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The role of locomotion in the acquisition and transfer of spatial knowledge in children

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The role of locomotion in the acquisition and transfer of spatial knowledge was investigated in 144 five-, seven- and eleven-year-old children. Two experiments were conducted in the Kiel locomotor maze. In the first experiment, one group of children explored the spatial layout by walking through the maze, while another learned the maze by surveying the layout. In the second experiment, children were exposed to one of two orientation tests in the maze, one of which could be solved using "landmark orientation", the other only using a "relational place orientation". Children sitting by the side of the experimental chamber surveying the maze needed fewer trials to learn the spatial layout than children exploring the environment in the locomotion condition, but in the orientation test demanding the "relational place orientation" children who had explored the maze in the locomotion condition outperformed the children in the non-locomotion condition. Results are discussed in the context of cognitive mapping models.

Key words: Locomotion, children, spatial learning, spatial orientation.

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All moving species need somehow to represent space. Tolman (1948) showed that rats are able to take unknown shortcuts in a maze they have explored before, thus demonstrating a mental representation of the space they were moving in. O'Keefe and Nadel (1978) called this phenomenon a cognitive map and proposed that all moving organisms are able to represent space via a cognitive map. In the course of exploring an environment, such a cognitive map will be established.

The development of spatial competence in children has been of much research interest for more than 50 years. Piaget and Inhelder (1948) were the first to investigate the development of children's spatial cognition. In concordance with their general theory of development, they proposed a model of different stages of spatial development. According to that model, children's orientation first is egocentric. Infants try to locate an object by using visual information from an egocentric perspective as long as their bodies are relatively static (see also Acredolo, Adams & Goodwyn, 1984; Bremner & Bryant, 1977). Children's orientation then becomes landmark oriented. As soon as infants are able to move, they attempt to discover the object by manipulating the spatial relationships among the objects, themselves and the environment. Later, their orientation is route oriented. Finally, all landmarks and routes are mentally connected to yield a relational overall representation of the environment.

Siegel and White (1975) demonstrated, similarly to Piaget and Inhelder, that spatial representations in children are first landmark oriented. Later, children develop spatial mini-maps, in which some landmarks are related to each other. Finally, a cognitive map of the environment is represented, putting all landmarks in relation to each other. This enables children to use an observer-independent relational orientation strategy, which has also been called allocentric (O'Keefe & Nadel, 1978). It is seen as an integrated understanding of the configurational relations among the elements of an environment.

While it is agreed among researchers that exploration plays a vital part in establishing a cognitive map of an environment (Evans, Marrero & Butler, 1981; O'Keefe & Nadel, 1978), it is not clear whether active locomotion is necessary. In reviewing the literature, we found inconclusive results and thus set out to examine the role of locomotion in the acquisition of spatial knowledge and for the stability of the cognitive map in children.

Investigations into children's cognitive mapping abilities have examined the relationship between different types of environmental exploration and subsequent memory for spatial location. Some researchers investigated the role of active versus passive exploration on spatial memory. For example, Feldman and Acredolo (1979) found that preschoolers remembered locations more accurately after walking alone (active condition) than when they were led by an adult (passive condition), but method of exploration did not affect the accuracy of nine- and ten-year-olds. Herman (1980) found that five- to eight-year-olds located objects more accurately if they had walked through an area rather than around it,

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suggesting that the way of interaction with the environment may play an important role. In another experiment, Herman, Kolker and Shaw (1982) investigated the effects of motor activity on five- and eight-year-old children's memory for spatial locations. Only the five-years-olds' accuracy increased as a function of the amount of motor activity, demonstrating that they depend on motor activity more than eight-year-olds to learn about the location of objects in an unfamiliar environment.

Foreman, Foreman, Cummings and Owens (1990) and Foreman, Gillett and Jones (1994) investigated the role of choice autonomy and active locomotion in six-year-old children. They showed that in a radial search task, children trained entirely passively (transported in a push-chair and prevented from exercising autonomous choice when choosing between room locations) performed very poorly when eventually tested on foot with autonomous choice. Children who were led by the hand (walking, but without autonomous choice) performed reasonably well, but children who were allowed autonomous choice, whether walking or transported, performed at a high level, demonstrating that six-year-old children who are transported can acquire as much spatial knowledge as a locomoting individual if they are allowed choice autonomy. On the other hand, they demonstrated in another study that physically disabled children had impaired spatial abilities (Foreman, Orencas, Nicholas & Morton, 1989).

Recent studies have pointed out the important role of active locomotion. Klatzky, Loomis, Beall, Chance and Golledge (1998) investigated spatial updating of self-position and orientation during real, imagined and virtual locomotion. They demonstrated that when proprioceptive cues to change in heading are lacking, subjects fail to update the heading representation that governs the response return. Rieser, Garing and Young (1994) showed that three- to five-year-old children performed better in a test of spatial memory in a locomotion condition than in an imagination condition. This indicates that proprioceptive cues may play a vital part in establishing spatial orientation.

In a meta-analysis of 19 studies that investigated the developmental influence and the effects of locomotor experience on children's spatial search performance, Yan, Thomas and Downing (1998) found that locomotion improves children's spatial search. Prior to locomotion, the infant's view of the environment is primarily egocentric and based on body location. After acquiring locomotor skills, environmental landmarks become a more stable means of coding spatial information. When children have enriched locomotor experiences, more visual cues are available for the searching activities, thus improving spatial search. Therefore self-locomotion might especially influence the development of allocentric spatial behavior.

Hiraki, Sashima and Phillips (1998) proposed a computational model of spatial development. They proposed a robot that learned to track a target mentally, and demonstrated that, in the absence of the capacity for self-locomotion, the robot made errors that were self-centered. When given the ability of self-locomotion, the robot responded allocentrically.

Taken together, it may be concluded that active locomotion plays an important role in the development of children's spatial abilities. Yet this may not be of equal importance at all ages, as suggested by the previously reported research. Motor involvement may be more important for young children than for older children (Herman *et al.*, 1982). Also, active locomotion need not necessarily facilitate the acquisition of a spatial layout. Spatial layouts might be learned just as quick or even quicker without locomotion, when just a survey of the layout is given. Maps, for example, provide quick and simple survey knowledge. Most theories of the development of spatial knowledge agree that it takes people much longer to construct a survey representation from exposure to the environment (Garling & Golledge, 1989; Siegel & White, 1975). Yet the stability of the cognitive map established by different types of exploration might also differ. The cognitive map that is established by walking through an environment might be more stable and more flexible than a map established by a survey. Rossano, West, Robertson, Wayne and Chase (1998) demonstrated that spatial knowledge acquired from maps is orientation specific, while that acquired from direct experience is not. Orientation specificity refers to the fact that a person's spatial representation has a preferred orientation in memory, corresponding to that which was present on the map, leading to orientation errors when the actual environmental orientation is not congruent with the orientation on the map. Locomoting learners typically do not suffer from this same limitation. Locomoting through an environment implies gaining many different views. This might be beneficial in situations when the person is forced to relocate himself, for instance when being placed in a new position. Therefore, the effect of locomotion on spatial performance also depends on the spatial test applied. If children have to remember a spatial routine that can be solved by egocentric, self-centered strategies, they might depend less on active locomotion during exploration than when solving an orientation test demanding the use of allocentric orientation strategies, as is suggested by the findings of Hiraki *et al.* (1998).

Thus we set out to examine which role locomotion plays, firstly in the acquisition of a spatial layout, and secondly for the flexibility of the spatial map. We hypothesized that while locomotion might not be necessary to learn a spatial layout, self-locomotion would facilitate establishing a stable allocentric spatial map.

We investigated 5–12-year-old children in two experiments. In the first experiment, we investigated spatial learning under two experimental conditions, a locomotion condition and a non-locomotion condition. Children had to learn and remember different spatial locations in an experimental chamber under completely controlled cue conditions. They were either allowed to walk through the environment or they had to sit at the side, surveying the chamber. All children were given choice autonomy. In a second experiment, the children had to solve one of two orientation tests. Each test demanded the use of an allocentric orientation strategy. While it was possible to solve test 1 with a "landmark strategy", orienting towards proximal landmarks, test 2 could be mastered only using a "relational place strategy". The use of a relational place strategy implies considering the configuration of distal cues of an environment (Chapillon, Roullet & Lassalle, 1995; Olton & Samuelson, 1976; Overman, Pate, Moore & Peuster, 1996). It was hypothesized that self-locomotion facilitates establishing a stable allocentric spatial map, leading to better performance in the orientation tests in the locomotion group than in the non-locomotion group, especially when a complex relational place strategy is demanded.

EXPERIMENT 1

Method

Participants. Participants consisted of 144 children from schools and kindergartens, aged 5–12 years: 48 aged 51–68 months ($M = 58$ months), 48 aged 76–95 months ($M = 83$ months) and 48 aged 120–155 months ($M = 137$ months). Each group consisted of an equal number of boys and girls. Informed consent was obtained from the parents. Children with a history of birth complications or brain trauma were excluded from the study. All children had normal or corrected-to-normal vision. They had had no previous experience of the Kiel locomotor maze. All children were assessed with an intelligence test (K-ABC; Kaufman & Kaufman, 1983; German edition, Melchers & Preuß, 1991) and a test of reaction and selective attention (Romny test, Rugland, Henriksen & Bjønæs, 1991), in order to make sure that they were all of normal intelligence and that attention was normally developed.[1] Three of the five-year-olds scored more than one standard deviation below the mean according to test norms in the K-ABC or the Romny test. The data of these children were excluded from analyses and they were replaced by new children.

Apparatus. The Kiel locomotor maze has been described in earlier publications (Lehnung *et al.*, 1998; Leplow, Höll, Zeng & Mehdorn, 1998), and thus only a short description will be given here.

The maze consists of a round experimental chamber with a double wooden floor 3.6 m in diameter. Under the floor there are 20 capacity detectors. These record changes in the ion concentration above them when a participant steps on them. They are connected to a computer in another room processing these signals. The floor is covered with a dark brown carpet. The location of the detectors is made visible by a very thin glass fiber cable, the brightness of which can be adjusted. Locations can be defined as "positive". A "positive" location yields a tone of about 160 Hz when first being stepped on, while the other locations do not. Children have to learn and remember the positive locations while avoiding the other ones.

The chamber is surrounded by black curtains and is only dimly lit by a lamp fastened to the ceiling, in the middle of the chamber. Cues in the maze consist of two "proximal" cues, a toy mouse and a toy rabbit, depicted in fluorescent paint, sitting on the carpet at defined positions, and four "distal" cues, posters showing the sun, the moon, stars and a comet, all made of fluorescent foil (0.75 m × 1 m) hanging from the curtains, each 90° apart from the other. Fig. 1 shows a schematic drawing of the Kiel locomotor maze.

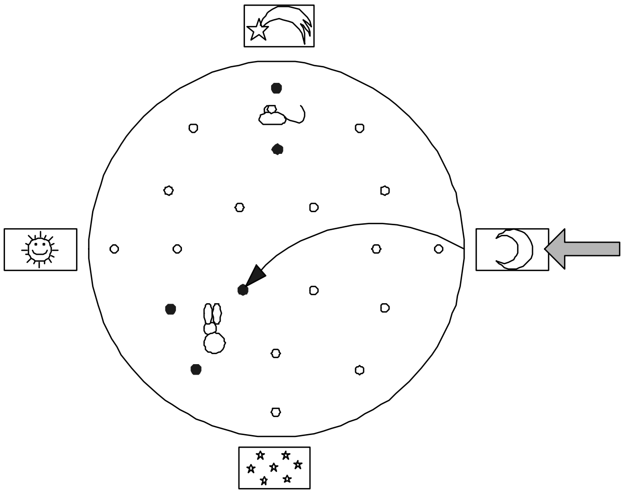


Fig. 1. Schematic drawing of the Kiel locomotor maze. Black dots indicate "positive" locations. The set-up shown was used with 10–12-year-old children during the acquisition phase, Experiment 1.

Procedure. The children in each age group were assigned randomly to one of two groups, an "active locomotion" group and a "non-locomotion" group, each containing the same number of boys and girls. Children were tested individually on one day. The locomotor maze was individually prepared for the children. Pretesting had revealed that it was best to expose children of different ages to different numbers of locations, according to their age. Five-year-olds were exposed to a chamber with three "positive" locations out of 15 locations, seven-year-olds were exposed to four "positive" locations out of 16, and 10–12-year-olds were exposed to five "positive" locations out of 20. This had been shown before to determine task difficulty and to keep training times to approximately the same length (Lehnung *et al.*, 1998; Lehnung, 2000). Thus treatment effects are not confounded with age effects.

In the "locomotion" group, the light points in the floor indicating the location of the detectors were dimmed in such a way that they could not all be seen at once. Only three or four lights could be seen simultaneously, thus preventing the use of algorithmic or geometric coding of the target locations. Children were allowed to walk by themselves through the maze, discovering which locations yielded a tone and which did not, by stepping on every location where they saw a light point. Then they were told to try now to go to the positive locations only and only once, avoiding the other locations. After having found all positive locations one trial was finished, which was indicated by a sequence of tones. Then a new trial started. Children were allowed to take as many trials as they needed to reach the learning criterion, which consisted of two consecutive trials without any error.

In the "non-locomotion" group, the light points in the floor indicating the location of the detectors were brightened in such a way that they could now all be seen at once. Children were seated on a chair by the side of the experimental chamber and handed a laser pointer. With this they were to direct the experimenter through the maze by pointing to the location they wished him or her to go to. The experimenter then stepped on the indicated location. Again the children were allowed to take as many trials as they needed to reach the learning criterion, which consisted of two consecutive trials without any error.

Data analysis. For the acquisition phase, the number of trials to reach the learning criterion were recorded. Data were analyzed by a

3 (age) × 2 (locomotion condition) two-way parametric analysis of variance (ANOVA). For contrast analysis, Student's multiple t-tests according to Kirk (Kirk, 1995) were used, with MS within cells as an estimator of the population error variance. Using this test, special contrasts were calculated in the case of significant interaction to compare the differences between the locomotion condition and the non-locomotion condition of two age groups. The advantage of this approach is that the influence of the main effects is eliminated. Two-tailed probabilities are reported, with values of $p < 0.05$ being considered significant.

Also, the sum of errors during the first ten trials was analyzed. Taking into account that the total number of locations varied for children of different ages, we divided the errors by the number of possible locations. Thus we had a relative sum of errors measure (rSUM). Data were analyzed by a 3 (age) × 2 (locomotion condition) two-way parametric ANOVA. Because of equation of task difficulty we assumed that no differences would emerge here, with values of $p > 0.25$ being considered significant.

Results

No significant sex differences were found at any age level, thus data were collapsed for both sexes.

Number of trials to reach learning criterion. The analysis of the number of trials to reach the learning criterion revealed a significant main effect for age, the older children needing fewer trials than the younger children, $F(2, 138) = 5.345$, $p < 0.01$, and a significant main effect for experimental condition, indicating that the children exploring and learning the layout by active locomotion needed more trials to reach the learning criterion than the children exploring the maze in the survey condition without locomotion, $F(1, 138) = 23.809$, $p < 0.000$. Interaction between age and experimental condition showed a marginally significant difference, $F(2, 138) = 2.365$, $p = 0.098$. Fig. 2 shows the number of trials to reach the learning criterion for the three age groups and both experimental conditions.

Paired comparisons revealed that while the differences in performance in the two experimental conditions were statistically significant for the five-year-olds, $t(43.5) = 3.87$, $p < 0.000$, and for the seven-year-olds, $t(42) = 2.67$, $p < 0.01$, differences for the 11-year-olds failed to reach statistical significance, indicating that the acquisition of a spatial layout is more dependent on the way of learning in younger children than in older children.

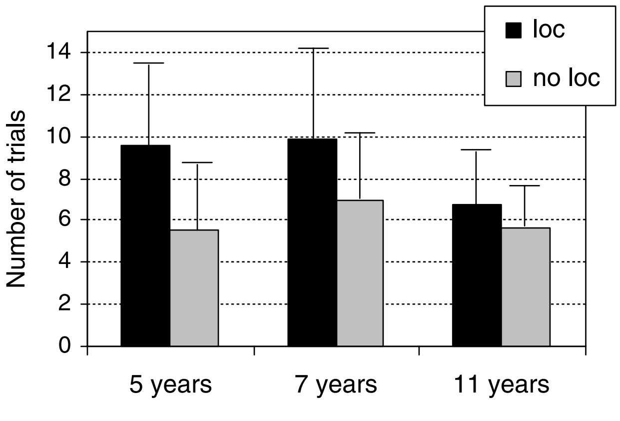


Fig. 2. Number of trials to reach the learning criterion in Experiment 1, for the three age groups and both experimental conditions (loc = locomotion condition, no loc = non-locomotion condition).

Sum of errors. The analysis of the mean relative sum of errors during learning did not yield significant differences. Neither did we find a main effect of age, $F(2, 138) = 0.87$, $p = 0.425$, nor a main effect of experimental condition, $F(1, 138) = 0.46$, $p = 0.49$, nor an interaction effect.

The absence of a main effect of age is in accordance with our previous findings and with our hypothesis, confirming that the equation of task difficulty had been approximately achieved for the three age groups by giving them different numbers of locations, according to their age (Lehnung *et al.*, 1998; Lehnung, 2000).

The absence of a main effect of experimental condition indicates that task difficulty was the same for both experimental conditions.

EXPERIMENT 2

In this experiment we investigated the influence of the two different ways of learning a spatial layout (with or without locomotion) on the performance in two different orientation tasks.

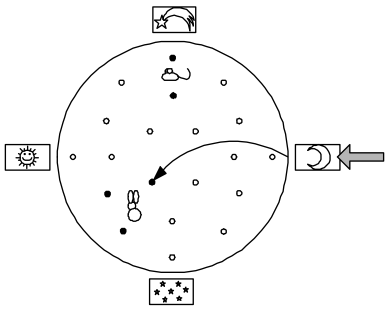
Method

Participants. Since all children who had participated in Experiment 1 had reached the learning criterion, all of them participated in Experiment 2 also.

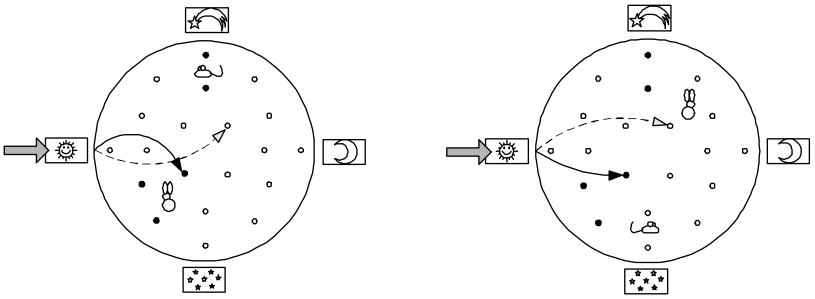
Apparatus and procedure. The same apparatus was used as in Experiment 1. Children were assigned to one of two orientation tests. Half of the children who had explored the maze in the locomotion condition were randomly assigned to orientation test 1, the other half to orientation test 2. Also, half of the children who had explored the maze in the non-locomotion condition were randomly assigned to orientation test 1, the other half to orientation test 2. All children were led with eyes closed to the opposite side of the former starting point, after having been rotated several times with eyes closed. Children then had to find the positive locations again. All children in both tests were allowed to walk by themselves.

In test 1, the cues all remained in the position where they had been during Experiment 1 (see Fig. 3). In order to find the positive locations again, children had to abandon an egocentric orientation strategy. They could master the task by orienting towards either the proximal or the distal cues.

In test 2, the proximal cues were rotated 180° (see Fig. 3). Here, children had to orient only with respect to the configuration of the distal cues, which has been called a relational place strategy (Lehnung *et al.*, 1998). It has been agreed that this kind of orientation strategy demands a flexible cognitive map (Chapillon *et al.*, 1995; Olton & Samuelson, 1976; Overman *et al.*, 1996). Using any other orientation strategy in this test would produce errors.



Acquisition



Response rotation Cue rotation

Fig. 3. Schematic drawing of the testing procedures in the Kiel locomotor maze in Experiment 2. Arrows indicate direction of approach to the maze.

Data analysis. Because all children had reached the learning criterion and thus achieved an equal level of performance, we considered it justified to analyze the sum of errors as a measure of orientation performance. The sum of errors were divided by the number of possible locations for each age group, yielding a relative sum of errors measure (rSUM). Data were analyzed by a 3 (age) × 2 (orientation test) × 2 (locomotion condition during acquisition) three-way ANOVA. In cases of significant interactions, further analysis was carried out. For contrast analysis, Student's multiple t-tests according to Kirk (Kirk, 1995) were used, with MS within cells as an estimator of the population error variance. Two-tailed probabilities are reported, with values of $p < 0.05$ being considered significant.

Results

The performance of the three age groups in both orientation tests and for both experimental conditions is presented in Fig. 4. As no significant sex differences were found at either age level, analysis of variance was performed for girls and boys combined.

The analysis revealed a significant main effect for age, the older children performing more accurately than the younger ones, $F(2, 132) = 9.346$, $p < 0.000$, and a significant main effect for orientation test, $F(1, 132) = 71.154$, $p < 0.000$, the children in test 1 outperforming the children in test 2. Previous research has already shown that orientation test 2, which demands the use of a relational place strategy, is more difficult than orientation test 1 (Lehnung *et al.*, 1998). The interaction of age × locomotion condition was also significant, $F(2, 132) = 4.145$, $p < 0.02$, showing that locomotion is not of the same importance at all ages. Since the interaction of age × orientation test × locomotion condition was marginally significant, $F(2, 132) = 2.744$, $p = 0.06$, we considered it worthwhile looking at this interaction as well, because this indicates that, under different orientation test conditions, age and the way a layout is explored may both have a differential influence on performance.

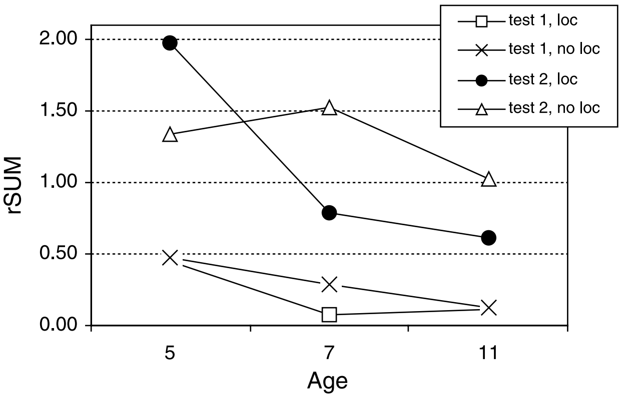


Fig. 4. Relative sum of errors (rSUM) for the three age groups in both spatial tests and for both experimental conditions.

Separate two-way ANOVAs for each orientation test revealed a significant interaction of age × locomotion condition only for test 2, $F(2, 66) = 4.58$, $p < 0.01$, indicating that the type of exploration made a difference when a relational place orientation was demanded in the orientation test, yet not to the same degree at all ages.

Five-year-olds made many errors in both locomotion conditions in test 2. Paired comparisons did not show significant differences. This finding is in accordance with previous results showing that five-year-olds are not yet able to master this testing condition (Lehnung *et al.*, 1998; Lehnung, 2001). Seven- and 11-year-olds who had explored and learned the maze by actively walking outperformed those children who had explored and learned the maze without locomotion. Paired comparisons in seven-year-olds reached statistical significance, $t(17) = -2.137$, $p < 0.05$, while in 11-year-olds the difference just failed to reach statistical significance. This indicates that active exploration of an environment is helpful when the individual is later confronted with a task demanding the use of a relational place strategy. This will be discussed below.

DISCUSSION

The main findings of the two experiments show that learning a spatial layout is possible with and without locomotion in children. In the non-locomotion condition, children sitting by the side of the experimental chamber surveying the maze needed fewer trials to learn the spatial layout than the children who explored the environment in the locomotion condition. The number of errors they made did not differ, indicating that the task was of equal difficulty in the two experimental conditions. Yet, in Experiment 2, when spatial knowledge was assessed by a test demanding the use of a relational place orientation, seven-year-old children who had explored the maze in the locomotion condition in Experiment 1 outperformed the children who had explored it in the non-locomotion condition, thus proving that their spatial representation of the maze was more stable and flexible. In 11-year-olds, this difference did not reach statistical significance. Five-year-olds were not able to master the task after either condition.

In extension to other studies of the spatial mapping abilities of children, we used a highly reliable assessment instrument, the Kiel locomotor maze. Data were recorded and computed automatically. Visual cues were completely controlled. Task difficulty was equalized across age groups. This yields the advantage that treatment effects are not confounded with age effects. The ecological validity of the experiment seems to be high: the task resembles activities that children often have to do in everyday life, like searching for a lost toy, playing "hide and seek", or simply exploring new environments (Lehnung, 2000). In our two experiments we did not only measure spatial learning and memory for spatial locations, but we also applied tests of allocentric orientation and thus were able to investigate spatial mapping abilities. Therefore, the obtained results are able to extend previous findings.

It is interesting to note that children in the non-locomotion condition needed fewer trials to learn the maze than children in the locomotion condition. This finding has not previously been reported. It indicates that it is easier to acquire knowledge of a spatial layout by surveying an environment than by walking through it. Yet this knowledge seems to be orientation specific. This became obvious during the orientation tests. These results are reminiscent of findings demonstrating that spatial knowledge acquired from maps is orientation specific while that acquired from direct experience is not (Rossano *et al.*, 1998).

Five-year-olds were able to learn the layout and to solve the "test 1" condition, yet they were not able to master the "test 2" condition, neither when walking through the maze during acquisition nor when surveying the maze during acquisition. While test 1 can be solved by orienting towards the two proximal cues and thus demands a "landmark strategy", test 2 demands the use of a relational place strategy: children have to orient themselves with respect to the configuration of the distal cues. Previous research has shown that tasks demanding relational place strategies cannot be solved by children under the age of seven years (Lehnung, 2000; Lehnung *et al.*, 1998; Overman *et al.*, 1996).

Performance in the relational place orientation task among seven-year-olds turned out to be dependent on the way children had acquired the layout: children in the locomotion condition outperformed the children in the non-locomotion condition. It has been shown before that children around the age of seven are at an age of transition, at which relational place orientation is just being developed (Lehnung, 2000; Lehnung *et al.*, 1998; Overman *et al.*, 1996). Our results demonstrate that active locomotion facilitates relational place orientation at this age, presumably by helping children to build up a flexible cognitive spatial map.

No significant differences were seen in 11-year-olds concerning the way children learned the layout: they performed almost equally well whether they had learned the layout walking through the maze or sitting by the side of it. This result may indicate that spatial maps are more easily established in older children; thus they are less dependent on the way by which acquisition of a layout is achieved than are younger children. It has been shown before that spatial competence and the ability to apply relational place strategies are well established by about ten years of age (Lehnung *et al.*, 1998). Yet, when looking at the data, it is still apparent that active exploration during the acquisition makes it easier even for older children to establish a stable cognitive map than acquiring the layout while sitting by the side of the maze (see Fig. 4).

Our results confirm and extend the findings by Herman (1980), by Rieser *et al.* (1994) and by Yan *et al.* (1998). Herman found that children located objects more accurately if they had walked through an area rather than around it, pointing out the importance of active locomotion. Rieser *et al.* showed that children performed better in a spatial memory task in a locomotion condition than in an imagination condition. In a meta-analysis, Yan *et al.* pointed out that locomotion improves children's spatial search. The computational model developed by Hiraki *et al.* (1998) also needed the ability of self-locomotion if the robot was to respond allocentrically.

On the other hand, Foreman *et al.* pointed out that it did not matter whether their children were seated in a push-chair or walking, as long as they were allowed choice autonomy (Foreman *et al.*, 1990, 1994). Thus they claimed that individuals who are transported in a push-chair could acquire as much spatial knowledge as a locomoting individual. Our findings seem to contradict the results of Foreman *et al.*, since we found significant differences between the locomotion and the non-locomotion groups, especially when allocentric relational place orientation was assessed. Yet this might be due to an important procedural difference between the two studies. While our children in the non-locomotion condition sat by the side of the chamber surveying the maze, the children in Foreman *et al.*'s experiments sat in a push-chair, being pushed around. Thus these children were able to gain different views of the maze during exploration, while our children in the non-locomotion condition had only one view of the maze. Gaining different views of a spatial layout might be a critical issue when establishing a spatial map. Poucet (1993), in his model of spatial representations, points out that spatial maps consist of "local views" which are integrated into local charts, that is, location-dependent representations. Ultimately, vector information contained in each location-dependent representation is combined into a more global representation. In other words, spatial maps are based on local views of the environment from specific locations. Different local views are integrated into a spatial map. In the light of this model, it is possible to explain the above mentioned contradictions. In order to establish a stable and flexible cognitive map, children have to gain different views of an environment. This will normally happen by walking around, but apparently this can be also achieved when a child is pushed in a push-chair, supposing he or she is paying attention, as was apparently the case in Foreman *et al.*'s choice-autonomy condition. Only surveying a spatial layout, gaining only one view and perspective, does not produce flexible spatial maps in children. Still, it seems to take longer to build up a spatial representation by locomoting through an environment than by surveying the same, as is shown by our results: children in the locomotion condition needed more trials to reach the learning criterion than children in the non-locomotion condition. This finding is in accordance with previous results, indicating that it takes people longer to construct a survey representation from exposure to the environment than, for example, from a map (Garling & Golledge, 1989; Siegel & White, 1975).

Our findings may have some important implications. In order to develop spatial competence, children should be allowed to walk around new environments. A lack of locomotion may lead to weak spatial maps and a diminished spatial competence.

Physically disabled children are known to be impaired in spatial tasks when compared to their peers (Foreman *et al.*, 1989). This may well be because of the lack of locomotion that normally is necessary to establish spatial maps. These children should be given as much opportunity as possible to be taken through environments while paying attention, because it may not be so much the lack of locomotion but the lack of different "local views" that is responsible for their spatial impairments. In cases where it is not possible to take these children into the environment, it may be possible to simulate the environment in virtual reality. Preliminary results, obtained in a virtual version of the Kiel locomotor maze, hint at the possibility of a good transfer in healthy children (Foreman *et al.*, 2000). Future research will have to determine whether this proves to be true for physically disabled children also.

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NOTE

[1] Unpublished developmental norms were obtained from Dr Carlsson, Clinic of Pediatrics, University of Kiel, Germany.

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