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Empirical evaluation of virtual environment technology as an experimental tool in developmental spatial cognition research

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The study compared developmental aspects of spatial knowledge acquisition in a real and a virtual large-scale environment according to the classical study of Cohen and Schuepfer (1980) with 40 younger children (7–8 years old), 40 older children (11–12 years old), and 40 adults. All participants learned the correct route through a maze, recalled the inherent landmarks, and drew a map of the maze. The results revealed equivalent age effects for these tasks in the real and the virtual world. In both conditions younger children needed more trials to learn the route and showed less configurational knowledge than older children and adults. Age group performance on landmark recollection did not differ in either the virtual or the real world maze. Except for the map drawing task performance was always worse in the virtual world condition. Because the developmental process was comparable in real and virtual environments, the results support the use of virtual environments for the research on developmental aspects of spatial knowledge.

Keywords: Spatial cognition development; Virtual environments; Children and adults.

It is the main goal of this paper to evaluate virtual environments in spatial cognitive development research which will provide us with more insight in

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future research directions. The development of spatial cognition during childhood can be considered as a classical field of cognitive research since Piaget's and Inhelder's work on *The Child's Conception of Space* (1956). Piagetian theory about the different stages of reference systems in spatial learning children have to progress through (from egocentric to fixed relative to external objects, e.g., landmarks, to allocentric) has inspired further work on this topic. Siegel and White (1975) proposed an influential model of the development of spatial representations in environments, which are not perceivable from one vantage point, the large-scale environments. They assume that the acquisition of spatial knowledge follows a developmental sequence that starts with the knowledge of landmarks, proceeds in route and ends in survey knowledge.

Although this model was influential it was often challenged on empirical and conceptual grounds. Nowadays it appears that the theoretical analyses are comprehensive whereas the empirical support remains problematic (Jansen-Osmann, 2007). The reason for this is that research on human spatial cognition is difficult to conduct. Whereas the investigation of spatial behaviour and spatial knowledge in real settings contends with the threats to internal validity, particularly the difficulties of controlling all environmental parameters and replicating experiments, classical laboratory settings (with slide or video projections) are often unrealistic and the degree of interactivity is low (Jansen-Osmann, 2007; Peruch & Gaunet, 1998; Wartenberg, May, & Peruch, 1998). Thus, computer simulated (virtual) environments (VE) became a promising tool for studying spatial cognition. Today VE technology varies along several dimensions, among other things the degree of immersion in the environment. Whereas immersive virtual environments (IVE) lead to perceptions of being included in the environment (e.g., by head-mounted-displays and interface devices that provide a sensory feedback), desktop systems usually display the visual information of an environment on a computer monitor or a projection screen and provide no proprioceptive cues (Blascovich et al., 2002; Jansen-Osmann, 2007; Richardson, Montello, & Hegarty, 1999).

Many studies using VEs have focused on spatial learning and the training potential of VEs in large-scale environments (e.g., Bliss, Tidwell, & Guest, 1997; Darken & Sibert, 1996; Foreman et al., 2000; McComas, MacKay, & Pivik, 2002; Witmer, Bailey, Knerr, & Parsons, 1996) and in small-scale environments (e.g., Belingard & Peruch, 2000; Regian, Shebilske, & Monk, 1992; Tlauka, 2004). Some studies tried to recreate classical experiments on spatial cognition and compared the obtained data with the former results (Ruddle, Payne, & Jones, 1997). Major advantages of VEs are the possibility to control environmental parameters tightly and to design and adapt an environment economically, quickly, and in accordance with the hypotheses to be tested. Furthermore the influence of visual information on spatial learning can be extricated, and data of spatial behaviour can be collected easier and with continuous measurements (Peruch & Gaunet, 1998; Wartenberg et al., 1998). At least a strong argument for using VEs instead of more traditional laboratory settings is the greater degree of interactivity given here. Subjects can explore the environment actively and they can control what they experience. Besides the advantages of using VEs the criticism increases as it is the lack of ecological validity (Spiers & Maguire, 2004) and of body-based information that was shown to be essential (Ruddle & Lessels, 2006).

Up to now only few studies exist which investigated the development of spatial cognition in VE (for an overview compare Jansen-Osmann, 2007). One of them was the replication of the classical study of Cohen and Schuepfer (1980) by Jansen-Osmann and Wiedenbauer (2004b). Cohen and Schuepfer instructed their subjects (second graders, sixth graders, and college students) to learn a route through a series of corridors, which were connected to form a maze. An overview of the maze, which is used in this study, too, is given in Figure 1.

The route was depicted on slides with each slide containing a centre hallway and a configuration of three landmarks and three intersecting halls. The aim of the study was to investigate the selection and use of landmarks during route learning as well as the ability to integrate environmental experiences into consistent route and survey maps. Their data provided evidence for the model of Siegel and White (1975). Second graders were more influenced by the presence, position, and sequence of landmarks than sixth graders and adults and only the adults were able to produce consistent survey map presentations.

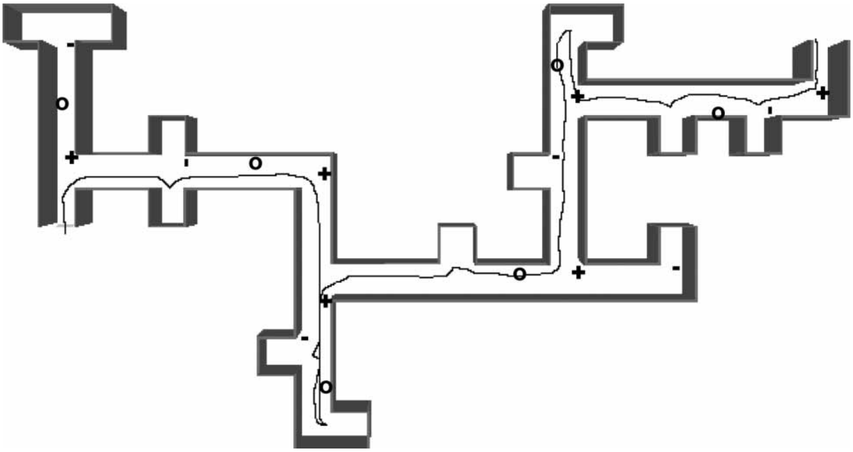

Figure 1. An overview of the maze ("+" denotes a landmark adjacent to a correct turn, "-" denotes a landmark adjacent to a wrong turn, "**o**" denotes a landmark adjacent to no turn). The walk of a participant was traced back through the maze.

Although most of the results of the study of Jansen-Osmann and Wiedenbauer (2004b) were in line with the data obtained by Cohen and Schuepfer (1980), few were not. For example, whereas Jansen-Osmann and Wiedenbauer (2004b) found that the presence of landmarks was more important for second graders than for older children and adults, they failed to demonstrate differences between sixth graders and adults concerning the relevance of landmarks. Of course this disparity between original and replication raised some substantial methodological questions. Some of them concerned the comparability of the two studies itself (active vs. passive navigation, continuous vs. discontinuous presentation of the environment, different salience of landmarks). But more crucial were those dealing with the ecological validity of both experimental settings. If there are already differences between the two experimental laboratory settings, we have to ask if we are able to compare the spatial behaviour in a virtual and a real world at all. Furthermore the idea of using VEs as a new experimental tool for investigating the development of spatial cognition was challenged due to the fact that no empirical work at least in developmental research exists on evaluating these environments. As the "reality" of VEs can be considered to be crucial for this research we decided to use a virtual setting and an experimental design that were already validated in former studies. We chose the virtual maze designed in accordance to the maze of Cohen and Schuepfer (1980)—a VE already reliably tested (Jansen-Osmann, 2002; Jansen-Osmann & Wiedenbauer, 2004b; Wiedenbauer & Jansen-Osmann, 2006) that showed great promise for a real world replication. In creating an experimental design with a maximum degree of similarity between VE and real world as well as with control, transparency, and total availability of the obtained data most methodical problems of preceding replication studies were solved.

A second focus of the present study was to examine the potential value of VEs for the research on developmental aspects of spatial cognition. Thus, effects of age and especially the question of equivalence in age effects between virtual and real environments were of substantial interest. The model of the development of spatial representations proposed by Siegel and White (1975) served as frame of reference in evaluating VEs as the new tool. Results obtained in the real and virtual maze were compared regarding their accordance with the model.

METHOD

Participants

One hundred and twenty participants of three age groups took part: younger children aged 7 or 8 (mean age: 7.63), older children aged 11 or 12 (mean age: 11.58), and adults aged between 19 and 45 (mean age: 24.69). There were 19 boys and 21 girls in both children groups, and 20 males and 20 females in the adult group. Equal numbers of subjects of each age group were assigned to the two conditions (virtual and real maze). The numbers of males and females in each of the six groups were almost equal. Children were either members of an established subject pool at the Department of Experimental Psychology at the Heinrich-Heine University, Duesseldorf, reached through advertisements in local newspapers or recruited from a primary school (Catholic School, Ittenbach). Adults were students of the Heinrich-Heine University, Duesseldorf.

Materials

The material consisted of two corridor systems (real vs. virtual) in correspondence to the study of Cohen and Schuepfer (1980). Their system of main corridors and cul-de-sacs was transformed into a virtual version, which has already been used in former studies of our group (Jansen-Osmann, 2002; Jansen-Osmann & Wiedenbauer, 2004b; Wiedenbauer & Jansen-Osmann, 2006). Thus, in regard to the floor plan, the maze displayed by Cohen and Schuepfer is identical to the real world maze and the virtual maze used in this study. The mazes consist of six main corridors (see Figure 1). Each main corridor offers three turns: two of these lead to dead ends and one leads to the next corridor and, ultimately, to the goal. That means that only one route leads to the goal. The correct sequence of turns from the start to the end of the maze was right, right, left, left, right, left. Exclusively 90° turns existed. When passing by a turn it was not possible in either the real or the virtual maze to see whether a turn was a dead end or not. The virtual as well as the real maze contained 18 different toy animals. The position of these landmarks was in accordance to the landmark positions in the study of Cohen and Schuepfer. Figure 1 illustrates the arrangement: a "+" denotes a landmark adjacent to a correct turn, a "**-**" denotes a landmark adjacent to an incorrect turn (that is a dead end), and a "**o**" denotes a landmark adjacent to no turn. It was not differentiated between landmarks adjacent to a correct turn where the correct turn has an alternative (i.e., first correct turn) and those where there is no alternative (i.e., second correct turn).

Virtual maze. The virtual maze condition was conducted in a virtual world using the software 3D GameStudio A5 on an Intel Pentium M (2.0 GHz) laptop with a NVIDIA GeForce 6800 graphics card. The virtual maze was projected onto a 17-inch flat-screen monitor. The distance between the monitor and the participant was always about 0.4 m. Participants explored the virtual maze by using a joystick. Its rotation and translation settings were fixed for all participants except for the velocity of the simulated movement through the maze. Corresponding to the real world maze experiment, subjects could set the pace up to the limit of about 5 quants/tick (with 1 quant being about 14.29 cm, which results in a velocity of 8 km/h in a real world setting). Thus, the maximum speed of traversing the virtual maze was about 25 s, which was the fastest traversal time in the real maze as well. Figure 2a shows a snapshot into the maze.

Real maze. The real maze condition took place in an underground car park of the Heinrich-Heine University, Duesseldorf, where a temporary maze was installed. The maze was scaled up from the floor plan of the virtual maze. The size of the actual maze was 46 m in length and 24 m in width. The passage width of the corridors and cul-de-sacs was 2 m. Participants who traversed the maze on the correct route covered a distance of about 60 m. The walls of the maze were built of nontransparent construction foil, which were about two m high so that it was impossible

Figure 2. Insights in the virtual and real conditions. Snapshots into (a) the virtual maze and (b) the real maze. (c) An 8-year-old boy with helmet and glasses participating in the real world condition.

for any participant to overlook the maze from inside it. In constructing the maze, importance was attached to the fact that no other environmental features than the 18 toy animals could serve as landmarks. The toy animals were placed on blue buckets (see Figure 2b). Digitised photos of these landmark arrangements served for the landmarks in the virtual maze. Thus sequence, position, appearance and even the relative size of the landmarks (particularly with respect to the walls of the maze) were identical in the virtual and the real maze. Furthermore, participants wore special glasses that restricted their field of vision analogue in the virtual world condition (see Figure 2c). So a distinct turn of the head was required to identify a branching as a dead end. During the 5 weeks of conducting the experiment, the area of the underground car park where the maze was installed was closed to any traffic.

Procedure

To control for the influence of prior computer and joystick experience, all participants of the virtual maze experiment first spent time familiarising themselves with handling the joystick by navigating through another (nonexperimental) maze. When the subjects declared that they were comfortable with their performance and the experimenter agreed with them, practice was terminated and the experiment itself began. At the beginning of the experiment in the real maze all participants were equipped with a helmet on which the camera was installed and special glasses that restricted their field of vision (see Figure 2c). At each trial participants were blindfolded while being guided to the start of the real maze. The experimental procedure was identical for the real and the virtual worlds and in accordance with the former studies mentioned earlier. There were five experimental phases:

1. *Learning Phase I*: All participants had to traverse the maze (real and virtual world maze respectively) until they reached the goal in four consecutive trials without an error in less than 16 trials. This criterion of four consecutive trials was chosen in accordance to the study of Jansen-Osmann and Wiedenbauer (2004b) and Wiedenbauer and Jansen-Osmann (2006). An error was defined as choosing a wrong turnoff by walking or looking into it. During the learning phase all landmarks were present. Participants were informed about the criterion (four consecutive trials with no error) and about the way errors were assessed. The number of trials to reach criterion performance level was recorded.

2. *Test Phase*: All landmarks were removed from the maze. After that, participants were instructed to follow the "correct" route, that is, without errors, to the goal. The test phase consisted of only one trial. The number of errors in this trial was recorded.
3. *Learning Phase II*: The landmarks were again placed into the maze in the original, correct order. Participants had to navigate through the maze in two consecutive trials without an error. This criterion was again chosen in accordance to the studies of Jansen-Osmann and Wiedenbauer (2004) and Wiedenbauer and Jansen-Osmann (2006). They were instructed that in contrast to Learning Phase I now only two faultless trials were required. The number of trials to reach criterion were registered.
4. *Recall Test*: In moving through the empty maze (all toy animals were absent), either with the help of the joystick in the virtual maze or by walking in the real world, the subjects had to recall the location and kind of the 18 landmarks, that is they had to indicate the position and name of the animals. These specifications were documented by the experimenter on a sheet of paper where the floor plan of the maze was mapped out. Participants had not been informed about this task in advance. Landmark knowledge was assessed by the number of accurately recalled landmarks (name and position were correct).
5. *Map Task*: Subsequent to these experimental phases all participants had to draw a map of the maze. The subjects were instructed to depict the maze from a bird's eye view and to include not only the correct route but also wrong turnoffs and dead ends in the drawing. The interpretation of the map was based on countable aspects, like number of main corridors, (correctly drawn) dead ends, turnoffs, etc. These crude values were transformed into scores, with high scores indicating good performance. For example the correct number of main corridors in the maze was six, so a map depicting six main corridors was scored with 6, a map depicting five or seven main corridors was scored with 5, and so on. In order to avoid low scores for participants who didn't encounter all the dead ends because they learned quickly to traverse the maze on the right path, the interpretation of the map focused on the area directly associated with the correct route. That is, only those cul-de-sacs that were visible from the correct route were included in the analysis. An overall score of "map correctness" was computed in summing the scores for the number of drawn corridors, the number of depicted dead ends (regardless of their position), the number of correctly drawn dead ends (i.e., the position of the dead end had to be right, too), and the number of correctly mapped turnoffs (that is, up to the point where the turning sequence—right, right, left, left, right, left—was depicted wrong for the first time a point was added). A maximum of 6 points could be achieved for all four features, so

the hypothetical highest value for the overall score of "map correctness" was 24. Cronbach's alpha was .73.

Although gender differences were sometimes found in spatial cognition research (Devlin & Bernstein, 1995; Lawton, 1994), our own research revealed a completely undifferentiated picture regarding spatial performance and knowledge in a virtual environment (compare Jansen-Osmann & Heil, 2007). For that reason gender was not regarded as an experimental factor.

Experimental design

The factors age group (7- to 8-year-old children, 11- to 12-year-old children, and adults) and world (virtual, real) 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 number of learning trials, number of errors in the test trial, number of recalled landmarks, and overall score of "map correctness".

RESULTS

Data analysis

Computer experience was not further analysed because none of our other studies showed any influence of computer experience on the measurements obtained (compare Jansen-Osmann & Fuchs, 2006; Jansen-Osmann, Schmid, & Heil, 2007a, 2007b; Jansen-Osmann & Wiedenbauer, 2004a, 2004b, 2004c).

In the virtual maze experiment, the relevant data (see earlier) were recorded by an experimenter on a sheet of paper. In addition the program documented for each trial the route a participant navigated. In the real world maze, the data were also recorded by an experimenter on sheets of paper. For these purposes it was necessary to accompany the subjects during each trial. The experimenter avoided providing any indication of the correct route while traversing the maze. In addition to the experimenters' documentation, all trials of each subject were videotaped by a helmet camera. The documentation of the helmet camera and the VE program allowed a reliable measuring of the dependent variables.

The statistical significance level was set at $\alpha = .05$.

Statistical results

Learning Phase I: Number of trials to reach criterion performance level. A univariate analysis of variance on the number of trials revealed a significant main effect of the factor age group, $F(2, 114) = 7.53$, $p < .01$, $\eta^2 = .117$, and a significant main effect of the factor world, $F(1, 114) = 70.62$, $p < .001$, $\eta^2 = .383$. Younger children ($\bar{x} = 9.17$, $s_{\bar{x}} = 0.44$) and older children ($\bar{x} = 8.7$, $s_{\bar{x}} = 0.42$) needed more trials than adults ($\bar{x} = 7.45$, $s_{\bar{x}} = 0.36$). In the virtual world participants ($\bar{x} = 10.02$, $s_{\bar{x}} = 0.35$) needed more trials to reach criterion than in the real maze ($\bar{x} = 6.86$, $s_{\bar{x}} = 0.19$). There was no significant interaction between the factors age group and world, $F(2, 114) = 0.69$, *ns*, $\eta^2 = .012$. The results are shown in Figure 3.

Test Phase: Number of errors. The factor world had a significant effect on the number of errors in the test trial, $F(1, 114) = 15.55$, $p < .001$, $\eta^2 = .121$. In the virtual world maze ($\bar{x} = 1.29$, $s_{\bar{x}} = 0.28$) participants made more errors than in the real world maze ($\bar{x} = 0.18$, $s_{\bar{x}} = 0.06$). There was no significant main effect of age group, $F(2, 114) = 1.02$, *ns*, $\eta^2 = .018$, and no significant interaction between the factors age group and world, $F(2, 114) = 0.88$, *ns*, $\eta^2 = .015$.

Learning Phase II: Number of trials to reach criterion performance level. An analysis of variance on the number of trials in Learning Phase II revealed no significant main effects for age group, $F(2, 114) = 0.04$, *ns*, $\eta^2 = .001$, or for world, $F(1, 114) = 1.52$, *ns*, $\eta^2 = .013$, or an interaction of both factors, $F(2, 114) = 0.89$, *ns*, $\eta^2 = .015$. Most of the participants reached criterion in two trials, that is, they did not make any errors in traversing the maze in Learning Phase II.

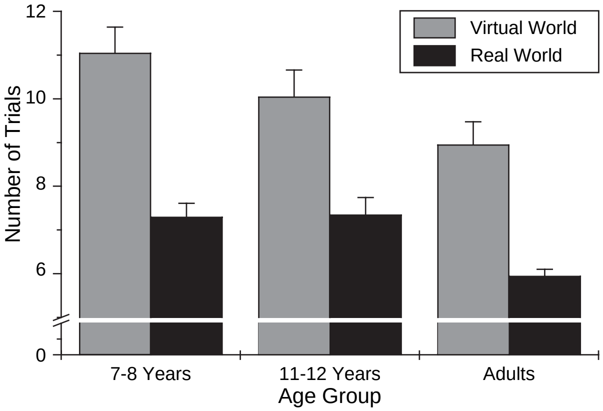

Figure 3. Means and standard errors for the trials needed, dependent on the age group and the world.

Recall of landmarks. A 3 (age group) × 3 (kind of landmark) × 2 (world) mixed factorial analysis was performed on the kind of landmarks that were recalled correctly. This analysis revealed significant effects of world, $F(1,\ 114) = 9.7$, $p < .01$, $\eta^2 = .08$, and kind of landmark, $F(2,\ 228) = 355.35$, $p < .001$, $\eta^2 = .76$, and a significant interaction between both factors, $F(2,\ 228) = 12.94$, $p < .001$, $\eta^2 = .09$. There was no influence of the factor age group, $F(21,\ 114) = 1.6$, *ns*, $\eta^2 = .03$, or of interactions Kind of landmark × Age group, $F(4,\ 228) = 0.76$, *ns*, $\eta^2 = .013$, Age group × World, $F(2,\ 114) = 1.01$, *ns*, $\eta^2 = .019$, and Kind of landmark × Age group × World, $F(4,\ 228) = 0.72$, *ns*, $\eta^2 = .009$.Participants in the real world remembered more landmarks adjacent to no turn than participants in the virtual world, $F(1,\ 118) = 35.37$, $p < .001$, $\eta^2 = .231$. Furthermore, participants remembered more landmarks adjacent to an incorrect turn in the real than in the virtual world, $F(1,\ 118) = 7.21$, $p < .01$, $\eta^2 = .058$; even the effect size is much smaller as the one mentioned previously. There was no significant difference between both worlds concerning landmarks adjacent to a correct turn, $F(1,\ 118) = 0.78$, *ns*, $\eta^2 = .001$ (see Figure 4).

Map drawing test. An analysis of variance on the overall score of map correctness revealed a significant effect of age group, $F(2,\ 114) = 18.13$, $p < .001$, $\eta^2 = .251$. Younger children ($\bar{x} = 11.97$, $s_{\bar{x}} = 0.83$) performed worse than older children ($\bar{x} = 16.1$, $s_{\bar{x}} = 0.85$), who in turn got less points than adults ($\bar{x} = 18.76$, $s_{\bar{x}} = 0.67$). There was no significant effect of world, $F(1,\ 114) = 2.50$, *ns*, $\eta^2 = .023$, on the map correctness score and no significant interaction of the factors world and age group, $F(2,\ 114) = 0.315$, *ns*, $\eta^2 = .006$. The results are shown in Figure 5.

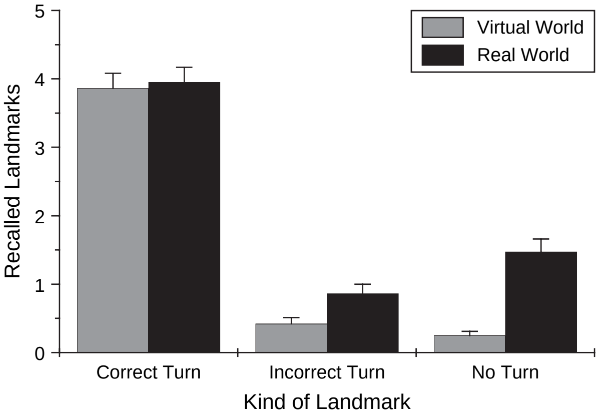

Figure 4. Means and standard errors of the landmarks recalled at correct positions, dependent on the kind of landmarks and on the age group.

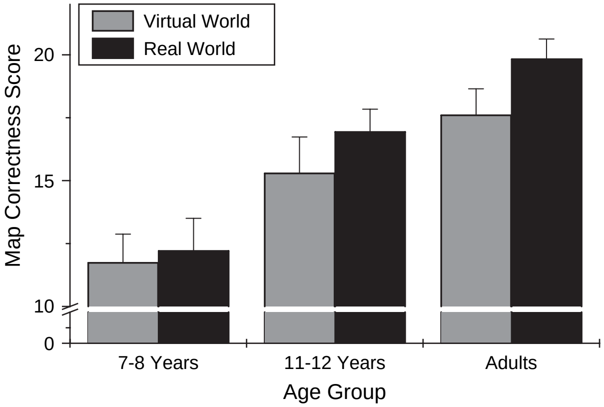

Figure 5. Means and standard errors for the map correctness score, dependent on the age group and the world.

DISCUSSION

The main goal of this study was to compare age effects of spatial cognition obtained in a real world and a virtual world condition. Our results support the claim for VEs as a new experimental tool within developmental spatial cognition research, as the pattern of differences concerning the performance on spatial tasks between the three age groups was comparable in the real world and the virtual world setting. That is, whenever age effects were revealed, they were found in both experimental conditions. In the virtual as well as in the real maze younger children needed more trials than older children and adults to learn the route initially. Furthermore they performed worse on the map drawing test, which was also seen in both experimental conditions.

However, although there was an equivalence in age effects between real and virtual world, it is also imperative to mention the differences between the two conditions. Performance was often worse in the virtual maze than in the real maze: In the virtual world participants needed more trials to learn the route, made more errors when the landmarks were removed, and recalled fewer landmarks adjacent to no turn. These results are in line with other VE studies. Richardson et al. (1999), for example, showed that in a complex two-floor environment spatial knowledge acquisition was poorer for VE learners than for participants who learned from maps or direct experience. Ruddle (2001) found extremely inefficient searching behaviour for some participants who had to find targets by navigating in a VE. The poor performance in desktop VEs is often attributed to participants' disorientation (Richardson et al., 1999; Ruddle, 2001; Ruddle et al., 1997). Although not the focus of our investigation, there was support for this assumption by the kind of errors participants made in the first learning phase. While in the virtual maze, walking into a wrong turnoff was often followed by choosing the wrong direction in returning on the corresponding main corridor (that is, participants moved backwards to the starting point instead of forwards to the goal); this behaviour was rarely documented in the real maze condition. These findings indicate that participants are more likely to get lost or disorientated in a desktop VE than in a real world environment. This raises the important issue of the role of body-based information for the performance of spatial tasks. Ruddle and Lessels (2006) could show that participants who acquired information from full physical movement (translation and rotation) performed better on navigational tasks than participants who were provided with only visual information or visual and rotational, but not translational information.

Although our results demonstrate poorer performance in the VE condition for route learning this effect was not found for the map drawing test, where performance was equal for the virtual and the real world conditions. A likely explanation for this is that in our study the acquisition of survey knowledge remained unaffected by the lack of proprioceptive information given in a desktop VE, because route finding performance was almost perfect for all participants when they traversed the maze in the second learning phase. Concerning the retrieval of landmarks we found a poorer performance in the VE condition for those landmarks that do not lie at a correct turn. That means that landmarks that have a positive decision-making function are as well recognised and memorised in virtual as in real environments. This is quite a new and interesting result. One might speculate that in virtual environments the function of landmarks, and in this case, the route leading function, is more important than in real environments where their pure existence plays a more substantial role. This observation could be related to the results of a neuroscientific study by Janzen and van Turennout (2004). Their participants learned a route through a virtual museum. After that, fMRI data were required while remembering landmarks. The results showed a different activity for landmarks that lie on a decision or a nondecision point. Both studies show the different value of landmarks is dependent on the function within the route and in our study is dependent on the kind of environment.

Even if the process of spatial knowledge acquisition seems to take longer in virtual than in real environments, the investigation of the developmental process seems to be possible in virtual environments. What is the implication for further studies?

This study gives a hint that virtual environments do not seem to be that inadequate for the investigation of spatial cognition. Their use seems to depend on the "application area" (adequate tool for research on developmental aspects), the experimental measurements, the "reality" of the virtual environment, as well as the comparability to the real world. Furthermore, it might be important what kind of knowledge is retrieved. Although navigation processes seem to be impaired in virtual environments (compare Ruddle & Lessels, 2006), this is not evident for the survey component of spatial knowledge. Beside the methodological aspects of this study, the results could be interpreted with regard to the study of Cohen and Schuepfer (1980) and the model of Siegel and White (1975). This will be explained next.

The actual data reveal that under both conditions (real and virtual) the youngest children needed more trials to learn the route comprehensively than older children and adults. In our former study (Jansen-Osmann & Wiedenbauer, 2004b) no age effects were found. These discrepancies can be attributed to differences between the virtual mazes used in the studies, namely, size and kind of landmarks as well as velocity of the simulated movement. In the actual VE experiment landmarks were smaller than in the former study and the maximal velocity was higher to make experimental setups in the real and virtual world comparable. This might have affected the route learning abilities of the youngest children. In contrast to the study of Cohen and Schuepfer (1980) as well as our former study (Jansen-Osmann & Wiedenbauer, 2004), we also failed to show that younger children relied more on the presence of landmarks than older children and adults. The performance of the three age groups did not differ in the virtual maze or in the real world maze when the landmarks were removed. Furthermore in both conditions (real and virtual world) we didn't find age effects for the recall of landmarks, which is also at odds with the preceding studies. A likely explanation for these results is that during the initial learning phase (which ends by reaching the goal in four consecutive trials with no error) the groups get matched on performance. As there were major age effects on the initial acquisition of the route, with younger children requiring more trials than older children and adults, it is possible that this extended exposure to the environment has substantial training and learning effects that counter-balance the poorer performance attributed to the developmental status. Following this argument the age effects revealed for the learning phase can be interpreted as differences in route knowledge, which would be in line with the model of Siegel & White (1975). Also in line with the model of Siegel and White is the result that in the real world as well as in the virtual world condition younger children showed less configurational knowledge than older children, which in turn showed less than adults. This is also consistent with the results of Cohen and Schuepfer, who found that only adults produced fully consistent representations of the environment.

In summary, the development of spatial representation as described in the model of Siegel and White (1975) is supported by both results obtained in a real world setting and results obtained in a virtual world setting. Age effects were comparable in the two experimental conditions; thus, VE technology might be useful for the research on developmental aspects of spatial cognition. Further studies have to follow to investigate this assumption in more detail, namely, to exclude a possible interaction between age and environment in more complex environments.

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