ($\bar{x} = 3.5$, $SE = 0.22$), younger children ($\bar{x} = 1.4$, $SE = 0.4$) located fewer categorical landmarks than adults ($\bar{x} = 3.5$, $SE = 0.22$). Such an influence was not demonstrated for the recall and localization of the randomized landmarks.

Discussion

This is the first study that investigated the wayfinding behavior and spatial knowledge acquisition in an environmental space with and without landmarks under a developmental perspective. Our results confirm that fine-space information improved wayfinding behavior for both children and adults in quite the same manner. They both needed fewer trials to learn a way in an unknown environment with landmarks than in an environment without landmarks. This result contrasts with the interpretation of Cohen and Schuepfer (1980). Children did not rely more on the presence of landmarks than adults; both children and adults used this kind of information to solve a wayfinding task, which allowed for exploring and learning a way in a self-determined manner. This indicates that children as well as adults use fine-space information for close locations (place-connectivity) in their wayfinding behavior. On the other hand, we did not find a benefit due to the presence of landmarks, either for the orientation behavior or for the acquisition of spatial knowledge (measured by detour tasks, direction estimation, and a map task) by adults and children. These results emphasize the importance of landmarks as navigation aids (Golledge, 1991) but challenge their importance for spatial knowledge acquisition. In addition, our results show that the association of the landmark's function with a semantic category did not influence wayfinding behavior or spatial knowledge. This result contrasts with the hypothesis that the category association should at least influence spatial knowledge (i.e., Hund & Plumert, 2003) and might be explained by the assumption that the categorical affiliation was not sufficiently salient or intuitive. Therefore, an additional experiment should be conducted where the importance of other categories of landmarks could be investigated (like local vs. global landmarks; see, e.g., Cornell, Hadley, Sterling, Chan, & Boechler, 2001).

The categorical accentuation of landmark-location pairings did, however, influence the retrieval of landmark knowledge itself: Younger children recalled more landmarks adjacent to a correct turn than adults when these landmarks belonged to a single category. Because there was no correlation between the number of learning trials in the wayfinding task and the recall of landmark knowledge, this knowledge was not influenced by how often participants saw the landmarks during the wayfinding phase. In contrast to the improved recall performance, younger children were less capable than adults of locating categorical landmarks adjacent to the correct turn at the correct location. The association between a categorically emphasized function of a landmark and its correct location was much more difficult for them than for adults. This result indicates that children as young as 8 years old did recognize the semantic or categorical value of landmarks but were at this point not able to integrate this in the process of forming a survey representation. In other words, the representation of the coarse-grained information concerning the memory of location (see Huttenlocher et al., 1991) was not developed completely yet at the age of 8.

Being aware that we now turn to the speculative part of the discussion, the differential effects of categorical landmarks on subjects' recall versus localization performance as a function of age might indicate a differential organization of spatial knowledge. We propose that the strength of the memory representations of the landmarks, on the one hand, and the association between the landmarks and their spatial localizations, on the other hand, might differ for children versus adults. Children did show very good memory for categorical landmarks without being able to localize them correctly. Therefore, we suggest that children do store the existence of landmarks, but that the landmarks are only weakly associated to their spatial location. Additionally, we assume that in addition to route knowledge, adults also form survey knowledge. This knowledge, in return, serves as a retrieval cue. So, despite their poor performance in the



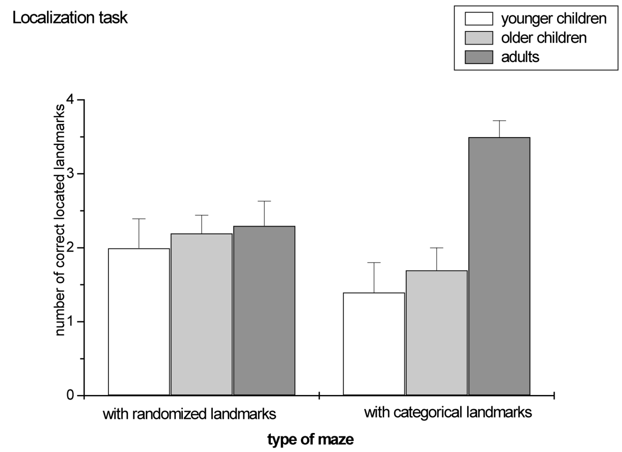


Figure 5. Mean number of landmarks recalled (Figure 5a) and located correctly (Figure 5b) as a function of *age-group* and *type of maze*. (Error bars indicate standard errors.)

recall task, adults' performance improved when the environmental space served as a retrieval cue. To put it more clearly, what we suggest are the following hypotheses: Whereas children remembered a landmark and also the correct wayfinding decision associated with the landmark, the spatial position of this landmark was only poorly represented. Adults, in contrast, might represent wayfinding decisions, but more importantly, might form survey representations (more) independent of landmarks. Future work should evaluate the empirical basis of these speculations.

Taken together, the overall results show the importance of the category affiliation for the retrieval of landmark knowledge, but not for wayfinding performance, orientation behavior, and spatial knowledge. This complements a recent study by Wiener and Mallot (2003), which showed that if region-connectivity is emphasized, the neighborhood of objects from the same object category eased wayfinding performance. Whereas Wiener and Mallot divided the space into regions through a clustering of objects, the object category in the study presented here solely amplified the course-maintaining function of the landmarks, which means only place-connectivity was accentuated. Therefore, we can conclude that the clustering of objects due to their categorical value affects different levels in a graphlike representation in a different manner.

In addition, due to the overall influence of landmarks on wayfinding performance but not on orientation behavior and spatial knowledge, the results hint that these aspects of spatial cognition might be dissociable. This is an assumption that is in line with our former studies, where we showed, for example, that structuring by color influenced wayfinding performance but not spatial knowledge acquisition (Jansen-Osmann & Wiedenbauer, 2004b); the learning of a structural map influenced spatial knowledge acquisition but not wayfinding behavior (Jansen-Osmann, Wiedenbauer, Schmid, & Heil, 2005); and the symmetrical structure of the explored environment ameliorated the wayfinding behavior of younger children and did not influence spatial knowledge acquisition (Jansen-Osmann & Schmid, 2005). These results confirm the well-known distinction between *doing and knowing* in spatial cognition research (Liben, 1988, 1999) and the assumption of Creem and Proffitt (1998, 2001) that there are two different systems for processing spatial information: a perception-action system where spatial information is provided for guided action or motor responses and a cognitive system, which contains internal representations. But surely, although both systems can be dissociated, they might also have common features, which should be investigated in further studies in more detail. Lastly, it has to be taken into account that the possible dissociation of wayfinding performance, orientation behavior, and spatial knowledge demands on the one hand a more contextual perspective on spatial cognition development and, on the other hand, an extension of such a theoretical assumption as the model of Siegel and White (1975).

Concerning the developmental aspect of this study, most measurements obtained here revealed differences between children and adults: Concerning the *wayfinding performance*, younger children needed more trials to learn the route than older children and adults, a result that was independent of the existence of landmarks. Regarding their *orientation behavior* while learning a route, younger children orientated themselves more often at the start position and turned around more frequently than adults. This is a result that is in line with our earlier studies (see, e.g., Jansen-Osmann, 2005). Furthermore, adults went fewer segments twice than children, even though only the difference between adults and older children reached statistical significance. Concerning spatial knowledge, age differences were found in all measurements. The direction estimation of younger children was less accurate than the estimation of the adults and of the older children, whereby the direction estimation error for the younger children was noticeably high ($\bar{x} = 61.57$). This result is in accordance with two previously conducted studies showing a comparably high direction estimation error in younger children (Jansen-Osmann, 2005; Jansen-Osmann & Schmid, 2005). This indicates that younger children had substantial difficulties estimating a direction in a desktop virtual world. The direction estimation error of adults and older children corresponds to that found in a study by Waller, Montello, Richardson, and Hegarty (2002). Furthermore, Waller, Beall, and Loomis (2004) recently showed in a study with adults that direction estimation turned out to be as accurate in a desktop virtual situation as in an immersive virtual environment or a real environment. Controlling the factor age-group, there was no relation between the different number of trials in the wayfinding phase and the spatial knowledge measurements. As a result, we can rule out that the differences in spatial knowledge and wayfinding performance might be attributed to a different amount of experience of the maze.

To summarize, with this experiment, the first step has been taken to investigate the role of landmark-location pairings for wayfinding behavior and spatial knowledge acquisition, respectively, in an environmental space for adults and children. Our study confirms—in a systematic investigation, with a control group learning a way through an unknown virtual space without landmarks—that school-age children are able to use fine-space information in the same manner as adults during the wayfinding process and did not rely more heavily on the existence of landmarks regarding wayfinding behavior. Furthermore, the retrieval of landmark knowledge was dependent on the course-maintaining function of the landmarks and on the membership in a semantic category.

Taking these fruitful results into account, it seems to be worth it to go ahead and investigate, for example, the questions of the development of the coarse-space planning process in more detail; a developmental achievement from second graders to sixth graders is expected due to the studies of Cornell and his colleagues (e.g., Cornell, Heth, & Broda, 1989), and because further studies showed that a mental subdivision of spaces is not present until the age of 10 (Newcombe & Huttenlocher, 2000; Sandberg, 1995). Furthermore, we know that people use a variety of methods when asked to solve wayfinding tasks in an environmental space (Golledge, 1991; Cornell & Heth, 2000; Cornell, Sorenson, & Mio, 2003). A systematic investigation of the orientation behavior, which means of different wayfinding strategies, therefore, might be reasonable (compare Dalton, 2003; Hochmair & Frank, 2000). Finally, a last aspect concerning the use of desktop virtual environments has to be investigated in future work: One drawback often observed is that spatial information that is learned in a virtual environment is orientation specific (see for an overview Montello, Hegarty, Richardson, & Waller, 2004; Christou & Bülthoff, 1999; Richardson, Montello & Hegarty, 1999). In the present study, this seems to have been less of a problem. There was no difference concerning the overall distance walked in the two detour tasks. Given that this is in line with the assumption that spatial memory seems to be independent of orientation if self-determined exploration is allowed (Evans & Pezdek, 1980), the different results compared to the studies of Christou and Bülthoff (1999) and Richardson, Montello and Hegarty (1999) should nevertheless be examined in more detail.

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