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The representation of landmarks and routes in children and adults: A study in a virtual environment

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Abstract

Experimental results obtained in a traditional laboratory setting by Cohen and Schuepfer (J. Exp. Child Psychol. 30 (1980) 464) where participants learned a route by a slide presentation were replicated in a computer-simulated environment. Twenty second graders (6 years 11 months to 8 years 5 months), sixth graders (10 years 10 months to 12 years 10 months), and adults learned a route through a virtual maze and had to recall the inherent landmarks. The results showed that second graders relied more on the presence of landmarks than sixth graders and adults, and recalled fewer landmarks. Sixth graders and adults did not differ in their use and recognition of landmarks, which was in contrast to the study of Cohen and Schuepfer (1980). Furthermore, contrary to the original study sex differences were found, females relied more on landmarks than males did. These different results were discussed with regard to the developmental influence of sex in different spatial cognition measurements and the different methods, passive learning through slide presentation and active navigation in virtual environments.

1. Introduction

Humans acquire spatial knowledge of a new environmental space—a space, which is not perceivable from one single vantage point—by travelling through this environment. This wayfinding ability can be accomplished through a variety of means, for example cue-based piloting, path integration, navigation by cognitive maps (for an example see Newcombe & Huttenlocher, 2000) or by guidance instruments like a compass and materials like photos or verbal descriptions (Golledge, 1999). Humans may also use olfactory and tactile cues to orientate themselves (Loomis, Klatzky, Golledge, Cicinelli, Pellegrion, & Fry, 1993). Furthermore, external cues, like landmarks play an important role to maintain orientation (for a review of controversly discussed studies see Kitchin & Blades, 2001).

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1.1. The role of landmarks

Landmarks may be defined in a number of ways, whereby one can differentiate between landmarks as an organizing concept and as navigation aids (see Golledge, 1991): As an organizing concept landmarks may serve as a reference point that determines the localization of other points in the environment (Sadalla, Burroughs, & Staplin, 1980), or serves as a prototype location (Newcombe & Huttenlocher, 2000). Landmarks as visual objects, which are perceived and remembered because of their shape and structure (Presson & Montello, 1988) or their sociocultural significance (Appleyard, 1969) may help to find the way around. Denis (1997) describes the following key functions of landmarks: (1) signaling sites, (2) help for the location of other landmarks and (3) confirmation of the route followed. In an early study, Lynch (1960) classified landmarks into strategic and thematic nodes, paths, boundaries, and districts, and identified them as one key entity for people to get around in their environment. Further studies showed very well that landmarks affect the spatial representation and the acquisition of route- and survey knowledge (Beck & Wood, 1976; Carr & Schissler, 1969).

1.2. The role of landmarks for the development of spatial cognition

First of all, it is well known, that children and adults judge the value of landmarks differently; Allen, Kirasic, Siegel, and Herman (1979) showed that there is an influence of age in children selecting scenes with a high potential landmark value and that children at middle and late childhood are less capable than adults in judging the value of potential landmarks as distance cues. Concerning the development of spatial knowledge, there is ample evidence that children's acquisition of spatial knowledge of large-scale space environments becomes more and more accurate over the course of middle and late childhood (Cohen & Schuepfer, 1980). 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). In a search task, 5 year old children preferred a cue strategy orientating towards local, proximal cues, whereas 10 year olds chose a place strategy, orientating towards global, distal cues (Lehnung, Leplow, Friege, Herzog, Ferstl, & Mehdorn, 1998). Almost thirty years ago Siegel and White (1975) presented a formal description of the development of spatial knowledge. They assume that children firstly acquire landmark knowledge, followed by route knowledge, which is integrated by survey knowledge. This was confirmed by Cousins, Siegel, and Maxwell (1983).

1.3. The role of landmarks and gender differences in spatial cognition research

In general, gender differences in spatial cognition research are well known, especially for some kind of spatial ability like the mental rotation, where males out perform females (e.g. Harshman, Hampson, & Berenbaum, 1983; Sanders, Soares, & D'Aquila, 1982). Concerning the strategies used for spatial orientation by analyzing verbal description of the route, several studies showed that males paid greater attention to configurational aspects like distance or direction, and female used more frequently terms indicating landmarks (for example Dabbs, Chang, & Strong, 1998; Miller & Santoni, 1986). This result was confirmed by studies which used self-report questionnaires for strategies (Lawton, 1994, 1996): Females rely more on landmarks and on procedural "route" strategies than males, who prefer configurational strategies. For children it was shown, that gender differences emerge soon after 9 years of age: boys demonstrate better sense of orientation, and girls attend to a greater amount of landmarks (Joshi, Mac Lean, & Carter, 1999).

1.4. The use of virtual environments in spatial cognition research

Spatial behaviour can be investigated either in naturalistic settings or in laboratory experiments. Nowadays, virtual environments (VE), which allow the simulation of three-dimensional environments on a computer, have been increasingly used. VEs can be divided in desktop and immersive systems, and an intermediate solution between both. They are useful options for the simulation of spatial environments. In desktop systems conventional desktop computer displays are utilized, whereas an immersive virtual environment is one, where the user is situated in the virtual environment by the use of special output devices like head-mounted displays. Intermediate solutions use a projection-screen or three-dimensional monitors (cf. Jansen-Osmann, 2002). Advantages of using VEs are for instance the following: Spatial relations and environmental features can be varied quickly and in an economic manner, participants can operate in a self-determined way, nearly all kind of environments can be simulated and navigation can be measured on-line (Goldin & Thorndyke, 1982; Péruch, Belingrad, & Thinus-Blanc, 2000). Furthermore, people can acquire knowledge about directions and distances (Albert, Rensink, & Beusmanns, 1999; Willemsen & Gooch, 2002), develop route- and survey knowledge (Gillner & Mallot, 1998; Jansen-Osmann, 2002), and navigate effectively in a virtual environment (Darken & Silbert, 1996; Ruddle, Payne, & Jones, 1999). Next to the positive aspects there are some limitations especially in the use of desktop VEs, e.g. lack of proprioceptive sensory information (Witmer, Bailey, Knerr, & Parsons, 1996). However, evidence indicates that missing proprioceptive feedback might not be crucial regarding spatial learning. Waller, Knapp, and Hunt (2001) showed that there was no difference between learning the spatial representation of mazes in wire-frame virtual and in real-world conditions. Furthermore, Westerman, Cribbin, and Wilson (2001) showed that the efficiency of navigation was poorer in an immersive VE than in a desktop VE.

All the studies mentioned above were conducted with adults; in studies with children, VEs were mainly used to train children's spatial abilities. A transfer of spatial information from a virtual to a real environment has been shown in studies with healthy children (Foreman et al., 2000; McComas, Pivik, & Laflamme, 1998). Furthermore a positive effect of training in disabled children could be demonstrated (Stanton, Wilson, & Foreman, 1996; Wilson, Foreman, & Tlauka, 1996). So far as we know, there is only one study in which one aspects of spatial knowledge—distance knowledge—is investigated in children in a desktop virtual environment (Jansen-Osmann & Wiedenbauer, in press).

It is one goal of this paper to evaluate the use of VEs in developmental spatial cognition research. One possible way to evaluate VEs is to replicate results obtained in former experiments. For example Ruddle, Payne, and Jones (1997) could replicate the results on direction and distance knowledge in real-world settings obtained by Thorndyke and Hayes-Roth (1982) in a desktop virtual environment. Further on, Jansen-Osmann and Berendt (2002) and Jansen-Osmann and Wiedenbauer (in press) replicated the processes of distance estimations obtained in a study by Sadalla and Magel (1980).

1.5. The study of Cohen and Schuepfer (1980)

The experiment presented here was conducted according to a study of Cohen and Schuepfer (1980) who investigated the representation of landmarks and routes in children and adults. 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—eighteen toy animals—with different functions (adjacent to a correct, incorrect, or no turn; see Fig. 2). Cohen and Schuepfer brought about systematic variation by way of discontinuous presentation of six scenes as a slide on a projection-screen. Participants saw one main corridor with three-arms branching off and three landmarks with different functions (see above). After the presentation of each slide, participants were asked to decide which way they would take to reach the destination. If their answer was correct, the next slide was presented; if their answer was incorrect, they had to try again. This sequence decision task was complete when a participant managed to predict the way correctly six times in consecution without any error. In the following test phase, slides of the maze were shown without landmarks and participants were asked to indicate the correct turn in each case. Second graders made significantly more incorrect turn choices than sixth graders, who, in turn, made more errors than adults. This means that children relied more on the position and sequence of landmarks than adults did. After a second learning phase, a recall test showed that landmarks adjacent to a correct turn were significantly better remembered and localized than those that were adjacent to an incorrect or to no turn. Younger children recalled fewer landmarks adjacent to an incorrect turn than older children, which showed similar performance as adults. Concerning landmarks adjacent to a correct turn, second graders remembered fewer landmarks than older children who, in turn, remembered fewer landmarks than adults. Cohen and Schuepfer (1980) did not find any gender differences.

Jansen-Osmann (2002) repeated the experiment of Cohen and Schuepfer (1980) in a virtual environment with adults. The maze was similar to that used by Cohen and Schuepfer, landmarks were eighteen virtual toy animals. In contrast to the Cohen and Schuepfer study, half of the adults had to explore the maze with landmarks, the other half without landmarks until reaching a learning criterion. Adults who learned the maze without landmarks needed more learning trials. The finding of the recall test could be replicated in a virtual environment with adults: Landmarks which are associated with turns towards the destination are better remembered and localized than the other ones.

1.6. Overview of this study

The present study investigated if the results obtained by Cohen and Schuepfer (1980) could be replicated in a virtual environment with adults and children. On the basis of Cohen and Schuepfer's results, the following hypotheses could be revealed:

1. Children rely more on the position and sequence of landmarks than adults.
2. Children recall fewer landmarks than adults.
3. Landmarks which have a route maintaining function are better remembered than landmarks which do not have such a function. This holds for adults and children.
4. The role of gender differences has to be investigated.

2. Method

2.1. Participants

Forty healthy children at two grade levels (2nd and 6th) and twenty adults participated in the study. The mean age of the second graders was 7.8 (6 years 11 months to 8 years 5 months; 7 boys and 13 girls), sixth graders 11.8 (10 years 10 months to 12 years 10 months; 10 boys and 10 girls), adults 25.9 (23 to 36 years; 10 men and 10 women). Children were recruited through advertisements in the local newspapers. Prior to testing, all parents gave their informed written consent to take part in the study. The local ethics committee approved the experimental procedure.

2.2. Materials

A questionnaire about the use of computer-games and the joystick was constructed. Children and adults were asked how often they play computer games (in hours per week), which kinds of games they played, and which input device they use for playing.

The experiment was conducted in a virtual world using the software 3D GameStudio A5 on a Pentium 4 (2.0 GHz) PC with a nVidia Geoforce 4 graphic-card. A maze was programmed in correspondence to the paths of Cohen and Schuepfer (1980) (see Figs. 1 and 2). The virtual world was projected on a 1.6 m × 1.3 m screen by a video-beamer. The distance between projection-screen and participant was 2 metres. The participants explored the simulated maze by using a Microsoft-Sidewinder joystick. The joystick's rotation and translation settings were fixed for each participant. The virtual maze consisted of six main corridors (see Fig. 2). Two secondary corridors branched off from each main corridor and ended in a cul-de-sac. There were only 90° turns. Only one route led to the goal. To reach the goal, the correct sequence was right, right, left, left, right, left (in total three times left and three times right). While passing by a turnoff, it was not possible to see whether it is a dead end. To decide if a turnoff is a dead end, it was required to rotate the joystick into the direction of this route segment. The maze contained 18 different virtual toy animals. These landmarks were located at the same position as in the study of Cohen and Schuepfer (1980). In Fig. 2, a "+" denotes a landmark adjacent to a correct turn (in line with the correct route to the goal), a "–" denotes a landmark adjacent to a wrong turn (leads into a dead end) and a "o" denotes a landmark adjacent to no turn. The maze itself was identical in all trials except for the presence of the landmarks: The learning trials contained landmarks, while the test and recall trial did not. The routes explored by the participants were automatically recorded. Fig. 1 shows a snap-shot into the maze.

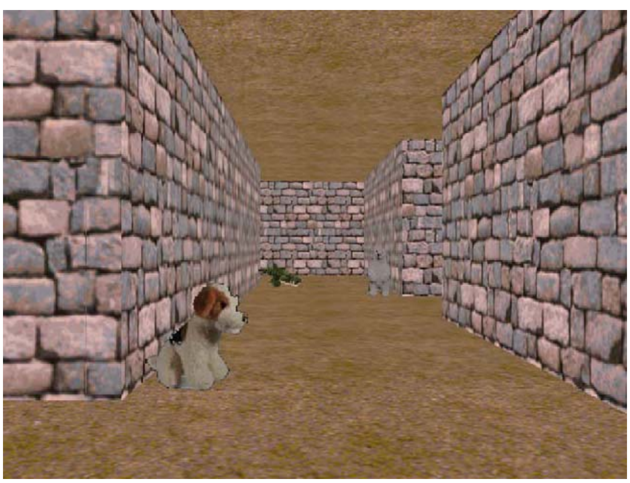

Fig. 1. A snap-shot into the maze.

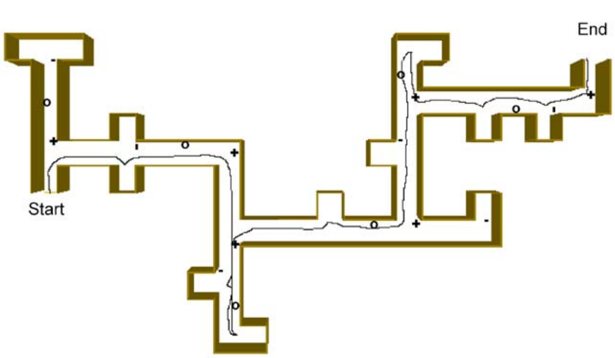

Fig. 2. An overview of the maze ("+" denotes a landmark adjacent to a correct turn, "–" denotes a landmark adjacent to a wrong turn, "o" denotes a landmark adjacent to no turn). The walk of a participant was traced back through the maze.

2.3. Procedure

Individual test sessions lasted 20 minutes and took place in a laboratory at the Heinrich-Heine-University of Duesseldorf. Participants were assigned to the experimental groups by sex and age. To exclude the influence of prior joystick experience, the subjects had to get familiarized with the use of it—or if they were already used to it—with the special joystick's rotation and translation in another nonexperimental virtual environment, where they had to move around. As soon as they were sufficiently familiar with the joystick, the experiment itself began. There were four experimental phases:

1. *Learning phase* 1: Participants had to explore the maze until they reached the goal in four consecutive attempts without an error. An error was designed as choosing a wrong turn (by walking or looking into it). All kind of landmarks were present in the learning phase. The number of learning trials as well as the distance walked in each trial was recorded.
2. *Test trial*: Participants had to explore the maze without landmarks. Errors on their way to the goal (walking or looking into a wrong route segment) and the distance walked were recorded. After completing this trial, a second learning phase started like in the experiment of Cohen and Schuepfer (1980).
3. *Learning phase* 2: All participants had to reach the goal in the presence of all landmarks without an error in two consecutive trials. Thereafter, a recall test began.
4. *Recall test*: Participants had to walk through the empty maze recalling the names and the positions of the animals. The name of the animals and their assumed positions were registered in an overview of the maze on a sheet of paper by the experimenter. Children and adults did not know before that they had to recall the landmarks.

2.4. Experimental design

The factors AGE GROUP (second graders, sixth graders, and adults) and SEX (male, female) were manipulated between subjects. The factor KIND OF LANDMARK was varied within subjects (adjacent to a correct turn, adjacent to an incorrect turn, and adjacent to no turn).

Dependent variables were:

1. Trials to reach the criterion in learning phase 1
2. Distance walked in learning phase 1
3. Number of errors in the test trial
   In accordance to the study of Cohen and Schuepfer (1980) an error was defined, when participants travelled down a dead end, or looked around the corner which leads to a dead end. There was no error when participants deviated slightly from the optimum path without leaving the corridor, which defined the shortest route.
4. Distance walked in the test trial
5. Trials to reach the criterion in learning phase 2
6. Recall of landmarks:
   Recall of landmark names
   Recall of landmark positions

3. Results

The path participants took was recorded for analysis. The arrow trace from the bird's-eye view of the maze shows whenever a participant strayed from the direct route to the destination (Fig. 2).

3.1. Computer-experience

A univariate analysis of variance revealed a significant difference in computer-experience (hours per week) between AGE GROUPS ($F(2,53) = 19.59$, $p < .001$, $\eta^2 = .425$) and SEX ($F(2,53) = 5.7$, $p < .05$, $\eta^2 = .09$). A Bonferroni adjusted post-hoc comparison revealed that older and younger children played computer-games more often ($\bar{x} = 1.65$, $s\bar{x} = 0.15$ and $\bar{x} = 1.66$, $s\bar{x} = 0.16$) than adults ($\bar{x} = .48$, $s\bar{x} = 0.15$). There was only one child never having played computer games, whereas half of the adults did not have any experience with computer games. Furthermore, males ($\bar{x} = 1.47$, $s\bar{x} = 0.13$) played more often computer games than females ($\bar{x} = 1.05$, $s\bar{x} = 0.12$).

3.1.1. Trials to criterion in learning phase 1

The univariate analysis of variance on the number of trials for initial learning revealed neither statistical significant main effects nor an interaction in the total number of trials required for participants dependent on AGE GROUP and SEX (means without criterion run $\bar{x} = 3.2$; $\underline{SE} = 0.3$ (grade 2), $\bar{x} = 2.85$; $\underline{SE} = 0.34$ (grade 6), and $\bar{x} = 2.7$; $\underline{SE} = 0.25$ (adults) and $\bar{x} = 2.77$; $\underline{SE} = 0.27$ (male) and $\bar{x} = 3.01$; $\underline{SE} = 0.24$ (female)).

3.1.2. Distance walked in learning phase 1

Distance was measured in units of the software. The univariate analysis of variance on distance walked for initial learning revealed neither significant main effects nor an interaction in the mean walked distances per trial for participants ($\bar{x} = 947.85$; $\underline{SE} = 30.84$ (grade 2), $\bar{x} = 973.36$; $\underline{SE} = 46.04$ (grade 6), and $\bar{x} = 983.06$; $\underline{SE} = 40.64$ (adults)) and $\bar{x} = 940.98$; $\underline{SE} = 34.75$ (male) and $\bar{x} = 994.79$; $\underline{SE} = 31.24$ (female)). An analysis of number of errors made in the learning phase is redundant due to a high correlation between distance walked and errors (compare "distance walked in test trial").

3.1.3. Number of errors in test trial

Fig. 3 shows the number of errors in the test trial.

There was an effect of AGE GROUP ($F(2,57) = 12.27$, $p < .001$, $\eta^2 = .389$): Bonferroni adjusted post-hoc test revealed that second graders made more incorrect turns ($\bar{x} = 2.35$, $\underline{SE} = 0.45$) than sixth graders ($\bar{x} = 0.7$, $\underline{SE} = 0.23$) and adults ($\bar{x} = 0.2$, $\underline{SE} = 0.08$). There was no difference between older children and adults. Furthermore there was an effect of SEX GROUP ($F(l,57) = 6.06$, $p < .05$, $\eta^2 = .1$). Females ($\bar{x} = 1.37$, $\underline{SE} = 0.22$) made more errors than males ($\bar{x} = 0.56$, $\underline{SE} = 0.24$). There was no significant interaction.

There was no significant correlation between the frequency participants played computer games and the number of errors in the test trial when controlling for AGE GROUP and SEX ($r = .18$, n.s.).

3.1.4. Distance walked in test trial

Fig. 4 shows that there was an effect of AGE GROUP ($F(2,57) = 10.67$, $p < .001$, $\eta^2 = .27$): Second graders

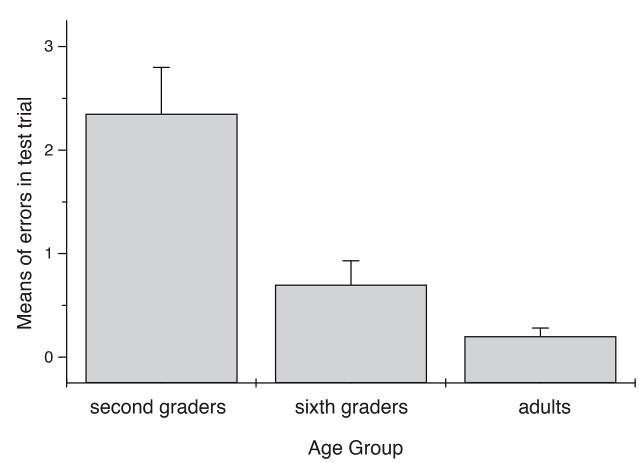

Fig. 3. Means of errors in test trial dependent on the age group. Error bars indicate standard errors.

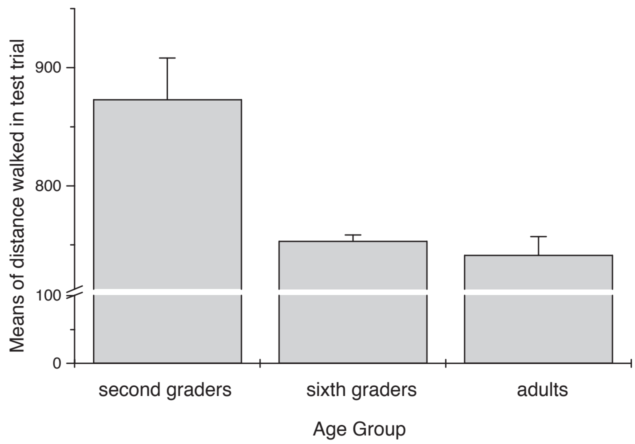

Fig. 4. Means of distance walked in test trial dependent on the age group. Error bars indicate standard errors.

($\bar{x} = 873.15$, SE = 35.0) walked much longer distances than sixth graders ($\bar{x} = 753.3$, SE = 15.55) and adults ($\bar{x} = 741.55$, SE = 4.99). The standard errors show the declining variability with increasing age. There was neither an effect of SEX nor a significant interaction between these two factors. There was a significant positive correlation between errors in test trial and distance walked ($r = .9$; $p < .001$).

3.1.5. Trials to criterion in learning phase 2

All children—except for two of the younger age group—and all adults did not make any errors in the second learning phase.

3.1.6. Recall of landmark names and positions

The number of recalled landmark names was influenced by the age group ($F(2, 57) = 5.67$, $p < .01$, $\eta^2 = .16$). Bonferroni adjusted post hoc test revealed that second graders ($\bar{x} = 7.85$, SE = 0.55) recalled fewer landmarks than older children ($\bar{x} = 10.35$, SE = 0.55) and adults ($\bar{x} = 9.7$, SE = 0.55). Whereas the comparison between second and sixth graders was statistically significant, the comparison between adults and youngest children failed to reach significance. There was no effect of SEX, but a significant interaction between both factors ($F(2, 57) = 3.66$, $p < .05$, $\eta^2 = .12$) (see Fig. 5). The youngest boys ($\bar{x} = 9.14$, SE = 0.86) recalled more landmarks than the girls at the same age ($\bar{x} = 7.15$, SE = 0.64), but men ($\bar{x} = 8.7$, SE = 0.4) recalled less landmarks than women ($\bar{x} = 10.7$, SE = 0.93). There was no sex difference between the boys ($\bar{x} = 9.9$, SE = 0.75) and girls ($\bar{x} = 10.8$, SE = 0.8) in the older age group.

Figs. 6a and b show the mean number of landmarks recalled correctly dependent on the kind of landmark and the age group in the present study (Fig. 6a) and in the study of Cohen and Schuepfer (1980) (Fig. 6b).

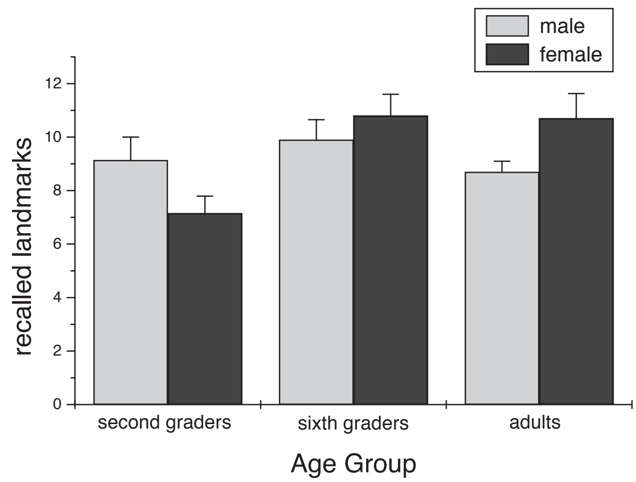

Fig. 5. Number of recalled landmark names dependent on the age group and sex.

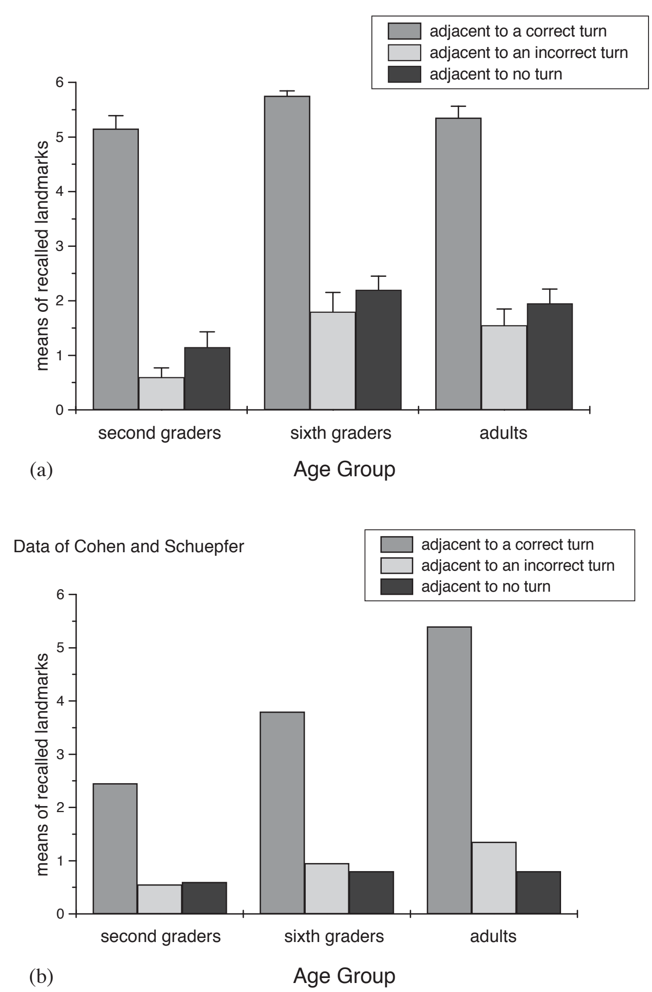

Fig. 6. Means of the landmarks recalled at correct positions dependent on the kind of landmarks and on the age group. Error bars indicate standard errors. (a) Data of the experiment in this study. (b) Data of the experiment by Cohen and Schuepfer (1980).

A 3 (AGE GROUP) $\times$ 3 (KIND OF LANDMARK) $\times$ 2 (SEX) mixed factorial analysis was performed on the kind of landmarks which were recalled correctly. This analysis revealed significant effects of AGE GROUP ($F(2, 54) = 5.63$, $p < .01$, $\eta^2 = .17$ and KIND OF LANDMARK ($F(2, 108) = 333.28$, $p < .001$, $\eta^2 = .86$). Adults ($\bar{x} = 2.95$, SE $= 0.18$) and sixth graders ($\bar{x} = 3.25$, SE $= 0.18$) recalled more correct landmarks than second graders ($\bar{x} = 2.3$, SE $= 0.18$) (Bonferroni adjusted). In general, participants recalled more landmarks adjacent to a correct turn ($\bar{x} = 5.42$, SE $= 0.16$) than landmarks adjacent to an incorrect turn ($\bar{x} = 1.32$, SE $= 0.17$) ($F(1, 54) = 481.22$, $p < .00$, $\eta^2 = .9$) or adjacent to no turn ($\bar{x} = 1.77$, SE $= 0.16$) ($F(l, 54) = 414.43$, $p < .001$, $\eta^2 = .86$), respectively. Furthermore, the difference between the number of recalled landmarks adjacent to no turn and to an incorrect turn was also significant ($F(l, 54) = 128.28$, $p < .001$, $\eta^2 = .7$). This was true for all age groups. There was no effect of SEX, but a significant interaction between SEX and AGE GROUP ($F(2, 54) = 5.12$, $p < .01$, $\eta^2 = .16$); the youngest boys ($\bar{x} = 2.86$, SE $= 0.42$) recalled more landmarks at the correct location than the girls at the same age ($\bar{x} = 2.0$, SE $= 0.24$), but men ($\bar{x} = 2.63$, SE $= 0.12$) recalled less landmarks than women ($\bar{x} = 3.2$, SE $= 0.39$). There was no sex difference between the boys ($\bar{x} = 3.07$, SE $= 0.18$) and girls ($\bar{x} = 3.4$, SE $= 0.24$) at the older age group.

Due to the similarity of the structure of the maze and the kind of landmarks in this experiment and in the original study of Cohen and Schuepfer (1980), a descriptive comparison between both studies seems to be reasonable. Comparing the number of landmarks at correct positions, both children groups remembered more landmarks in the experiment presented here (younger children: $\bar{x} = 5.15$, SE $= 0.24$, older children: $\bar{x} = 5.75$, SE $= 0.1$) than in the study of Cohen and Schuepfer (younger children $\bar{x} = 2.45$, older children: $\bar{x} = 3.8$). Adults remembered more landmarks, which were adjacent to no turn ($\bar{x} = 1.55$, SE $= 0.29$) or to an incorrect turn in this study ($\bar{x} = 1.95$, SE $= 0.27$) than in the study of Cohen and Schuepfer ($\bar{x} = 0.8$ and $\bar{x} = 1.35$).

3.1.7. *Recall of landmarks dependent on the exploration frequency*

It could be argued that the recall was influenced by the fact that landmarks adjacent to the correct turn have to be passed more often than the other ones and are thus recalled more accurately. That means that the effect of kind of landmark could be confounded with the landmark passing time. To test this, the landmarks adjacent to incorrect turns were divided in the following two groups: one group with landmarks, which the participants had to pass on their way to the goal (3 landmarks) and another group with landmarks beyond the correct way (3 landmarks). The number of recalled landmarks of these two groups were compared with the number of recalled landmarks adjacent to correct turns (divided by 2—this operation was allowed because the mean of recalled landmarks adjacent to a correct turn did not differ between the six different virtual toy animals). Those landmarks adjacent to an incorrect turn, which were lying on the way to the goal ($\bar{x} = 0.92$, SE $= 0.11$), were recalled better than those adjacent to an incorrect turn, which were not lying on the way to the goal ($\bar{x} = 0.4$, SE $= 0.09$) ($F(2, 59) = 328.65$, $p < .001$, $\eta^2 = .327$). Furthermore, the landmarks adjacent to an incorrect turn, lying on the way to the goal were recalled worse than landmarks adjacent to a correct turn ($\bar{x} = 2.71$, SE $= 0.06$) ($F(2, 59) = 251.71$, $p < .001$, $\eta^2 = .81$).

Finally, errors made while exploring the maze without landmarks were correlated with the number of toy animals recalled at correct positions ($r = -.383$, $p < .01$): Participants who made fewer errors finding the way through the maze in the test phase recalled more landmarks at correct positions. Due to these findings one can exclude a better recall for landmarks adjacent to correct turns only because of a higher passing by frequency.

4. Discussion

4.1. *The role of landmarks for adults and children*

Cohen and Schuepfer's (1980) findings concerning the relevance of landmarks in learning a route could be replicated in a virtual environment with children and adults. The youngest children made more incorrect turn choices when landmarks were removed. Consequently, they walked longer distances than the older children and the adults did. This result was independent of the distance walked in the learning phase. These results presented here are in accordance with other studies in which 8 year old or younger children rely predominantly on landmarks when learning a route (Beilstein & Wilson, 2000; Blades & Spencer, 1990; Blades & Medlicott, 1992) and studies which emphasize the importance of landmarks on special spatial knowledge tasks for adults and middle school aged children comparably (Cornell et al., 1989; Cornell, Heth, & Rowat, 1992).

Furthermore we could show a pronounced effect-size concerning the relevance of different kind of landmarks and confirm the results obtained by Cohen and Schuepfer (1980). Both landmarks adjacent to a correct turn and adjacent to no turn were better recalled than those to an incorrect turn. This result does not depend on the exploration frequency. Further experiments could clarify if this dismissing function of a landmark leads to memory decay. If this assumption is confirmed the differentiation of landmarks with regard to their function must be discussed. It also has a practical aspect: In official buildings landmarks should stand on those turns, which lead to the correct goal dependent on the degree of utilization of the corridors.

4.2. The role of landmarks and the influence of sex under a developmental perspective

In contrast to the study of Cohen and Schuepfer (1980) it has been shown that there was no difference in the performance between older children and adults: Sixth graders did not make more errors and did not walk longer distances than adults, what means that they were fully co-ordinating their route knowledge in this study. This result is reflected in the results of the recall test: Adults and sixth graders recalled more landmarks than second graders. Whereas Cohen and Schuepfer revealed a difference concerning the amount of recalled landmarks adjacent to a correct turn between adults and both older and younger children, there was no difference found in this study.

Contrary to the study of Cohen and Schuepfer (1980) effects of sex were found: First of all, females made more errors exploring the maze without landmarks. This is in accordance with the result mentioned above that females rely more on the existence of landmarks than males (Dabbs et al., 1998; Miller & Santoni, 1986). The fact that sex differences were found only in the absence of landmarks is in accordance with a result of Sandstrom, Kaufman, and Huettel (1998). They conclude that males can better adapt their strategies dynamically to the information available in the environment.

Second, concerning the recall of landmarks, young boys recalled more landmarks than young girls, whereas women recalled more landmarks than men. Already Galea and Kimura (1993) showed that there was a better recall of landmarks for women than for men, which was not simply a by-product of a better visual-item memory. In literature, there is little agreement if the onset of sex differences is before or after puberty. Johnson and Meade (1987) showed in a study with 1800 children of different age levels that a male advantage in spatial performance appears reliably by the age of 10, which is in line with the results of a study of Kerns and Berenbaum (1991). Concerning the recall of landmarks and the wayfinding in a maze without landmarks the results of this study show an age difference even in younger children. For that, the onset of sex differences must be investigated in more detail with respect to the kind of spatial task.

4.3. Explanation of the different results of this and Cohen and Schuepfer's study

The results of this study (regarding the missing difference between older children and adults and the influence of gender) are partly in contrast to those of Cohen and Schuepfer (1980), but are more in line with the literature. It might be assumed that their tasks might have been too artificial and too complex for the participating children, so that both age groups showed a minor performance than adults. In contrast, when using virtual environments, children were able to navigate actively through the maze. Single sections of the maze could be explored from several perspectives. Landmarks could be seen from different viewpoints. Active navigation facilitates the integration of spatial information in a more complex environmental configuration, and is helpful for children when acquiring spatial knowledge (Cohen & Weatherford, 1980; Feldman & Acredolo, 1979; Herman & Siegel, 1978).

Furthermore, the possible argument that the familiarity with playing computer games accounted for the good performance of older children and men could be ruled out due to three observations: (1) No significant correlation between the frequency of computer use and errors in the test trial exists if the age group and sex were controlled. (2) Younger children did not perform as well as adults, even though they played as often computer as older children. (3) Men and older children are not better in all spatial tasks, so for example in the number of trials to reach the learning criterion. These observations are in line with a study of Moffat, Hampson, and Hatzipantelis (1998).They showed a male advantage in navigation in a virtual maze which could not be attributed to greater computer experience. Obviously, familiarity to computer games is not of any help for successfully performing the experimental task used here, even though Waller et al. (2001) showed that differences between individual characteristics as prior computer use account for variance in spatial tasks in a virtual environment.

Surely, it is to mention that this comparison across studies is quite difficult because it involves methods that did not differ only regarding active/passive navigation but along multiple dimensions, for example continuous (VEs) versus discontinuous (slide presentation) images of the environment. To support the assumption that route learning is affected by an interaction between developmental stage, sex, and type of environmental exposure, a systematic manipulation of these variables within the same experiment is needed. Active versus passive exploration could be manipulated in a VE comparing a group of participants who navigate actively through the maze (by means of a joystick) with a group who is exposed to a film of a walk through the maze (without any control over navigation). It seems that learning a path in a VE is much more closely related to acquiring route knowledge in the real world than learning a way through a slide presentation, but this has to be proven in a subsequent experiment.

The better recall of landmarks in this study in comparison to the study of Cohen and Schuepfer (1980) might indicate that the active navigation in VEs ameliorates the learning and storage of environmental landmarks. Alternatively, the difference can also be due to a possible difference in the salience of landmarks, this means that the landmarks in our study might have been more eye-catching due to colour, size, or body structure. To investigate this assumption the salience of landmarks might be varied.

4.4. Using VEs in developmental spatial cognition: Advantages and drawbacks

Given these results, another relevant finding could be pointed out: VEs seem to be a reliable method to investigate factors of spatial development and must therefore be increasingly appreciated in investigations with children. One reason for this might be the opportunity to draw new conclusions about some aspects of cognitive development. Here, it was shown that children at the age of 11 and 12 were as good as adults in finding a new way and in remembering some landmarks on the route, which is in accordance with a study of Cornell, Heth, and Alberts (1994) who analysed developmental differences in finding a way back: 8 year olds had more difficulties than 12 year olds who did not differ from adults. In their study the children were also able to learn the way by active navigation—in this case in a natural environment.

The use of VEs seems to bridge the gap between the need to test children in environments, which permit experimental control and those, which have some ecological validity (Blades, 1997). The use of VEs provides continuous measurements during navigation (see for an example Fig. 2) and allows the registration of strategies children use to get along in an unfamiliar environment (compare studies with adults Dalton, 2003; Hochmair & Frank, 2000; Kuipers, Tecuci, & Stankiewicz, 2003). Furthermore, this study shows that by means of VEs developmental diversity, whose importance was recently pointed out by Liben (2003), can be investigated in a reliable manner.

In this study we have used a desktop virtual system, which is widely used and appreciated for the investigation of the cognitive processes of spatial cognition (for example Gillner & Mallot, 1998; Ruddle, Payne, & Jones, 1997, 1999). Desktop virtual systems have the drawback that they do not allow for the integration of self-motion as being equivalent to actual environmental experience (Witmer et al., 1996). The missing of this self-motion might be much more critical for more perception-based tasks like path-integration than for more cognitive tasks (Jansen-Osmann & Berendt, 2002). 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. The use of an immersive virtual system, in which updating at least the head-position is possible, could ameliorate spatial learning, but is also discussed critically (Westerman et al., 2001). In spite of the advantage of being completely immersed in the virtual world, immersive systems have a great disadvantage, namely the common occurrence of after-effects, which include symptoms of motion sickness, disturbance of balance, and drowsiness (Stanney & Salvendy, 1998). Until the improvement of the immersive virtual environment technology, its use in developmental research seems to be dispensable.

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