

Wayfinding Performance in and the Spatial Knowledge of a Color-coded Building for Adults and Children

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The study reported here investigates the effect color has on the performance in a wayfinding task, the wayfinding strategies used and the acquisition of survey knowledge of a total of sixty participants: twenty second graders, sixth graders, and adults each. All participants had to find their way to a goal in a virtual environment with either a colored or a gray ground. After that, they had to find the shortest way from the start position to the goal in two consecutive trials, to draw a sketch map of the maze, and to mark the position of the goal figure in an overview of the maze. The results showed that color helped all participants to improve their performance in the wayfinding task, influenced the use of some wayfinding strategies but did not improve the acquisition of survey knowledge. Furthermore, there was a developmental achievement from second graders to adults. The results implicate firstly that children and adults similarly rely on the structuring of space through color when navigating through an unfamiliar large-scale environment, and secondly that there is a dissociation between wayfinding behavior and spatial knowledge.

Keywords: Spatial cognition, wayfinding, cognitive map, children, development, spatial strategies, virtual environments.

When children and adults explore an unfamiliar environmental space their wayfinding behavior and the acquisition of spatial knowledge is influenced by the existence of environmental factors such as landmarks (Beck & Wood, 1976; Carr & Schissler, 1969, Cohen & Schuepfer, 1980). Apart from landmarks, color

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can also be used as an environmental feature for structuring areas of space (Gärling, Böök, & Lindberg, 1986; Weismann, 1981). Although color-coding is being used more and more to help people to get around in official buildings such as hospitals, schools etc., there is only one study, in which the effect of color on cognitive mapping was investigated systematically (Evans, Fellows, Zorn, & Doty, 1980). These authors showed that an interior color coded building eased the wayfinding behavior and the acquisition of spatial knowledge of adults: Two groups of participants explored an unfamiliar university building with or without interior color. Participants in the color-coded condition made significantly fewer errors when finding the shortest way to three different destinations, located specific targets more accurately, and recalled more floor plans of the building than the participants in the condition without color. It is the main goal of our study to investigate the role of color coding for the wayfinding behavior, that means the performance to find a way and the strategies used, and the acquisition of spatial knowledge for children at school age and adults. We chose children at this age because there is ample evidence that children's spatial knowledge of large-scale space environments becomes more and more accurate over the course of middle and late childhood (Cohen & Schuepfer, 1980, Jansen-Osmann & Wiedenbauer, 2004). Advising 6 and 12 year old children to pay attention to landmarks near the route helps both age groups to retrace the route successfully, but only the older children could profit from being told to notice distant landmarks (Cornell, Heth, & Broda, 1989). Almost thirty years ago, Siegel and White (1975) presented a formal description of the development of spatial knowledge. They assumed that children firstly acquire landmark knowledge, followed by route knowledge, and then survey knowledge. This was confirmed by Cousins, Siegel, and Maxwell (1983) in studies with children of the age 8–13. Allen and Ondracek (1995) showed that the developmental improvement in children's performance on tasks requiring the acquisition of spatial knowledge was related to age-sensitive cognitive abilities.

While the importance of landmarks for the processing of spatial information in a large scale space in children at school age is well investigated, empirical studies investigating the possible important role of color are missing. We only know that color does not help younger children (around 2–4 years) to re-orientate themselves in a vista space—a space which includes the viewer and in which all objects and locations can be perceived from one single-vantage point (Gouteux & Spelke, 2001; Hermer & Spelke, 1996). Surely, we can not transfer these results to the navigation behavior of school aged children in an environmental space that easily. As Learmonth, Newcombe, and Huttenlocher (2001) pointed out, the size of the room was critical in obtaining the results found by Hermer and Spelke (1996).

It remains to be investigated, if color has an equally important role as landmarks for the spatial knowledge acquisition in an environmental space for children. On the one hand, color can structure space, on the other hand and in contrast to landmarks, it does not provide any spatial information. If color would have the same effect as landmarks, structuring by color should help younger

school aged children more than older ones and adults concerning the wayfinding performance in and the spatial knowledge acquisition of an unknown environmental space.

In contrast to the developmental studies of navigation performance and spatial knowledge acquisition, no studies exist about wayfinding behavior and strategies. Up to now, strategies are only investigated in relation to sex (for example Lawton, 1996) and only for adults (Haq & Zimring, 2003; Kuipers, Tecuci, & Stankiewicz, 2003). Most studies show that males prefer Euclidean cues, while females are more likely to memorize landmark cues (Galea & Kimura, 1993; Devlin & Bernstein, 1995; Lawton, 1996). Because strategic behavior may be reflected in directional choices, some studies analyze the directions chosen by participants: Hochmair and Frank (2000) postulated the least angle strategy, which is based on the navigator's heuristic of selecting the street segment at an intersection, which is most in line with the target, or the believed target's direction. Dalton (2003) postulated a complexity minimizing strategy, whereby people unconsciously attempt to steer a straight path. When analyzing the participant's navigational behavior in a virtual environment, she recorded the mean chosen angle at each decision point and could show that the choices made by participants are not at random. It appeared that participants chose the straightest possible routes as opposed to more meandering ones. What we do not yet know is how the structuring of space influences different wayfinding strategies such as the complexity minimizing strategy used by children and adults. This might be due to the fact that appropriate environments were missing until the emergence of virtual environments, which are appreciated more and more in general spatial cognition research.

In the present study we used a desktop virtual system, which displayed the environment on a computer monitor. Apart from desktop virtual systems, there are immersive systems, which use devices like Head Mounted Displays and give the user the impression of being completely immersed, without any trace of the real world left. Desktop virtual systems, which are widely used and appreciated for the investigation of the cognitive processes of spatial cognition (for example Gillner & Mallot, 1998; Ruddle, Payne, & Jones, 1997; 1999) simplify the investigation of spatial knowledge by creating environments of varying complexity, taking online measurements during navigation, and controlling many spatial learning parameters (Péruch, Belingrad, & Thinus-Blanc, 2000). The drawback is that they do not consider the integration of self motion to be equivalent to actual environmental experience (Witmer, Bailey, Knerr, & Parsons, 1996). Richardson, Montello, and Hegarty (1999) suggest that similar cognitive mechanisms are involved in a desktop virtual and real learning condition, but that participants are susceptible to disorientation after rotation. Waller, Beall, and Loomis (2004) recently showed that direction estimations were more accurate in a real environment and in an immersive desktop virtual environment compared to a static visual image of the environment and a traditional paper-and-pencil direction measurement method. Because immersive virtual environments have the great disadvantages that aftereffects (motion

sickness, disturbance of balance, and drowsiness) occur in many participants (Stanney & Salvendy, 1998), it seems irresponsible to use immersive virtual environments in research with children.

Overview of This Study

The present study investigates the influence that structuring space according to color has on wayfinding performance, wayfinding strategies, and spatial knowledge in an unfamiliar virtual environment. A virtual environment was chosen because it allows to economically vary the coloring of the environment and to register the navigation behavior and strategies used. A large environmental space could be simulated adequately in that kind of virtual space. Additionally, our study was conducted under a developmental perspective. We chose school aged children because previous studies showed a related spatial cognitive developmental improvement between second and sixth graders beside a general cognitive advancement (Allen & Ondracek, 1995). Contrary to other studies, we allowed participants to explore the virtual environment self determined. Although this has the disadvantage that exposure to the environment could not be strictly controlled, this method seems to be closer to reality and especially helpful for children when acquiring their knowledge (Feldman & Acredolo, 1979). Furthermore, it has been shown that allowing people to navigate on their own leads to a better performance than passive exposure to a desktop virtual situation (Farrel, Arnold, Pettifer, Adams, Graham, & MacManamon, 2003).

The following hypotheses were addressed:

- A color-coded environment does help both children and adults to find their way and to develop survey knowledge.
- It remains to be tested, if the structuring by color affects the wayfinding behavior and the use of different wayfinding strategies.
- It remains to be investigated, if younger children rely more on the existence of color than older ones and adults.

Method

Participants

Forty children from two grade levels (second and sixth) and twenty adults participated in the study. The mean age of the second graders was 7.9 years, the sixth graders 11.8 years, and the adults 23.5. There were 10 females and 10 males in each age group. Children were recruited through advertisements in local newspapers. Prior to testing, all parents gave their informed written consent for participation in the study. The local ethics committee approved the experimental procedure.

Materials

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 and which input device they use for playing. The experiment was conducted in a virtual world using the software 3D GameStudio A5. The virtual maze consisted of three main quadratically arranged route networks linked by eight routes which branched off at an angle of either 90° or 45° . Therefore, at decision points participants could choose between routes which branched off at an angle of either 0° (straight ahead), 90° , 45° , or 135° . The maze was constructed orthogonally, because we know from previous studies that such regular environments eased navigation behavior (Ruddle & Péruch, 2004).

Two versions of the maze existed: One in which the ground was only gray and one in which the grounds of the three main route networks were colored differently (green, red, and yellow). Figure 1 shows an overview of the maze with the correct shortest route from the start to the goal (Figure 1a) and the different colors of the floors (Figure 1b), to get an impression of the coloring arrangement. The virtual world was projected onto a 17-inch flat screen monitor. The distance between monitor and participant was 0.5 meters. Participants explored the simulated maze by using a joystick.

The start position was in a small cul-de-sac with brown walls. All other walls in the maze were gray. Therefore the start position could be identified during each walk through the virtual world. A toy figure resembling a popular figure, *Bob the Builder*, was placed in the second route network in the right half of the maze and served as the target figure.

Figure 2 shows a snapshot into the maze without color (Figure 2a) and with color (Figure 2b).

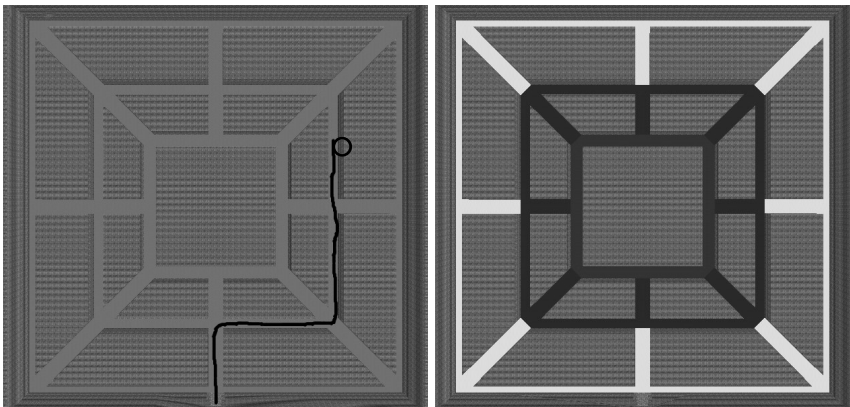


Figure 1. An overview of the maze with gray floor (1a) and the maze with colored floor (1b). Figure 1a shows the arrow trace from the bird's-eye view of the maze (shown is the correct way from the start to the goal). The position of the goal figure is symbolized by a circle.

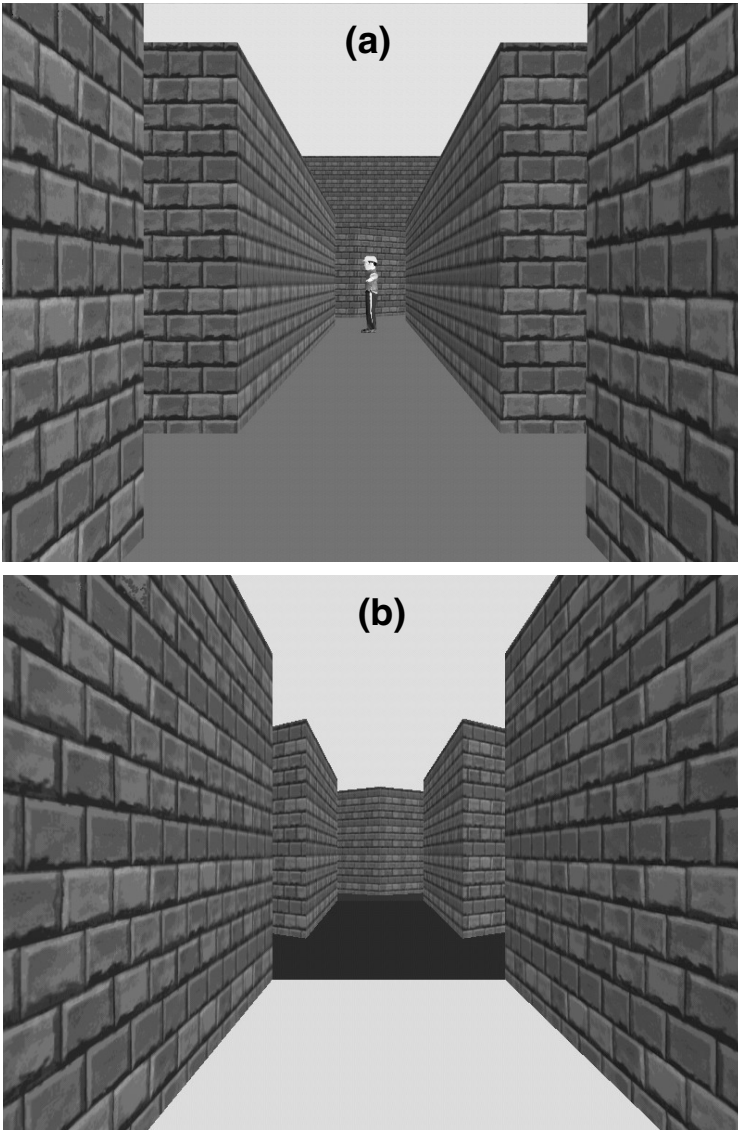


Figure 2. A snap-shot into the maze. Figure 2a shows the maze without color; figure 2b the maze with color from different viewpoints. Figure 2a shows *Bob the Builder*, the goal figure. Both mazes were identical in their geometrical structure.

Procedure

Individual test sessions lasted about 20 minutes and took place in a laboratory at the Heinrich-Heine-University of Duesseldorf. First, children and adults reported their experience with computers. Second, all participants were given the opportunity to practice handling the joystick by navigating through another–non experimental–maze. In this “learning maze” as well as in the following experimental maze the walking speed approximated a real life walking speed. In order to control velocity, the joystick had to be pushed until dead stop. Rotation and translation velocity were the same. The rotation at different angles was equally difficult. Participants from each age group were randomly assigned to one of the virtual mazes (colored vs. gray ground). There were three experimental phases (exploring, learning, and test phase):

Exploring phase. Participants received the following instruction: “Now, you shall explore an unknown virtual environment. Please push the joystick until dead stop. The exploration will end, if you find a well known toy figure, Bob the Builder. Do you know Bob the Builder? (If not, the figure was described). Beside Bob, there are no other objects in the maze. If you see Bob, please navigate directly to him until you hit it.” Because this kind of instruction did not predetermine navigation behavior in the exploring phase, this first phase varied between participants.

Learning phase. After having explored the maze once, participants had to find the shortest way from the start position to the target figure in two consecutive trials. This route (see Figure 1a) was defined as the one with the shortest distance to walk *and* which had only two turns. Only one correct route was possible: Participants had to turn right at the second intersection and to turn left at the next intersection. All other possible routes were longer or had more turns. In contrast to the exploring phase in which the task was to merely reach the target figure, the learning phase constituted a problem-solving task, because the navigation behavior was further specified. That is the target figure Bob had to be reached by choosing two turns only.

Test phase. First, all participants were asked to draw an overview of the maze. Second, they were given a readymade overview of the maze and were asked to mark the position of the target figure and to mark the correct route to it.

During the first two experimental phases, each participant’s position was recorded 6 times per second while they moved through the virtual maze, and their paths taken in each trial were plotted onto an overview and could be retraced. This allowed for the counting of turns made, the registration of the behavior at decision points, and the distance walked in units of the software.

Experimental Design

The factors *age group* (second graders, sixth graders, and adults) and *type of maze* (maze with gray ground vs. maze with colored ground) were varied between subjects. The dependent variables–in relation to the type of knowledge investigated–are described below.

Wayfinding performance. The number of trials needed to reach the learning criterion in the learning phase, including the trial in the exploring phase, served as indicators for wayfinding performance. Each walk from the start position until the target figure was reached, was defined as one trial.

Wayfinding behavior and the used strategies. For analyzing the wayfinding behavior the number of turns and the distance walked were recorded. Concerning the wayfinding strategies two aspects were emphasized: a) the mean chosen angle and b) the frequency of choosing a sequence of right-left-right-left turns and vice versa or of choosing four or more turns of the same direction. The mean chosen angle served as an indicator for the use of a complexity minimizing strategy (see Dalton, 2003) and was computed as follows: The absolute angle, which was selected by the participant, was registered at each intersection. An average value of all angles selected at all junctions within the route was then calculated by dividing the amount of pursued angles by the number of turns. This variable was computed for the exploring phase and for the last trial in the learning phase before reaching the criterion. The last trial was considered especially important because it could be assumed that all participants had formed a well pronounced knowledge of finding their way by then. Furthermore, the difference between the chosen angle in the exploring and the learning phase was calculated to analyze changes in strategy between phases. The turn-sequence was analyzed to answer the question if the regular construction of the maze influences navigation behavior dependent on coloring. This was especially interesting for the exploring phase. In a regular environment it seems quite sensible to use a systematic behavior, like a systematic sequence of turns, to orientate.

Acquisition of survey knowledge. To analyze the precision of the acquired survey knowledge, a) the accuracy of the drawn map and b) the linear distance from the marked to the correct position of the target figure in the overview were computed. Regarding the first aspect participants' drawings of the maze were coded by two independent raters. The *map correctness score* indicates how many of the following characteristics were observable in the drawing: a rectangular structure, an angular configuration, symmetry of the maze, skew turnoffs, circular shape, ring structure, the correct sector from start to target, and similar lengths of single route segments. Furthermore, one point was assigned if the number of intersections drawn, differed no more than 25% from the correct number. All these variables were chosen because they represent the essential features of the maze. For each of the observable characteristics one point was assigned. A high score of 9 points showed a perfect survey knowledge. Cronbachs Alpha was .81. Regarding the second aspect a good performance was indicated by a small linear distance from the correct to the marked position of the target figure.

Results

There were no sex differences in all measurements concerning wayfinding performance, wayfinding behavior and strategies used, and the acquisition of survey knowledge.

Computer Experience

A univariate analysis of variance did not reveal a significant difference in computer experience (hours per week) between age groups, $F(2,54) = 2.84$, *n.s.*, and type of maze, $F(1,54) = 0.99$, *n.s.*, nor an interaction between these two factors, $F(2,54) = 0.82$, *n.s.* Furthermore, there was no significant correlation between computer experience and wayfinding performance (trials to reach the learning criterion) and spatial knowledge measurements (correctness of the drawn map and straight line distance), respectively.

Wayfinding Performance

Trials to reach the learning criterion in learning phase 1. Figure 3 shows the mean number of trials needed to reach the learning criterion. The univariate analysis of variance in the exploring and learning phase revealed a statistically significant effect of age group, $F(2,54) = 6.79$, $p < .005$, and type of maze, $F(2,54) = 6.98$, $p < .05$. There was no interaction between

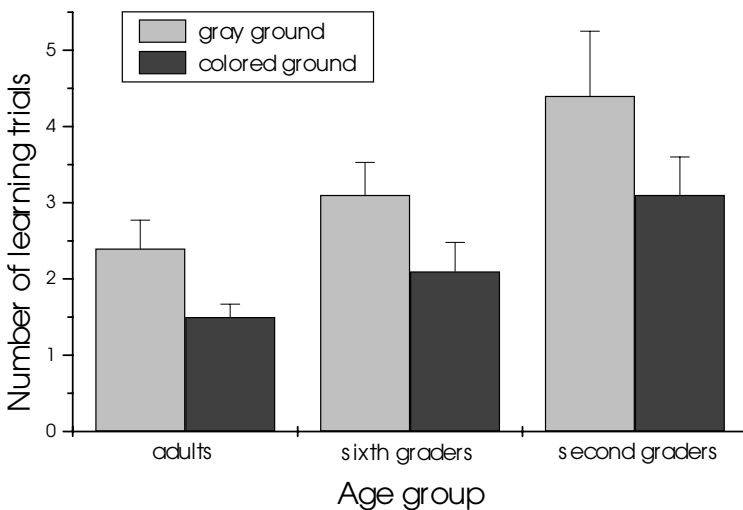


Figure 3. Mean number of trials needed to reach the learning criterion (depending on age group and type of maze (error bars indicate standard errors)).

these two factors, $F(2,54) = 0.22$, *n.s.* Bonferroni adjusted post-hoc testing revealed that second graders ($\bar{x} = 3.75$, $SE = 0.5$) needed more learning trials than adults ($\bar{x} = 1.95$, $SE = 0.22$) and sixth graders ($\bar{x} = 2.6$, $SE = 0.3$), whereby there was no significant difference between the latter two age groups. Furthermore, participants who were exploring the maze with gray floor needed more learning trials ($\bar{x} = 3.33$, $SE = 0.36$) than those participants who were exploring the colored maze ($\bar{x} = 2.3$, $SE = 0.4$). This was true for all age groups.

Wayfinding Behavior and Strategies

Figure 4 shows the distance walked for all participants in all learning trials depending on age group. It can be seen that the distance walked was reduced from one learning trial to the next. The decline was faster in the condition with colored ground compared to the condition with gray ground, and faster for adults than for children. Adults chose shorter routes to reorient themselves, and color helped all participants to re-orientate. Even if it is only descriptive, Figure 4 shows the influence of age and color on the learning behavior.

Number of turns, distance walked, and the mean chosen angle at decision points in the exploring and learning phase. Regarding the number of turns, the walked distance, and the mean chosen angle, the univariate analysis of variance revealed neither an effect of age group, $F(2,54) = .631$, *n.s.*, $F(2,54) = .695$, *n.s.*, $F(2,54) = 1.358$, *n.s.*, nor type of maze, $F(1,54) = .502$, *n.s.*, $F(1,54) = .159$ *n.s.*, $F(1,54) = 2.897$, *n.s.* There was a high correlation found between the number of turns made and the distance walked, $r = .972$, $p < .001$.

Concerning the number of turns, the distance walked, and the mean chosen angle in the last learning trial before reaching the criterion, there were no significant differences concerning the factors age group, $F(2,54) = .937$, *n.s.*, $F(2,54) = 1.488$, *n.s.*, $F(2,54) = .588$, *n.s.*, and type of maze, $F(1,54) = 1.068$, *n.s.*, $F(1,54) = .691$ *n.s.*, $F(1,54) = 2.92$, *n.s.* All means and standard errors are given in Table 1.

Frequency to choose a sequence of right-left-right-left turns and vice versa or to choose four or more turns of the same direction in the exploring phase. These variables were analyzed in the exploring phase only, because the distance walked and the number of turns in the learning phase were so small that frequency of sequences of turns and more than four turns could not reasonably be calculated. Concerning the frequency to choose a sequence of right-left-right-left turns, a significant main effect was found for type of maze, $F(1,54) = 5.44$, $p < .01$, (gray floor: $\bar{x} = 3.07$, $SE = 0.44$, colored floor: $\bar{x} = 1.87$, $SE = 0.27$), but not for age group, $F(1,54) = 2.53$, *n.s.*, (second graders: $\bar{x} = 3.1$, $SE = 0.39$, sixth graders: $\bar{x} = 2.6$, $SE = 0.52$ and adults: $\bar{x} = 1.7$, $SE = 0.45$). Concerning the strategy to choose four or more turns, two significant main effects for age group, $F(1,54) = 6.02$, $p < .005$, and type of maze, $F(1,54) = 4.36$, $p < .05$, could be revealed. Bonferroni adjusted post-hoc test revealed that both children groups (second graders: $\bar{x} = 2.5$, $SE = 0.46$, sixth graders: $\bar{x} = 2.1$, $SE = 0.45$)

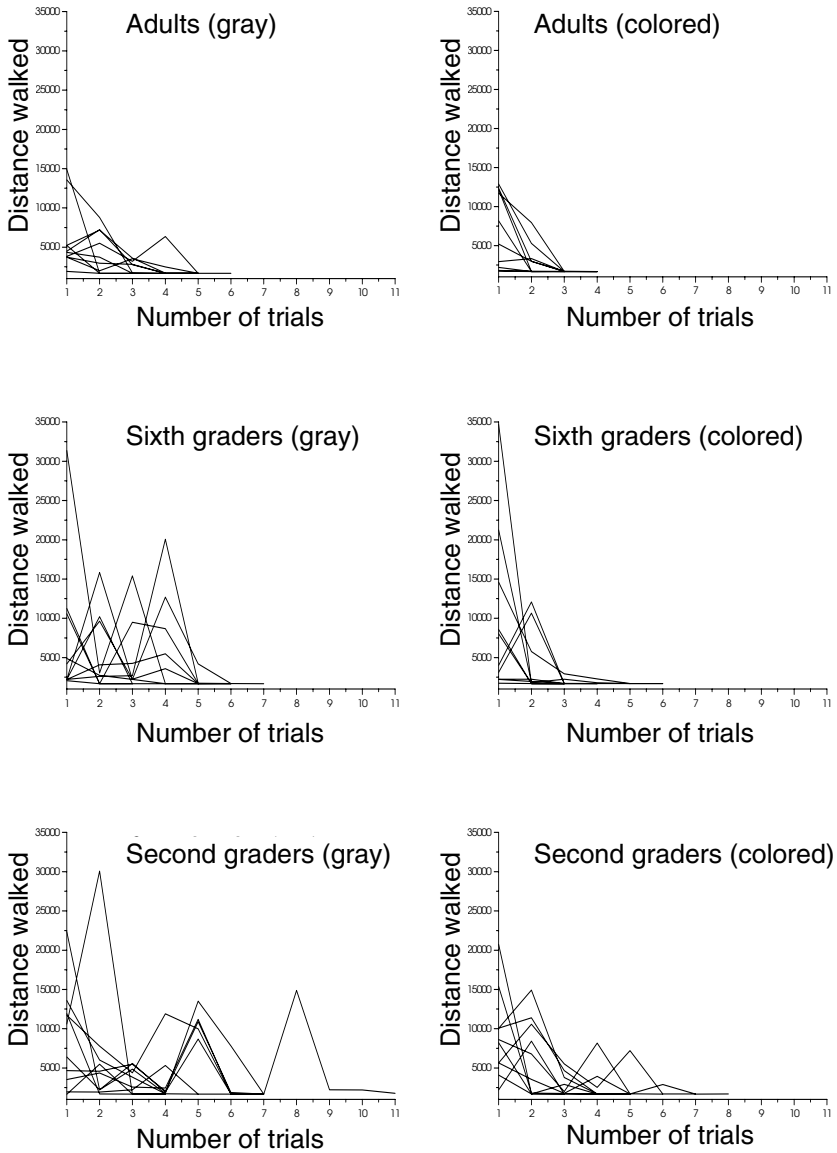


Figure 4. Distance walked in every trial plotted separately for the different age groups (adults, sixth graders and second graders, respectively) and the different types of the maze (gray vs. colored ground).

Table 1

Means and standard errors for the walked distance, the turns and the mean chosen angle in a) the exploring and b) the learning phase.

		(a)		
		distance	turns	mean angle
2nd graders	gray floor	8837.7 (6469.89)	14.9 (10.04)	72.61 (15.4)
	colored floor	9062.6 (5520.52)	15.9 (10.35)	70.07 (9.72)
6th graders	gray floor	7315.2 (9142.37)	15.2 (19.57)	78.97 (13.91)
	colored floor	10045.7 (10733.33)	15.9 (15.77)	72.61 (14.63)
adults	gray floor	6094.5 (4404.1)	10.3 (5.76)	73.34 (14.82)
	colored floor	7110.0 (4840.47)	12.5 (9.17)	63.73 (14.94)
		(b)		
		distance	turns	mean angle
2nd graders	gray floor	8892.7 (8243.17)	15.6 (15.46)	67.54 (14.01)
	colored floor	6459.6 (5523.57)	11.5 (10.01)	65.37 (12.26)
6th graders	gray floor	9163.3 (5612.46)	18.2 (10.1)	70.55 (10.77)
	colored floor	7364.1 (10202.68)	11.6 (15.46)	55.97 (17.27)
adults	gray floor	5256.3 (3983.94)	9.7 (5.44)	62.55 (11.65)
	colored floor	4851.9 (3483.52)	7.8 (6.11)	61.26 (14.73)

chose significantly more often 4 or more turns of the same direction than adults ($\bar{x} = 0.7$, $SE = 0.18$). Furthermore, the participants, who explored the maze with gray floor ($\bar{x} = 2.33$, $SE = 0.40$) chose more often this strategy than the other group ($\bar{x} = 1.33$, $SE = 0.25$).

Changing of strategy. We computed the absolute difference between the mean chosen angle at a decision point in the exploring phase and the learning phase (last trial before reaching the learning criterion). 26.7% of the participants needed only one learning trial to reach the learning criterion, so the difference between their chosen angles was 0. Consequently, trials needed to reach criterion and the absolute difference angle correlate significantly, $r = .508$, $p < .001$. For this, we considered the number of trials as a covariate. A univariate analysis of variance revealed a significant influence of the factor age group, $F(2,53) = 3.19$, $p < .05$. The difference was significantly higher for older children ($\bar{x} = 18.35$, $SE = 2.51$) than for adults ($\bar{x} = 10.23$, $SE = 2.63$) or younger children ($\bar{x} = 10.99$, $SE = 2.69$). There was no significant influence of type of maze, $F(1,53) = 0.39$, *n.s.*, (gray maze: $\bar{x} = 13.49$, $SE = 2.12$, colored maze: $\bar{x} = 12.89$, $SE = 2.11$).

Acquisition of Survey Knowledge

Correctness of the drawn map. For each participant the map correctness score (see method) was computed. The univariate analysis of variance on that

score revealed a significant statistical difference for age group, $F(2,54) = 7.00$, $p < .01$. There was no significant influence of type of maze, $F(1,54) = 0.89$, $n.s.$, (gray maze: $\bar{x} = 5.83$, $SE = 0.39$, colored maze: $\bar{x} = 5.67$, $SE = 0.45$).

Because there was no correlation between the trials needed to reach the learning criterion with the number of turns in all learning trials and the correctness of the drawn map as might be expected, $r = -.197$, $n.s.$ and $r = -.098$, $n.s.$, respectively, we considered neither the number of the trials needed to reach criterion nor the number of turns in all trials as a covariate. The relative number of explored turns (sum of all explored turns divided through the number of learning trials) was considered as a covariate. The map correctness score was significantly higher for adults ($\bar{x} = 7.3$, $SE = 0.48$) than for the younger ($\bar{x} = 4.62$, $SE = 0.47$) as well as for the older ($\bar{x} = 5.34$, $SE = 0.48$) children (see Figure 5). Bonferroni adjusted post-hoc test revealed that there was no difference between the two different children groups. No correlation was found between the number of trials needed to reach the learning criterion and the correctness of the drawn map, $r = -.137$, $n.s.$

Straight line distance from the marked to the correct position of the toy figure in the overview. The univariate analysis of variance on the straight line distance between the marked and the correct position of the goal revealed a statistically significant effect of age group, $F(2,54) = 3.76$, $p < .05$ (see Figure 6). Bonferroni adjusted post-hoc testing revealed that the registered straight line

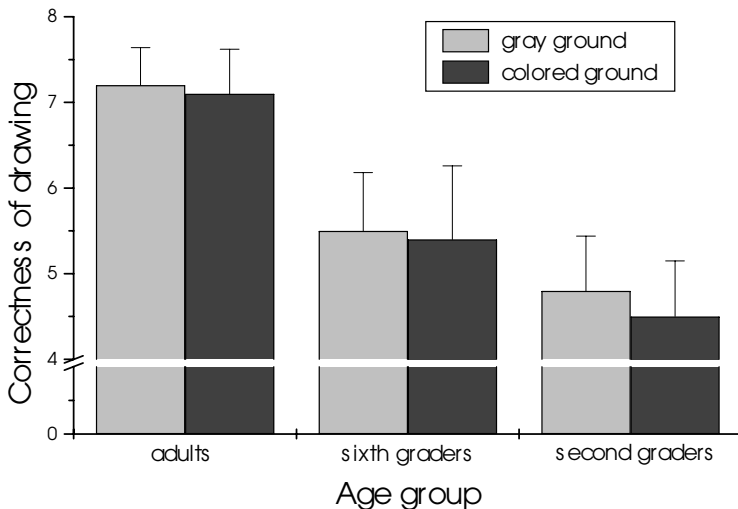


Figure 5. Mean correctness score of drawing a map depending on age group and “learning of a map” (error bars indicate standard errors).

distance was significantly shorter for adults ($\bar{x} = 3.68$, $SE = 0.79$) than for sixth graders ($\bar{x} = 5.68$, $SE = 0.51$), whereby the latter difference was not significant. There was no significant effect of type of maze, $F(1, 54) = 0.28$, *n.s.* (gray maze: $\bar{x} = 5.34$, $SE = 0.57$, colored maze: $\bar{x} = 4.93$, $SE = 0.55$). As might be expected, there was no correlation between the number of trials needed to reach the learning criterion with the number of turns in trials in the exploring and learning phase or the map correctness score, $r = .177$, *n.s.*, $r = -.171$, *n.s.*, respectively.

We computed partial correlations between the measurements of strategy (mean chosen angle in the exploring and the learning phase, difference of mean chosen angle, the frequency to choose a special sequence of turns) and the measure of wayfinding performance (number of trials to reach criterion) and spatial knowledge measure (correctness of the drawn map and straight line distance) controlling for age group. The following significant correlations were found only between the strategies and wayfinding performance: number of trial to reach the learning criterion and the frequency to choose a right-left sequence of turns, $r = .571$, $p < .05$, the frequency to choose four times the same kind of turn in a row, $r = .407$, $p < .05$, and the absolute difference between the mean chosen angle, $r = .462$, $p < .05$.

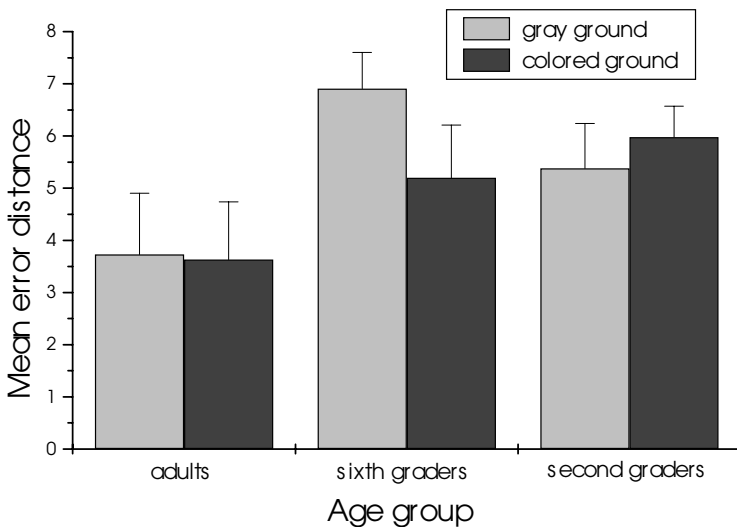


Figure 6. Means straight line distance between the marked and the correct position of the goal figure depending on age group and learning of a map (error bars indicate standard errors).

Discussion

A Color-coded Environment Helped Both Children and Adults to Find Their Way, But Did Not Ease the Development of Survey Knowledge.

Concerning the influence of color on *wayfinding performance*, our results showed, that color helps adults and children similarly when finding their way through unfamiliar surroundings; all participants needed fewer learning trials to find the shortest route to a goal when the ground was colored. This is in accordance with the study by Evans et al. (1980), which showed that color assists the wayfinding behavior of adults in an interior setting. We could show that color also helps children to get along in a new environment. If no landmarks are present—and only the start point serves as an orienting feature—color, by its differentiating function, seems to facilitate wayfinding behavior.

Concerning the influence of the *acquisition of spatial knowledge*, operationalized here by drawing an overview of the maze and the drawing of the linear distance between the correct and the marked goal figure, our results showed that there was no significant influence of color. The finding that color did not assist the acquisition of survey knowledge, is in contrast to the study by Evans et al. (1980). This might be due to task differences either during the learning phase or the test phase. Participants in the former study were taken on a timed, predetermined tour and had to draw their way on a plan of each floor containing the exterior walls of the building, but in the present experiment they could explore the maze by themselves and had to draw the complete structure of the environment. The differing results could not be due to the fact that participants in the color version of the maze learned it more quickly and as a consequence had less experience with the structure of the maze, because there was no positive correlation between the factors revealing survey knowledge and the number of trials needed to reach criterion, respectively the number of turns in all trials in the exploring and learning phase. One possibility is that once the structure of the maze and the location of the object are learned, color is no longer influential in the performance of survey knowledge tasks.

Beside these results we could show that acquisition of survey knowledge and wayfinding performance might be similarly influenced through different factors for children and adults. This is in accordance with a study by Allen, Kirasic, and Beard (1989), who assumed that task specific skills are involved in different products of spatial knowledge. They investigated children's locomotor maze learning and could show age related improvement in the number of trials needed to reach the criterion during learning, but few differences in various expressions of maze knowledge after learning. For that, the results suggest a dissociation between two different spatial cognition tasks, the investigation of spatial knowledge and wayfinding performance.

Structuring by Color Partially Affects the Use of Different Wayfinding Strategies.

Color influenced wayfinding strategies as measured by the frequency of taking right-left turns and the frequency of taking the same four directional turns in a row, which were both higher in the maze with gray floor. No such influence could be revealed for the distance walked, the number of turns, and the mean chosen angle. The use of some systematic strategy, like taking a systematic sequence of turns, seems more appropriate in a maze with gray floor than in the colored one. This systematic behavior serves as an orientation strategy and is much more needed in a less structured environment. Furthermore, we could reveal a correlation between wayfinding performance and the strategies used. The more orientating strategies were used in the exploration phase the more learning trials were needed.

Younger Children Did Not Rely More on the Existence of Color Than Older Ones and Adults.

Contrary to studies emphasizing the importance of landmarks, especially for children to find their way around (for example Cohen & Schuepfer, 1980), color helped children and adults similarly to orientate: the missing interaction between age group and condition revealed that there was no advantage for younger children as might be expected. We can assume that color has a different quality than the existence of landmarks, even both structure space. These results expand the results of Hermer and Spelke (1996) and Gouteaux and Spelke (2001): There is no difference regarding the structuring of space through color of school aged children and adults, when investigating navigation in an environmental space. This is an important result, because it shows that there is an environmental factor which helps children in the same manner as adults. Furthermore, it has a theoretical developmental implication in that way, that the context of the spatial development analyze has to be integrated further. For that, the perspective has to be moved from a more cognitive constructive perspective to a contextual one, which assumes that spatial knowledge is more than thinking about the environment: "...it also involves acting wayfinding, exploration, orientation activities that enable the individual to function adaptively in the environment" (Heft & Wohlwill, 1987).

Regarding the *overall age effect*, we found differences in the *wayfinding performance*; younger children needed more learning trials than older ones and adults. This is in accordance with many other studies in spatial cognition research (Cohen & Schuepfer, 1980). Regarding *spatial knowledge*, our results revealed that children had less detailed knowledge than adults. This result was obtained through two different spatial tasks. The first one, drawing a sketch map, has two drawbacks: First, their use as a tool to externalize the child's cognitive map (Matthews, 1985) is limited because of different drawing skills (Blades, 1997). Second, we know that being able to use an external symbol system to represent spatial relations is a different ability than behaving efficiently in response to those spatial relations (Liben & Downs, 1989). The

first drawback was minimized in this study. Children and adults only had to draw a schematic plan of the virtual surroundings. The fact that children demonstrated poorer spatial knowledge when compared to adults is in accordance with earlier studies (for example Shemyakin, 1962), and might not be due to different drawing abilities. Furthermore, the result obtained through the drawing of sketch maps was confirmed by marking the goal figure in the correct position, which did not require drawing abilities. Because a translation from the direct experience to a spatial representation was required, the second drawback cannot be negated (compare Liben, 1997). Unfortunately, in this virtual setting without landmarks, it was impossible to investigate subjects' ability to use shortcuts, which is a more behavioral based approach to investigating survey knowledge.

Furthermore, we found differences in the *wayfinding strategies*; older children changed their strategy concerning the mean chosen angle from the first exploration trial to the last trial before reaching the learning criterion. While we could not explain this changing of strategy we could show that it did neither affect the wayfinding performance nor the acquisition of spatial knowledge. We might conclude that the difference found in the acquisition of survey knowledge was not due to this specific wayfinding strategy investigated here; rather it was based on cognitive development. This would be in accordance with a study of Allen and Ondracek (1995), which showed that the developmental improvement in children's performance on tasks requiring the acquisition of spatial knowledge was related to age sensitive cognitive abilities.

Further Experiments

Subsequent to the study presented here, two main questions remain which are worth being addressed in more detail. Firstly, the influence that color has on other unmentioned wayfinding strategies must be examined. The investigation of directional choices is only one possible strategic behavior. Furthermore, the reorientation to specific locations (e.g., start point) or the preference of an orientation or route strategy (Lawton, 1994; 1996; Pazzaglia & Beni, 2001) could be investigated in a virtual environment, which includes landmarks. Secondly it has to be investigated whether or not the existence of landmarks is more effective than color in allowing children to improve their spatial learning. Our finding that color does not help the younger children more than adults might account for the qualitative difference between both environmental factors. The question is: Do children rely more on a) sequential environmental learning (condition with landmarks only) than on b) environmental features which differentiate the environment through a grouping process (condition with colored ground only) respectively on c) both sequential environmental learning and a grouping process through environmental features (condition with colored ground and with landmarks) or d) the geometrical shape of the environment (condition with gray ground and without landmarks) during a wayfinding task in a large scale space?

The Use of Virtual Environments in Developmental Spatial Cognition Research

The experiment could be easily conducted in a virtual environment. Taking the drawbacks of using desktop virtual environments into account, we should appreciate that desktop virtual environments can provide important evidence for the understanding of how children and adults find their way. In the study described here it was much easier to analyze the spatial behavior of all participants in a reliable manner. The fact that participant's movements during navigation through the maze were continuously recorded allowed us to analyze the wayfinding strategy without asking the children and adults why they had chosen a special route. This analysis was not influenced by the cognitive and linguistic fitness of the children. It is evident that route descriptions are not appropriate for all age groups (Blades, 1997). Because we did not find a significant difference between the age groups in experience playing computer games, and thus no correlation between computer experience and the spatial cognition measurements, this influence might be denied in our study; although we know that it cannot be disregarded (Waller, 2000). These virtual environments are an appropriate simulation medium of large environmental spaces and its adequate use has been recently shown in spatial cognition research.

Conclusion

This study has two important results. Firstly, it shows that the structuring of space through coloring helps children at school age and adults in the same manner to find their way around. This is in contrast to the importance of landmarks in developmental spatial cognition research, where it has been shown that younger children rely more on their presence than older ones and adults. Secondly, color has an influence on the wayfinding performance and on some of the wayfinding strategies used, but not on the acquisition of spatial knowledge. This accounts for a dissociation in wayfinding behavior and spatial knowledge and demands a new, more contextual, perspective on spatial cognition development.

To conclude with a piece of practical advice: We propose to register color in wayfinding designs. Wayfinding designs are described as a set of tools devised to help people reach their destination in an unfamiliar environment (Dogu & Erkip, 2000). Because it is known that children and adults may not spontaneously select the same features as orienting landmarks (Allen, Kirasic, Siegel, & Herman, 1979), it seems to be difficult for architects to choose the "right landmark" as orienting help when designing public buildings.

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