Original Article

Spatial Tests, Familiarity with the Surroundings, and Spatial Activity Experience

How Do They Contribute to Children's Spatial Orientation in Macro Environments?

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Abstract. Spatial orientation as the ability to know the bearing to the origin of a walked path was investigated in two studies with ca. 140 preschool and primary school children who walked paths of about 1 km beginning at the familiar kindergarten or in a completely unknown territory. Path difficulty and familiarity with the surroundings influenced correctness of pointing. Spatial ability measured by test performance and spatial activity experience, i.e., children's reports about unsupervised walks, effected pointing accuracy as well. The data emphasize that spatial activity experience may be an important factor for spatial orientation beyond kindergarten age.

Keywords: spatial orientation, preschool children, spatial ability, spatial activity experience

Introduction

The term *spatial orientation* comprises several potential meanings. It can be defined as the complex of all the skills persons use for locating themselves with respect to a point of reference or an absolute system of coordinates (Coluccia & Louse, 2004). A macro (spatial) environment is so large that people can actually walk in it and there is no single vantage point along the route from which the entire area can be seen (Weatherford, 1985). For update-processes of spatial position when moving through macro spatial environments, at least two different mechanisms are known (e.g., Etienne, 1992): *Piloting* is the concept of navigating along specific landmarks in a familiar environment; *dead reckoning* is a strategy whereby actual information is continuously integrated to stay informed about the position relative to home. Piloting is mainly based on external acoustic or visual signals; dead reckoning uses internal and external information about velocity and direction.

Etienne (1992) postulates that both mechanisms work complimentarily for spatial orientation in macro spatial environments. Similarly, Newcombe and Huttenlocker (2000) describe an integrated spatial system of dead reckoning and place learning, i.e., information about distance and direction to a distal landmark. According to Rieser and Pick (2007), most daily tasks involve the coordination of self-to-object distances and direction. Distance estimation is known to depend on visual and acoustical ("optical and auditory flow cues," see Rieser & Pick, 2007) and body sense information (e.g., Kearns, Warren, Duchon, & Tarr, 2002; Popp, Platzer, Eichner, & Schade, 2004). Such information is continuously updated in conjunction with locomotion, resulting in actual spatial position information (Rieser & Pick, 2007).

The ability to know and hence point to the origin of a walked path, even if the target cannot be seen, is only one component emerging from this spatial information updating process called *path integration*. Dead reckoning is an important component of path integration. The drifting errors in dead reckoning, though small with short paths, may add up when the path gets longer. Additional external information makes the spatial information system more reliable (Newcombe & Huttenlocher, 2000). Additional information may be based on personal spatial knowledge such as the subjective cognitive map or on the individual's external frames of reference (Rieser & Pick, 2007). Even in preschool children can at least these two spatial system processes, i.e., path integration and cognitive map use, be demonstrated experimentally (Neidhardt, 2002).

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cations and pointing in the direction of the path origin is a task that measures the performance in this spatial updating process. Under specific circumstances even toddlers are successful in this kind of task (Rider & Rieser, 1988). Spatial orientation tasks in macro environments successfully managed by kindergarten children represent way-finding between home and nursery school (Spencer & Darvizeh, 1983), finding one's way back with the help of landmarks (Leplow et al., 2003), or planning the way with simple maps (Huttenlocher, Newcombe, & Vasilyeva, 1999). As correct map use is very difficult for preschoolers in natural settings (Plester, Richards, Blades, & Spencer, 2002), and because way-finding in familiar surroundings is very easy (Neidhardt, 2002), pointing to the origin of the walked path was chosen as an appropriate method of studying spatial orientation in preschool children.

Our studies aim to answer the question of which important sources of variance contribute to this kind of spatial orientation performance in preschool children. Sex, spatial ability (SA), familiarity with the surroundings (FS), and spatial activity experience (SAE) are all assumed to be potential candidates:

- Sex differences in preschool children's pointing performance were demonstrated in some studies (Lehnung, Leplow, Haaland, Mehdorn, & Ferstl, 2003) but not in others (Neidhardt, 2004); spatial ability (Fenner, Heathcote, & Jerrams-Smith, 2000), familiarity with the surroundings (Anooshian & Nelson, 1987; Lehnung et al, 2003), and spatial activity experience by independent navigation (Neidhardt & Schmitz, 2001) were found to correlate significantly with pointing accuracy in children. Path difficulty (PD) may be another influencing factor (Neidhardt, 2004).
- Spatial ability as measured by classical paper-and-pencil or online tests is one of Thurstone's seven primary factors of intelligence (Thurstone, 1938). It is not a homogeneous construct: There is still some debate concerning its components as well as the exclusion of overlapping abilities with other intelligence features (Carroll, 1993). In the context of our studies this discussion plays no major role. It is more important to understand the difference between spatial ability and spatial orientation (see also Coluccia & Louse, 2004). Test performances in classical tests of visualization or perceptual speed are taken as measurements for spatial ability. Spatial ability is important for map-reading performance, thereby mediating knowledge about environmental layout and improving way-finding in adults (Kiriasic, 2001**[in refs Kirasic, 2000]**)
- FS describes whether the surroundings of the kindergarten and the path is well known – children are assumed to show better spatial orientation if they live nearby because they use their personal cognitive maps, which should be richer and more realistic in familiar surroundings (Lehnung et al., 2003). FS has a variety of potential measures, though: Lehnung et al. (2003) defined it as the amount of years children attended the specific kindergarten where the path originated. In the study by Anooshian and Nelson (1987), distance to children's home served as criterion.
- SAE is conceived to be a personal characteristic rather than an experimental feature, i.e., it does not vary with the special path selected. As such it is believed to yield more stability than FS. From earlier studies we know that it is not important how often children play outside or whether they like to take walks; the decisive component of SAE is the child's responsibility to reach his spatial targets on his own without the company and the leadership of someone else (Davies & Uttal, 2007; Neidhardt, 2004).

The main goal of the studies presented here is to disentangle the relative importance of the factors sex, spatial ability, FS and SAE, and PD with respect to spatial orientation in preschool children.

Study 1

Method

Subjects

The data of 52 boys (mean age 5; 6 years, *SD* = 9 months) and of 42 girls (mean age 5;2 years, *SD* = 10 months) from four kindergartens in Marburg were included in this analysis. Age did not differ significantly between boys and girls (t(92) = 1.7, *ns*).

Procedure

The children's parents were informed about the experimental design. Only those children could join the study whose parents had given written consent. The children were tested individually. First they answered 12 interview questions asking for name, age, activities outside kindergarten and their way of finding self-concept. This "conversation" was part of the warming-up procedure between child and experimenter. The answers to two of the questions were later coded as indicators of the aforementioned categories: "Are there places where you go alone, without your parents and without other children, for example, to see your friends?" is taken as an indicator for SAE. "Do you normally walk to the kindergarten?" indicates FS. The interviewer explained that answering affirmatively indicated that they were brought by car or bicycle only when it rained or when their parents were in a great hurry. These special questions were taken as indicators for SAE resp. FS because in earlier studies they had been found to be the best predictors of children's spatial orientation performance scores (Neidhardt, 2004). After the interview the child was asked to accompany the experimenter on a path leading from the kindergarten to an endpoint about half a mile away. The paths lay either in an area of small houses with little gardens or in parts of the city marked by narrow streets lined with 19th-century 3-story buildings. All paths originated at the kindergarten. In front of the kindergarten the child was asked to point to the kindergarten entrance door and was told that this was the target for later pointing tasks. Children were trained to point with their outstretched arm and index finger in the same direction. Each child was led by one experimenter and did not know the layout of the path. At six different locations both stopped, and the child was asked to point to the then unseen kindergarten door (target). To help them to understand their task, the children were told to imagine they were birds that could fly directly to the kindergarten door, without any deviations. The target or any direct hint to the target could not be seen from any of the pointing locations. Pointing was done directly as finger pointing without any additional instrument and was measured by the experimenter standing behind the child with a compass adjusted to the child's arm. From earlier experiments (Lehnung, Haaland, Pohl, & Leplow, 2001) it was known that this kind of measurement provides more reliable data than pointer measurement for preschool children. The absolute differences between compass values (in degrees) of the child's pointing and the correct values that were taken from exact maps were calculated for each of the pointing locations. Dependent variable ("angular deviation") was the mean of these absolute differences. Measuring inaccuracy (compass reading, pointing reliability) had been estimated beforehand by testing six experimenters taking compass readings at the same time and 12 children pointing twice to the same target. This inaccuracy adds up to about 20°.

In earlier studies, pointing locations close to gardens or with distance to houses or walls had produced better pointing results than those very close to walls or in the proximity of high houses (Neidhardt, 2004). The path difficulty variable takes into account that some paths yield more pointing locations close to walls or high houses (difficult paths), while other contain more pointing locations near gardens or distal to houses (easy paths).

Figure 1 gives a schematic map of an exemplary path.

Spatial ability tests were administered to small groups of children on different days. The tests were varied between kindergartens to have an additional validation for the correlation between spatial ability test and pointing performance: Thurstone's original test for visualization was taken for two groups, and a self-made two-dimensional mental rotation test was used for the other groups. In the self-made test a figure was given at the top of the page ("original figure"). Four variations of the figure were then presented below: rotated, rotated and mirrored, rotated and one part mirrored, rotated and one part different. The child was asked to find exactly the rotated-only figure. Three commented training examples preceded 12 test problems. The original figures were either a snowman or a cat or an apple.

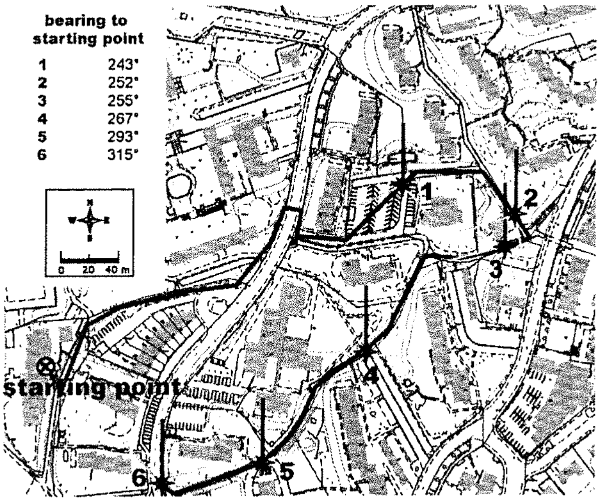

Figure 1. Exemplary path. The path origin is the pointing target for each of the 6 locations along the path where children stop and point. Distance indications, map orientation, and correct bearings (in angular degrees from North) are shown in the upper left corner of the map.

Test reliability calculation was based on a different sample of 90 kindergarten children: Cronbach's $\alpha = .73$.

The test variation had no differential effect on angular deviation. Hence test scores were *z*-standardized within kindergarten groups to get comparable values for the regression analysis. FS and SAE were coded as binary ("yes" or "no").

Differences between kindergarteners' pointing performance lie in varying PD (Neidhardt, 2004). Consequently, kindergarten was introduced into the analysis as an independent variable, standing for PD.

Results

Angular difference mean of all 94 tested children was 49.3° (*SD* 27.9°). An ANOVA check for sex differences revealed no significant effect, $F(1, 93) = 1{,}06$, $\eta^2 = .011$, *ns*; hence, sex was not included in the following analysis.

Children without SAE, i.e., those who told the interviewer that they never went anywhere unaccompanied, had a mean angular deviation of $M = 62.7°$ ($SD = 27.1°$), while children who reached at least one spatial target on their own had a mean deviation of $M = 40.7°$ ($SD = 25.1°$). Angular deviation was $M = 38.3°$ ($SD = 23.4°$) for children familiar with the surroundings and $M = 57.1°$($SD = 28.4°$) for children less familiar with the surroundings. Mean angular deviation for easy paths was $M = 45.7°$ ($SD = 25.3°$) and $M = 59.0°$ ($SD = 31.6°$) for difficult paths. In a 2 (SAE) × 2 (FS) × 4 (PD) ANOVA with Angular deviation as dependent variable, there were significant main effects for all three factors, $F_{\mathrm{SAE}}(1, 93) = 9.3$, $\eta^2 = .11$, $p < .005$, $F_{\mathrm{FS}}(1, 93) = 22.3$, $\eta^2 = .22$, $p < .001$, $F_{\mathrm{PD}}(3,93) = 2.7$, $\eta^2 = .10$, $p < .05$.

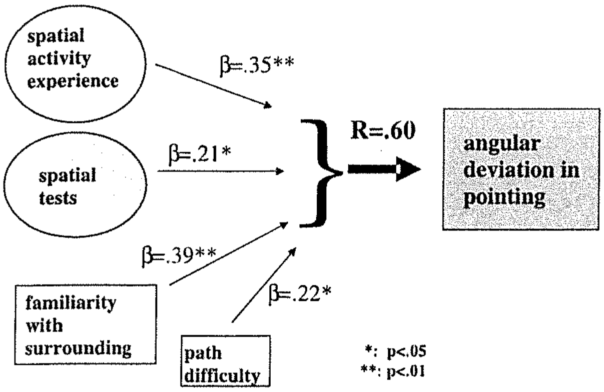

Figure 2. Regression analysis (df = 4,89) with angular deviation (in degrees) as dependent variable and SAE (walking alone), spatial ability (test scores), FS (walking to kindergarten), and PD (kindergarten) as regression model factors.

There was no significant interaction effect. Correlation between spatial ability test scores and angular deviation was $r = .33$ ($p < .01$). All four factors yielded small or medium effects in a standard stepwise linear regression analysis (Figure 2).

Figure 2 shows the results of a linear regression analysis with angular deviation as the dependent variable, and SAE, FS, PD, and spatial ability test results as included predictors, $F(4, 89) = 12.8$, $p < .001$, $R^2_{\text{corr}} = .34$. There are two factor groups with similar effect sizes ($\beta_{FS} = .39$ and $\beta_{PD} = .22$ vs. $\beta_{SAE} = .35$ and $\beta_{\text{spatial tests}} = .21$, $p < .05$). The two factors marked with rectangles (PD and FS) are probably varying within persons, i.e., depending on the specific surroundings where the person is navigating. The other two factors (SAE and spatial ability) are conceived as being more stable across situations, describing individual differences in spatial orientation in preschoolers. When calculated separately (by taking PD and FS off the equation by taking standardized scores) the effect of SAE and spatial ability combines to $R = .46$ $F(2, 91) = 12.4$, $p < .001$, $R^2_{\text{corr}} = .20$.

Two questions still remained: Because familiarity with the surroundings was found to be an important factor that varied only between very familiar and less familiar when the paths started in the normal kindergarten environment, the same study was conducted in a completely unfamiliar terrain within the campus of the university of the Bundeswehr in Neubiberg near Munich. This territory is closed to the public, hence children could not have seen any part of the path before. The other question to be answered concerned the stability of the SAE variable. For Marburg children SAE as measured in Study 1 is not a differential variable any longer once they attend primary school: Children who do not walk to school on their own are very rarely found. However, in huge cities such as Munich, first and second graders are not expected to get to school on their own. Thus, in Munich it is possible to estimate SAE effects in first- and second-grade children.

Study 2

Method

Subjects

39 second-grade children from a Munich center school nearby participated; there were 20 boys (M = 7 years 10 months, SD = 7 months) and 19 girls (M = 7 years 9 months, SD = 7 months).

Procedure

For the time of the experiment children had classes in one of the university classrooms. They were fetched there, interviewed in a separate room, and individually tested for pointing accuracy. The procedure was the same as described in Study 1, the difference being that the path did not originate at the entrance of the building but at a huge stone to which the child's attention was brought at the beginning of the tour. Children had no opportunity to become acquainted with the university campus terrain outside of the test trial.

Results

T-tests revealed no significant sex-related effects, $t(39) = .28$, *ns*).

In complete unfamiliarity with the surroundings pointing accuracy ($M = 60.9°$, $SD = 23.1°$) was about the same as for children in Study 1, who indicated that they normally do not get to the kindergarten on foot.

Mean deviation was $M = 68.7°$ ($SD = 22.2°$) for children who said that they were not allowed to walk alone to see friends, etc. Children with SAE had a mean angular deviation of $M = 55.0°$ ($SD = 22.5°$). Linear regression with angular pointing deviation as dependent variable confirmed the expected two important factors: SAE ($\beta = .30$, $p < .05$) and spatial ability test performance ($\beta = .30$, $p < .05$). These results confirm the influence of SAE and spatial ability on spatial orientation in second-grade children ($F(2, 36) = 4.0$, $p < .05$, $R^2_{\text{corr}} = .13$).

General Discussion

Spatial orientation was measured by asking children to point to the unseen origin of a walked path. No sex-related effects were evident in any of the studies presented here. In Study 1, pointing accuracy was higher when children were more familiar with the surroundings, and some paths yielded better pointing results than others.

Spatial ability (as one aspect of intelligence) and spatial activity experience proved to have similar effect sizes on pointing accuracy as familiarity with the surroundings and path difficulty. Being a component of intelligence, spatial ability is probably a stable factor; on the other hand, the correlations between spatial ability and spatial orientation seem to weaken as children grow older (Coluccia & Louse, 2004; Fenner et al., 2000). SAE is even more difficult to evaluate as a potentially strong influencing factor. Despite rather strong correlational data from about 100 kindergarten children, there remain a lot of questions to be answered. As our studies show, SAE is not the same as familiarity with the surroundings. Why do experiences of independent travel in familiar territory help children's spatial orientation in unfamiliar surrounding? This may be an example of the Rieser and Pick (2007, p. 89) statement that "learning in the context of one type of information for changes in spatial orientation should transfer to situations where other types are available." Perhaps SAE triggers specific cognitive processing for spatial orientation as postulated by Gärling, Selart, and Böök (1997). In any case, the results encourage a postulate for preschoolers' independent travel experiences.

The term spatial orientation yields several potential meanings. It can be defined as the complex of all the skills people use for locating themselves with respect to a point of reference or an absolute system of coordinates (Coluccia & Louse, 2004). A macro (spatial) environment is defined by two criteria: People can actually walk in it and there is no single vantage point along the route from which the whole area can be seen (Weatherford, 1985). For update-processes of spatial position when moving through macro spatial environments, at least two different mechanisms are known (e.g., Etienne, 1992): Piloting is the concept of navigation along specific landmarks in a familiar environment; dead reckoning is a strategy where actual information is continuously integrated to stay informed about the position relative to home. Piloting is based mainly on external acoustic or visual signals, whereas dead reckoning uses internal and external information about velocity and direction. Etienne (1992) postulates that both mechanisms work complimentarily for spatial orientation in macro spatial environments. Similarly, Newcombe and Huttenlocker (2000) describe an integrated spatial system of dead reckoning and place learning, i.e., information about distance and direction to a distal landmark. According to Rieser and Pick (2007) most daily tasks involve coordination of self-to-object distances and direction. Distance estimation is known to depend on visual and acoustical ("optical and auditory flow cues," see Rieser & Pick, 2007) and body sense information (e.g., Kearns et al., 2002; Popp et al., 2004). Such information is continuously updated in conjunction with locomotion, resulting in actual spatial position information (Rieser & Pick, 2007).

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Locomotion along a curved path, stopping at several locations and pointing in the direction of the path origin, is a task that measures the performance in this spatial updating process. Under specific circumstances even toddlers are successful at this kind of task (Rider & Rieser, 1988). Spatial orientation tasks in macro environments successfully managed by kindergarten children are way-finding between home and nursery school (Spencer & Darvizeh, 1983), finding one's way back with the help of landmarks (Leplow et al., 2003), or planning one's way with simple maps (Huttenlocher et al., 1999). Because correct map use is very difficult for preschoolers in natural settings (Plester et al., 2002), and because way-finding in familiar surroundings is very easy (Neidhardt, 2002), pointing to the origin of the walked path was chosen as an appropriate means of studying spatial orientation in preschool children.

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