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SPATIAL COGNITION AND MOTOR DEVELOPMENT: A STUDY OF CHILDREN WITH SPINA BIFIDA[1]

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Summary.—The purpose of this study was to examine the relation between motor development and spatial cognition. The sample was 20 children with Spina bifida (*M* age: 11.4 yr., *SD* = 1.7) and 20 healthy children as controls (*M* age: 11.8, *SD* = 1.8 yr.). An experimental assessment of motor development in spatial cognition in a simulated virtual maze by school-age children is lacking. In this study children with Spina bifida, who were impaired in walking since birth, completed four visuospatial tasks in a small-scale space (Mental Rotation, Water-Level Task, Embedded Figures Test, Visual Short-term Memory Test), and a spatial behaviour and knowledge task in a virtual maze. These children showed poorer performance than children in the control group on most measures. The results are discussed with respect to theoretical implications and further research.

This study focused on the issue of how much visual motor behaviour and active motor exploration is necessary for spatial cognition. Whereas the cognitive factors in spatial behaviour and knowledge for people with visual impairment or blindness are well investigated (e.g., Marston & Golledge, 2003) and possible assisting technologies are available (Loomis, Marston, Golledge, & Klatzky, 2005), investigations of people who were paralyzed since birth are still rare. One of these very few studies is the one of Stanton, Wilson, and Foreman (2002), who showed an impaired shortcut performance by disabled teenagers in a simulated maze.

Most people believe that motor development is a relevant factor for cognitive development, especially for spatial as well as for mathematical performance. Pahl (2002) provided an overview of the relevant published studies. These ranged from grade comparisons of sport and mathematics by high-school students, to associations between sports and cognitive performance with 700 pupils from Grades 1 to 4 (Krombholz, 1988), to a study of 30,000 participants regarding the relation of aerobic movement training and information-processing capacity (Ertelt, 2005).

In addition to these correlational approaches, evidence from recent studies demonstrates that motor training enlarged cortical areas. Plasticity has been demonstrated to occur after a period of extensive training that has

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repetitively activated certain receptive fields in the neocortex. In the case of such repetitive activity, the size of the activated area has been enlarged. There are quite similar results regarding the plasticity after training of juggling (Draganski, Gaser, Busch, Schuierer, Bogdahn, & May, 2004), sports (Kramer, Bherer, Colcombe, Dong, & Greenough, 2004), movement (Elbert & Rockstroh, 2004), and dance (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005). Calvo-Merino, *et al.* (2005) used fMRI to study differences in brain activity in watching an action one has learned to do and an action one has not learned. Experts in classical ballet, experts in capoeira, and non-expert control subjects viewed videos of ballet or capoeira actions. Comparing the brain activity while dancers watched their own dance style versus the other style suggested an influence of motor expertise on observation of action. Draganski, *et al.* (2004) showed that adults who were trained in juggling for 3 mo. showed an increase in the size of their cerebral cortex (mid-temporal area hMT/V5) and the left intraparietal sulcus) when examined with magnetic resonance imaging. After a break of 3 mo. from juggling, researchers observed shrinking of these areas. The largest differences were seen in the mid-temporal area, which is associated with the processing and storage of complex visual motion. The intraparietal sulcus is an area which is highly activated during a classical visuospatial ability task, the Mental Rotation Task (Jordan, Wüstenberg, Heinze, Peters, & Jäncke, 2002), and in a navigational task in a virtual environment (Jordan, Schadow, Wüstenberg, Heinze, & Jäncke, 2004). The development in these brain areas provides evidence that motor and spatial cognition processes are interconnected in some way. It might be assumed that patients with a motor deficit should be impaired also in spatial cognition processes, suggesting that the different aspects of spatial cognition must be investigated separately and in detail. These different aspects of spatial cognition comprise at least visuospatial ability in a small-scale space, i.e., mental rotation, visualization, and orientation, as well as spatial behavior and spatial knowledge acquisition in a virtual or video environmental space. These aspects were investigated in the present study, testing in children with Spina bifida.

Children with Spina bifida suffer from a malformation of the central nervous system based on a defect of the neural tube closure in early embryogenesis. Depending on the level of the spinal lesion, patients with Spina bifida are more or less severely physically handicapped. Additionally, even though children with Spina bifida show a full range of intellectual abilities, the distribution is shifted towards the lower end of the spectrum by about a standard deviation (Tew, 1977; Shaffer, Friedrich, Shurtleff, & Wolf, 1985; Wills, Holmbeck, Dillon, & McLone, 1990; Casari & Fantino, 1998; Jacobs, Northam, & Anderson, 2001). In most of these studies, this reduction was found to be related to lower performance IQ, which encompasses skills of logi-

cal and spatial thinking, processing speed, and visual perception and seems to implicate impairments of visuospatial thinking (Shaffer, *et al.*, 1985). However, the difference between Verbal IQ and Performance IQ seems to depend on the composition of the sample group, e.g., with regard to ethnicity, level of lesion, and so forth (see Fletcher, Copeland, Frederick, Blaser, Kramer, & Northrup, 2005). The spatial deficits were investigated in more detail, for example, by Sand, Taylor, Rawlings, and Chitnis (1973), who found children with Spina bifida to be impaired in figure-ground perception. Additionally, Dennis, Fletcher, Rogers, Hetherington, and Francis (2002) demonstrated that the impairments of children with Spina bifida were much larger on action-based than on object-based tasks. While the children with Spina bifida performed as well as the control group on facial recognition tasks, they were particularly impaired on tasks requiring dorsal stream visuospatial processing. These studies, however, concentrated mostly on the *visual* aspect of the visuospatial abilities measured by intelligence tests. It was the goal of the present study to investigate all aspects of spatial cognition with these children who had not been able to walk since birth. Their performance on spatial cognition tests, which reflect different aspects of spatial cognition, was expected to be impaired relative to that of a control group.

Method

Participants

Twenty children with Spina bifida and 20 healthy children as a control group took part. The children with Spina bifida were recruited by means of an advertisement in the *Journal of the German Society of Spina Bifida and Hydrocephalus*. Children of the control group were recruited from schools in and around Düsseldorf. All children in the Spina bifida group had myelomeningocele, and all but one child suffered from a shunted hydrocephalus. No child suffered from uncontrolled epilepsy, primary sensory loss, behavioral disorders, or motor impairments of the upper limbs. The location of the lesion was sacral in five children, lumbal in 11 children, and thoracal in four children. The vision of all subjects was corrected to 20/20. The mean age in which the children with Spina bifida learned to walk—with or without orthopaedic help—was 29.11 mo.

To form two comparable groups, 20 healthy children were matched according to sex, age, and Verbal IQ, as measured by the German version of the WISC–III, with the 20 children with Spina bifida. Consequently, the two groups did not differ in mean Verbal IQ (Spina bifida: $M = 96.55$, $SD = 12.88$; control: $M = 101.45$, $SD = 11.29$; $F_{1,38} = 1.73$, ns, $\eta^2 = .05$), but they differed in mean Performance IQ (Spina bifida: $M = 71.35$, $SD = 12.04$; control: $M = 98.3$, $SD = 12.78$; $F_{1,38} = 47.02$, $p < .001$, $\eta^2 = .58$) as well as in mean Full IQ (Spina bifida: $M = 82.9$, $SD = 10.05$; control: $M = 99.85$, $SD = 10.04$; $F_{1,38} =$

31.33, $p < .001$, $\eta^2 = .49$). Each group was composed of seven boys and 13 girls whose mean age was 11.4 yr. ($SD = 1.7$; range 8–14 years) for the Spina bifida group and 11.8 yr. ($SD = 1.8$; range 8–14 years) for the control group.

Motor development was described on a self-constructed questionnaire completed retrospectively by the parents concerning the exploration of space in infancy and childhood (onset of crawling and walking, if it was possible at all or the month of first movement with what kind of motor assistance, e.g., wheelchair). The age of walking was analyzed further.

Measures

The classical visuospatial abilities are differentiated into spatial perception, mental rotation, and spatial visualisation (Linn & Petersen, 1985). Spatial perception was tested on a water-level task, and mental rotation on a paper-pencil mental rotation task in accord with Lohaus, Schumann-Hengstler, and Kessler (1999). The water-level task, which had been used by Piaget and Inhelder (1967), requires the indication of the water-level in a drawing of an inclined water glass. In the mental rotation task, two block stimuli were presented, and children had to decide if the stimuli were the same or mirror-reversed. Spatial visualisation was measured by the Children's Embedded Figures Test (Witkin, Oltman, Raskin, & Karp, 1971), on which a specific shape had to be identified in a complex figure.

All tests were conducted without a time restriction to avoid a difference between the Spina bifida group and the control group based on their respective working processing time. Fig. 1 shows examples of the relevant tasks for each of the different factors.

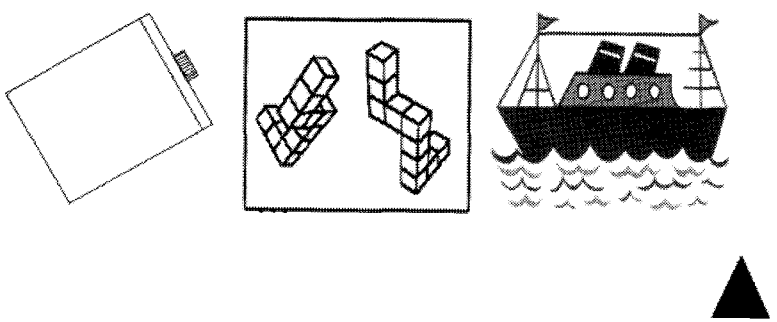

FIG. 1. Sample items of the Water-level Task, Mental Rotation Task, and one Children's Embedded Figures Test

Performance on spatial working memory was registered by the subtest Spatial Memory of the Kaufman-Assessment Battery for Children (Kaufman & Kaufman, 1983). Spatial behaviour and spatial knowledge acquisition in a

recognizable environmental space were tested in a virtual environment, which already has been tested successfully with adults (Jansen-Osmann, 2002) and with healthy children (Jansen-Osmann & Wiedenbauer, 2004). The reason for using this test was to investigate whether children with Spina bifida would need more trials to learn a specific route in an unknown environment and would show more difficulties in acquiring that spatial knowledge. The virtual maze was constructed with six main corridors, three of which branched off from each main corridor. Two of these three corridors were dead ends. The virtual maze contained 18 toy animals. In Fig. 2 is a photograph within the maze.

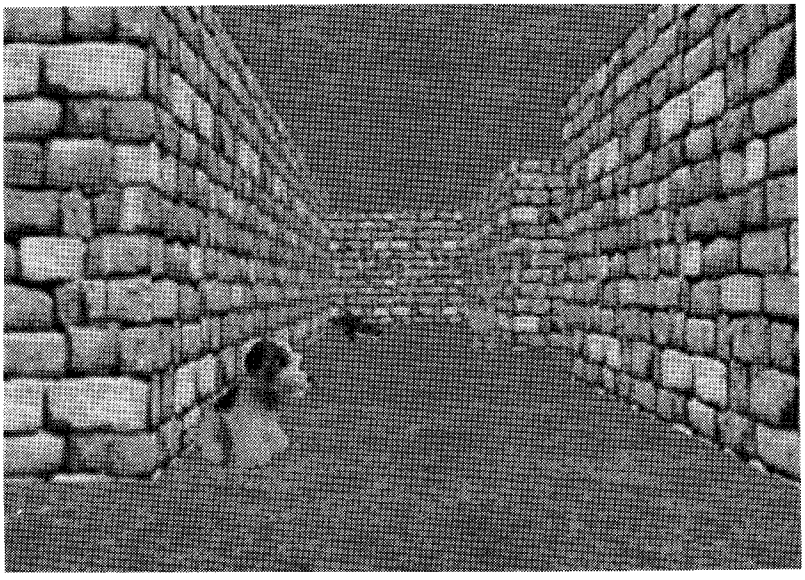

FIG. 2. Photograph of a corridor within the maze

Children were seated in front of a computer monitor and could navigate with the help of a joystick through the maze. The first task was to explore the maze until they reached the end of the maze in four consecutive attempts without any error. The landmarks, 18 toy animals, were present in the learning phase, and the number of learning trials (dependent variable) was recorded. With this test, spatial behaviour was tested. Thereafter, children had to navigate correctly through the maze without landmarks, and errors were recorded (dependent variable: error in the test trial). With this test route, knowledge was tested. After a second learning phase, where the children had to navigate correctly once when the virtual animals were ab-

sent, they had to navigate again through the maze without landmarks, and they had to indicate what the landmarks had been at each location. The recalled identities and locations were registered in an overview of the maze (dependent variable: recalled landmarks), and landmark knowledge was tested. All tasks were chosen because they had been well studied (Jansen-Osmann, 2002; Jansen-Osmann & Wiedenbauer, 2004; Schmelter, Jansen-Osmann, & Heil, in press).

The tests of the visuospatial ability and of the spatial behaviour and knowledge in a large-scale virtual space were administered during different sessions.[2]

Results

There was no main effect for sex of children in the analyses described below.

For each of the three tests of visuospatial ability there was a significant difference between the Spina bifida group and the control group, and also for the water-level task, ($F_{1,38} = 15.26$, $p < .001$, $\eta^2 = .30$), in the mental rotation task ($F_{1,38} = 7.12$, $p < .05$, $\eta^2 = .16$), and in the Children's Embedded Figures Test ($F_{1,38} = 56.52$, $p < .001$, $\eta^2 = .60$). Children with Spina bifida received fewer points than the children in the control group. They also showed poorer performance on the spatial working memory task ($F_{1,38} = 6.77$, $p < .05$, $\eta^2 = .15$). Means for number of correct hits are displayed in Table 1. When Performance IQ was used as a covariate, there was no significant difference between the two groups on the water-level task ($F_{1,38} = 1.54$, ns), mental rotation task ($F_{1,38} = 0.38$, ns), and the spatial working memory test ($F_{1,38} = 0.81$, ns). Only the difference in the Children's Embedded Figures Test was significant ($F_{1,38} = 13.19$, $p = .001$, $\eta^2 = .27$).

TABLE 1
Means and Standard Errors of Points Correct on Four Visuospatial Tasks by Healthy Control Children and Those With Spina Bifida

Group	Water-level Task		Mental Rotation		Children's Embedded Figures Test		Spatial Working Memory	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Spina bifida	1.24	1.97	4.60	1.39	12.40	4.95	14.40	3.50
Control	4.23	2.80	5.75	1.33	21.65	2.41	16.90	2.49

As it can be seen in Table 2, the Spina bifida group needed more learning trials than the control group ($F_{1,38} = 26.04$, $p < .001$, $\eta^2 = .41$) and made more errors on the maze without landmark information ($F_{1,38} = 12.04$, $p < .001$, $\eta^2 = .24$). The analysis of the number of recalled landmarks at their cor-

[2]Both studies have been described in greater detail by Wiedenbauer and Jansen-Osmann (2006a, 2006b).

rect locations (landmark knowledge) yielded a significant effect of group ($F_{1,38} = 10.96$, $\eta^2 = .22$). The children with Spina bifida recalled fewer landmarks. When the Performance IQ was used as the covariate, there was a significant difference between the children with Spina bifida and the children in the control group on number of learning trials ($F_{1,38} = 4.99$, $p < .05$, $\eta^2 = .12$) and the errors made in the maze without landmark information ($F_{1,38} = 4.6$, $p < .05$, $\eta^2 = .11$), but no significant difference between groups for landmark knowledge ($F_{1,38} = 1.2$, ns, $\eta^2 = .03$).

TABLE 2
MEANS AND STANDARD ERRORS ON THREE SPATIAL KNOWLEDGE TASKS BY HEALTHY CONTROL CHILDREN AND THOSE WITH SPINA BIFIDA

Group	No. of Learning Trials		No. of Errors in Test Trial		No. of Recalled Landmarks	
	M	*SE*	*M*	*SE*	*M*	*SE*
Spina bifida	6.2	2.7	2.5	2.3	5.3	2.8
Control	3.0	0.9	0.6	0.8	7.7	2.3

A correlation analysis was done between scores on the spatial-cognitive tasks with the age of walking by the children with Spina bifida and the control group, again controlling for the Performance IQ. There was a significant correlation between the age of walking and scores on the Children's Embedded Figures Test measured by number of points ($r = -.51$, $p = .05$) and .99 ($p < .05$, $\eta^2 = .12$), visuospatial memory measured by number of points ($r = -.69$, $p < .01$) and performance on the maze, measured by number of learning trials ($r = .65$, $p < .01$). Children with Spina bifida who learned to walk later in life had fewer points on the Children's Embedded Figures Test and on the visuospatial memory test and needed more trials to learn the correct way through the virtual maze.

DISCUSSION

These results confirmed the children with Spina bifida had difficulties in spatial cognition on all the different measured aspects in a small-scale space and on the virtual environmental space. At this point one cannot exclude that this impairment was due to the damage in the relevant brain areas for spatial cognition processing, the hippocampus (O'Keefe & Nadel, 1979) or the parietal lobe (i.e., O'Keefe, Burgess, Donnett, Jeffery, & Maguire, 1999). Dennis, Jewell, Edelstein, Brandt, Hetherington, Blaser, and Fletcher (2006) described some CNS anomalies in Spina bifida children, e.g., hypoplasia of the corpus callosum, thinning of the posterior cortex, etc. This is a relevant point which must be investigated further.

The investigation of spatial behavior and knowledge was done in a virtual environment, as a real environment was not appropriate, given the im-

mobility of the children. There is some controversy about a virtual setting in the literature. There is evidence from studies with adults that at least the most important properties of spatial representations which underlie spatial behavior can indeed by analyzed in both real and virtual environments (Loomis, Blascovich, & Beall, 1999), and that testing in virtual and real environments leads to similar results (Péruch & Wilson, 2004; Tlauka, 2007), but there is also evidence questioning the ecological validity of desktop virtual environments (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006). With the exception of three studies (Laurance, Learmonth, Nadel, & Jacobs, 2003; Plumert, Kearney, & Cremer, 2004; Schmelter, *et al.*, 2007), this comparison, however, still does not include studies with children. Interestingly, Laurance, *et al.* (2003) showed that children used the virtual space as if it were real. Comparing the different processing stages in virtual and real space with a sample of 120 participants (40 children at the age of 7 or 8 years, 40 children at the age of 11 or 12 years, and 40 adults) evidence was obtained that spatial behavior and knowledge acquisition was indeed comparable in both virtual and real environments (Schmelter, *et al.*, in press). At least, virtual environments seem to be a convenient way to test the spatial behavior of disabled children and adults (Stanton, *et al.*, 2002) and seemed to be a useful spatial training medium (Foreman, Stanton, Wilson, & Duffy, 2003). When using virtual environments, experience in using computer games must be controlled. Prior to the testing, the children were asked if they had played computer games previously. All children—the able-bodied as well as the Spina bifida children—were used to playing computer games. To summarize, the results of the present study show that virtual environments are appropriate for investigating spatial knowledge of physically disabled children. It was demonstrated that the acquisition of route knowledge in a large-scale environment was impaired in these children with Spina bifida. The next step would be to investigate the origin of such impairments in more detail.

Since the cognitive differences were controlled between children with Spina bifida and healthy children, the reduced performance of the Spina bifida group in the virtual maze might be attributable to their missing mobility. This seemed unlikely for the visuospatial tasks in a small-scale space. When Performance IQ was a covariate, the difference in the performance between groups disappeared, showing the high relation of these tasks with nonverbal intelligence. But this was not the case for the virtual maze tasks. This discrepancy is in line with a study of Stanton, *et al.* (2002), who showed that early mobility and self-governed exploration of the environment seem to be important in the development of spatial knowledge. Furthermore, the detrimental effects of restricted early spatial experiences might continue to affect spatial knowledge during patients' adolescence (Simms, 1987). Additionally, the results are also in line with recent studies showing

that learning of movement changed cortical plasticity (i.e., Draganski, *et al.*, 2004), demonstrating that mobility has a lasting effect. But to clarify the relation between impairment in mobility, neurological disorder, and spatial behavior, further research is required. Studies should be conducted with other patients, whose mobility is impaired but who do not differ in their general intelligence. The age of learning to walk and the age at which impairment of mobility began must be controlled. Further, the importance of the impairment in mobility has to be examined in more detail. One does not know whether the children with Spina bifida were more retarded with respect to spatial cognition given lack of experience in locomotion, or because they were not able to choose their own ways actively. Just the beginning of research on these issues has been undertaken. In addition, the neurological structure and functioning must be better understood.

To summarize, this study showed motor development is essential for visuospatial abilities and for spatial behaviour in a space, which is not perceived from one vantage point, i.e., an environmental space because this task is a virtual maze. This distinction might not be so important for later stages in the process of spatial cognition acquisition, but is crucial for every theoretical model of spatial cognition.

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