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Children's use of spatial skills in solving two map-reading tasks in real space

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Map reading is a cognitively demanding spatio-geometric activity for children that involve understanding and updating person-space-map relations during movement in a large environment. Drawing from the psychological literature, children's skills in reasoning about those relations were tested in two tasks of a map-based treasure hunt on the campus (self-location and place finding), and compared them to their performances in a set of spatial tasks in paper and pencil format. 9- to 12-year old children (N=240) placed colored stickers and arrows on the map to describe their location and orientation at three different places, and laid down three disks to mark locations they identified. Hierarchical linear regression analysis revealed that performances in a set of written spatial tasks predicted up to one quarter of the variance in performances in both map-reading tasks, while sex and strategy choice were not found to be important predictors.

Keywords: Geometry education, map tasks, spatio-geometric reasoning, spatial skills.

Introduction

Geometry education at primary school is often based on Freudenthal's idea of "grasping space" (1973), and thus aims to contribute to children's thoughtful interaction with the three-dimensional space in which they live, play, and move. Ideally, this goal is achieved at school with a range of spatio-geometric tasks that allow children to complete realistic geometric activities that are similar to their own everyday experience (Lowrie & Logan, 2007).

Within TWG4 of CERME, spatial reasoning and spatial skills have been identified as latent underlying cognitive skills that allow children to develop and apply the four core competencies (reasoning, figural, operational and visual) for geometrical thinking (Maschietto et al., 2013). Although their importance has been emphasized in a range of studies, their role in realistic spatio-geometric activities is little understood (Houdement, 2017). A review of the literature revealed that all studies on these activities in the working group are typically located in a space that is very close to the subject, like for example a sheet of paper, a set of small objects, or a computer screen (Houdement, 2017). In contrast, investigating activities that are located in larger, realistic interaction spaces such as map reading in real space would be closer to the original demand for realistic geometric activities that allow children to "grasp space."

Addressing this gap in the literature and extending the literature on spatial-geometric reasoning of primary children, this study presents two map-reading activities (self-location and place finding) as examples of spatio-geometric tasks that can be completed in larger spaces. By doing so, it seeks to empirically investigate the relative importance of spatial skills, sex, and strategy choice in these contexts.

Map reading, person-space-map relations and spatial skills

Maps are symbolic representations of the reference environment that allow to mediate between the immediate perception of space and the cognized inference about it, for instance during navigation with a map (Downs, 1981). Maps have been emphasized to foster spatio-geometric thinking in realistic contexts that require the integration of information from the real space that surrounds the learner rather than being based on material that can be perceived from one single vantage point (e.g. Liben & Downs, 1993). Maps provide therefore an important tool for completing spatio-geometric activities in large interaction spaces, which, in turn, requires cognitive processes (Montello, 1993) and spatial knowledge (Brousseau, 2000) that are different from processes and knowledge used to solve paper- and pencil spatial tasks.

To read a map, in particular to establish a relationship between the real physical environment and its abstract-geometric depiction, is a complex task that requires not only spatio-geometric skills, but also requires the understanding of basic mathematical concepts. Following a rather descriptive argumentation of Muir and Frazee (1986), eight skills relate to map reading: (1) interpreting symbols, (2) understanding scale, (3) calculating distances, (4) understanding perspective, (5) finding locations, (6) determining directions, (7) identifying elevation, and (8) imagining relief. Among those skills, three explicitly relate to spatio-geometrical ones ((4) – (6)). Although map reading can be considered being a complex activity that involves all eight skills in an interrelated way, the focus of this paper is on the skills of understanding perspective, finding locations and determining directions in this study, and approach and conceptualize them further from a psychological perspective.

Two typical tasks of map use that require all three skills outlined above, are direct navigation towards a certain goal (*place finding*) and understanding where you are on a map (*self-location*). Self-location is a prerequisite of further map use and requires linking their current location in the environment to the analogue location on the map. Hereby, locating themselves on a map does not only involve identifying their position on the map, but also considering their current orientation. Following Liben & Downs (1993), to do so, children must understand three different relations between themselves (person), the environment (space) and the representation of the environment (map). These three relations are perception and reflecting on the own location in space (*person-space* relation), understanding and establishing links between the space and its representation (*space-map* relation) and understanding their own location on the map (*person-map* relation).

Children acquire the knowledge to master the person-space relation relatively early in their development due to their sensorimotor exploration of space. That is, children demonstrate relatively early that they are for instance intuitively able to identify their home location or the location of other landmarks. However, adjusting this intuitive person-space understanding by taking information on the environment from a map, thus establishing geometrical correspondences between the environment and its depiction in a map, appears to be achieved much later in the children's development (see Liben & Downs, 1993, for references in the developmental literature).

In particular, understanding geometric correspondences comes to reason about the space-map relation by identifying whether the map aligns correctly with the environment and further involves projective reasoning for establishing the person-map relation. Whenever the map is not aligned with the

environment, children need to engage some form of cognitive compensation. Understanding the person-space-map relation then becomes an intertwined cognitively challenging process of mentally rotating the map to align it with the environment (thus establishing the space-map relation) and imagining the own locating and heading on a map (thus establishing the person-map relation).

Spatial cognition psychologists have modeled the skills to establish and maintain the correct person-space-map relations during navigation by relating them to the concept of spatial skills (e.g. Liben & Downs, 1993, Liben et al., 2013). Spatial skills is an umbrella term that refers to a set of cognitive skills that allow an individual to encode, maintain, and transform a spatio-visual stimulus to induce a certain inference or a spatial behavior. From this perspective, aligning a map with the environment has been modeled as mental rotation skill (e.g. Shepard & Hurwitz, 1984) and imagination of the own position on a map as perspective taking skill (e.g. Liben & Downs, 1993).

While the literature on spatial cognition proposed this relation at the level of latent cognitive processes, it is not clear whether this relation holds true from the perspective of individual differences. The goal of the study was therefore to empirically test whether and to and which extent individual differences in tasks requiring spatial skills are important predictors for individual differences in map-use tasks. It was also tested, whether sex (e.g. Voyer & Voyer, 1995) and spontaneous strategy use (e.g. Liben et al., 2013) were also important predictors.

Methods

Research design

This study used a quantitative design that was based on two psychometric tests: First, a paper-and-pencil test that measured performances in a set of spatial tasks that required the use of spatial skills. Second, a map-based orientation test that measured performances in self-location and place finding tasks that required the skills to constantly update person-space-map relations. Scores in the tests were interpreted as indicators of individual skill and related to each other in multiple regression models.

Participants

The sample consisted of 240 primary school children (111 boys, 129 girls) out of a town in Northern Germany. The children were aged between 9 and 12 years (mean age 9.17, $SD=.50$) and formed a heterogeneous sample in terms of scholar achievement and social background. The sample was not specifically chosen, but consisted of all children in the town that got the permission to participate in the study.

Paper and pencil tasks

The children completed a set of different paper and pencil tasks in 45 minutes. The test consisted of eight different tasks (see Table 1 for examples of tasks), four of them being adoptions of adult tasks (e.g., a 2D mental rotation tasks based on Ekstrom's Card Rotation Test, a 3D mental rotation task similar to the Vandenberg's Mental Rotation Test, a Paper Folding Task analogue to Thurstone's Punched Holes Test, and a perspective taking task analogue to the Guilford-Zimmermann boat test). The four other tasks were developed from the scratch and tested within a pilot study with $N=222$ children. Those tasks required for example perspective taking processes in labyrinths.

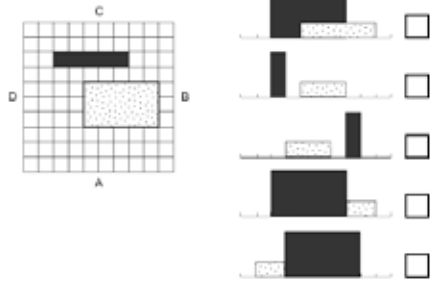
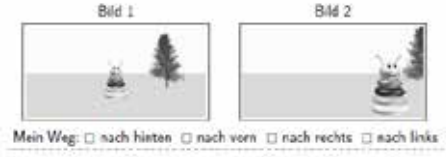
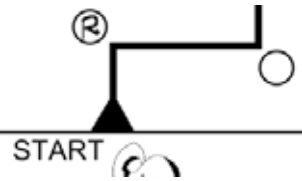
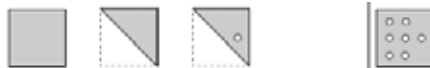
Task	Description and Scoring	Example item
Boxes	Requires sorting the corresponding side views of an array of boxes that is presented in plan view. The children need to sort all four side views out of five possible solutions. 3 items with polytomous scoring (2-1-0).	
MEADOW	Requires determining directions (forward/backward & left/right) of mental movement that explains a shift from picture one to picture two. 6 items with dichotomous scoring.	
LR	Requires imagining going along a path on a map and to decide on each crossing whether to turn left or right. 4 items with dichotomous scoring.	
PFT	Adoption of the Paper Folding Task. 6 items with dichotomous scoring.	

Table 1: Four tasks of the paper and pencil test.

Map-based orientation tasks

The field area was the campus of Leuphana University has a mostly symmetrical of buildings that are connected via perpendicular roads (see Figure 1). On the campus, the experimenter installed a yellow, a blue and a red flag. The children were individually given a map of the campus as well as a set of six stickers, three of them for indicating locations (points of 5mm diameter), and three of them for indicating directions (little arrow stickers). They further obtained a set of three numbered disks. After some preliminary tasks on map understanding, the children completed two map- tasks. During the tasks, they were forbidden to turn the map.

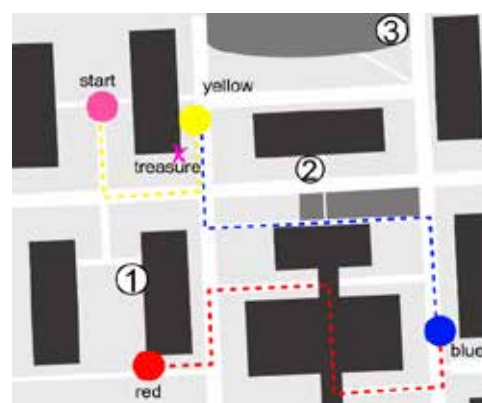


Figure 1: Flags and discs on the campus

1. *Self-location*: The children followed the experimenter to each of the flags and were asked to place the location and direction sticker. Wrong answers were corrected for maintaining equal change for every tasks after putting each sticker.
2. *Place Finding*: At the red flag, the children were told to find numbers on the map and place the corresponding disks at the right location on the campus. The experimenter recorded the locations

where each of the three disks were placed. Whenever a disk was misplaced, the children were corrected afterwards, thus maintaining equal chance for the subsequent disk.

These tasks required the children constantly update the space-map relation since they were not allowed to turn the map. Moreover, solving the tasks required to track where they are on the map, thus updating the person-map relation while integrating visuospatial information from the environment and update their person-space relation.

During the tasks, the experimenter recoded visible strategies such as *tracing* (follow the route with a finger on the map), *matching* (talking aloud about correspondences between map and buildings), *north-orientation* (child orients towards north all the time while walking with the experimenter) and *other* (speaking aloud of left-right changes, gesture, ...).

Data treatment

The X and Y coordinates of each sticker were encoded. Stickers were scored polytomously with a tolerance of 5mm and 7mm radius of the correct position, giving up to 2 points per sticker, and the direction stickers dichotomously. The locations of the discs were scored with up to two points per disk. In a subsequent step, the data was analyzed using listwise deletion for missing values that occurred during data collection in the map-based tasks.

Results

Descriptive statistics

To understand performances of the sample in both tasks, descriptive statistics for the tasks self-location and place location were computed. A descriptive analysis of the two tasks revealed that children performed below the expectation value for the self-location tasks (range=[0,8], M=3.11, SD=2.25, N=231) and about the expectation value in place finding tasks (range=[0,5], M=2.87, SD=1.77, N=207). These results indicate, that self-location tasks remain very difficult to master for children within the sample. In particular marking the correct positions (range=[0,5], M=1.43, SD=1.55) rather than understanding orientation (range=[0,3], M=1.67, SD=0.99) was difficult.

Hierarchical multiple regressions

Self-location performance in relation to individual variables. In a preliminary step, multiple regression analysis was used to test which of the eight spatial tasks that were solved in the test significantly contributed to explain variance in self-location performances. The results indicated that all eight predictors

	Step 1		Step 2		Step 3	
$R^2(p)$	.214 (.000)		.215 (.000)		.233 (.000)	
$\Delta R^2(p)$	.214 (.000)		.001 (.548)		.017 (.289)	
Predictor	β	p	β	p	β	p
LR	.21	.002	.21	.002	.22	.001
PFT	.22	.002	.22	.002	.20	.005
MEADOW	.18	.007	.17	.009	.18	.008
Sex			.04	.548	.01	.832
Tracing					.03	.648
Matching					-.07	.260
North					.11	.065
Other					-.02	.746

Table 2: Hierarchical linear regression analysis predicting self-location performances (N=230)

explained 23.0% of the variance ($R^2=.23$, $F(8,222)=8.38$, $p<0.001$). Three of these tasks, LR ($\beta =.17$, $p=.016$), PFT ($\beta =.14$, $p=.086$) and MEADOW ($\beta =.14$, $p=.048$), were found to predict self-location performances significantly ($p<0.01$), and kept for subsequent analysis. In the hierarchical multiple regression analysis, the spatial scores of these three tasks were added in Step 1, sex in Step 2 and four different strategy scores in Step3 (see Table 2).

As in the preliminary analysis, the three spatial tasks accounted for significant variance in the self-location performances first level of the model, $F(3,227)=20.61$, $p<0.001$, with PFT emerging as the most important predictor (see Table 2 for standardized betas and the corresponding probability levels for every step in the model). Prediction was not significantly improved by adding sex in Step 2. The addition of strategies in Step 3 led to a marginal increase of .017 in the amount of explained variance, and revealed walking with orientation towards the north as an almost significant predictor. However, in the overall model comparison, the final model did not differ significantly from the first one which explained 21.4% of the variance.

In summary, the results indicated that individual differences in three spatial tasks only can be seen as significant predictors of self-location performance, predicting a fifth of the variance. Sex and strategy use did not contribute significantly to explain variance.

Place finding performance in relation to individual variables. Again, in a preliminary step, multiple regression analysis was used to test which of the eight spatial tasks significantly contributed to explain variance in place finding performances. The results indicated that all eight predictors explained 25.3% of the variance ($R^2=.25$, $F(8,198)=8.37$, $p<0.001$). Three of these tasks, LR ($\beta =.16$, $p=.024$), PFT ($\beta =.14$, $p=.090$) and BOXES ($\beta =.22$, $p=.009$), were found to predict place finding performances significantly ($p<0.10$), and kept for the analysis.

In the hierarchical multiple regression analysis, spatial scores of these three tasks were entered in Step 1, sex in Step 2 and strategy choice in Step 3 (see Table 3). As in the preliminary analysis, the three spatial tasks accounted for significant variance in the first level of the model, $F(3,203)=21.87$, $p<0.001$, with BOXES emerging as the most important predictor (see Table 3 for standardized betas and the corresponding probability levels for every step in the model). Again, prediction was not significantly improved by adding Sex in Step 2. The addition of strategies in Step 3 led to a significant increase of .032 in the amount of explained variance, and revealed that ‘other strategies’ to be a significant inhibitor of place-finding performances. The final model was significant, $F(8,198) = 9.579$, $p<0.001$, with an $R^2=.28$.

	Step 1		Step 2		Step 3	
$R^2(p)$	.244 (.000)		.247 (.000)		.279(.000)	
$\Delta R^2(p)$	.244 (.000)		.003 (.372)		.032 (.072)	
Predictor	β	p	β	p	β	p
LR	.17	.015	.17	.015	.21	.003
PFT	.18	.017	.17	.022	.18	.017
BOXES	.27	.000	.26	.001	.27	.000
Sex			.06	.372	.06	.310
Tracing					-.06	.321
Matching					-.01	.906
North					-.01	.822
Other					-.17	.009

Table 3: Hierarchical linear regression analysis predicting place finding performances (N=205)

In summary, the results indicated that individual differences in three spatial tasks emerged as significant predictors of place finding performance, predicting a quart of the overall variance. Sex did not contribute significantly in the prediction. Strategy use led to an overall predicted variance of 28%, but revealed a less well defined strategy group as inhibitor.

Discussion

This study aimed at investigating children's performances in two map-reading tasks in real space and investigated their prediction by a set of spatial skills and the two other individual variables sex and strategy choice. As anticipated by labelling the proposed activity as a "complex" one, the results indicated that both, self-location and place finding remain challenging tasks for children by the end of primary school. Moreover, a hierarchical regression analysis showed that individual differences in written spatial tasks accounted for up to 25% of the variance in both map-based tasks. I sex nor strategy use were found to be significant predictors in both tasks.

Regression analyses revealed a set of four spatial tasks that predicted the outdoor tasks: LR and PFT were found to be predictors in both outdoor tasks, MEADOW and BOXES for self-location and place finding, respectively. An analysis of these tasks (see e.g. Linn & Petersen, 1985, for the PFT) reveals that they rely on multistep solution processes, in particular require a multistep manipulation of mental images that need to be updated correctly. Tasks that require singular 2D and 3D mental rotations were not found to be predictors. Similarly, perspective taking tasks that are bound to a very particular spatial setting (labyrinth-tasks) were not found to be predictors either. A tentative interpretation of this outcome for educational settings might be that spatial tasks that are interesting for application in real space should fulfill two criteria: first, they should be sufficiently complex, and second, they should not be presented in too particular contexts but rather in general-abstract contexts.

Since we drew on the literature concerning sex-differences in favor of boys in written spatial tasks, we expected to find sex an important predictor in the map-reading tasks in real space as well. In contrast to the literature (Liben et al., 2013), we did not find a male advantage at all. Although we recommend follow-up analyses including interaction terms into the models outlined above, there is an interpretative suggestion that activities with maps in the real space are equally cognitively accessible for boys and girls.

Contrary to other empirical findings (Liben et al., 2013), visible solution strategies did not predict performances in the map-based tasks. One possible explanation is that experimenters just observed the strategies, but the children were not explicitly interviewed. Furthermore, experimenters were not sufficiently sensitized to observe strategies. The documentation of strategies was therefore dependent on the different experimenters that might have documented them in a non-coherent manner. Further studies that focus on strategy use are important.

For a better understanding of the role of spatial skills in realistic spatio-geometric activities from a conceptual point of view, studies should conceptualize and analyze those skills in latent models, thus referring to classes of spatial tasks that share the same cognitive processes and to analyze their relation to the map tasks. This would allow researchers to make more generalized conclusions than it is the case in an analysis based on single spatial tasks.

Conclusion

By empirically testing psychological assumptions, this paper demonstrates that spatial skills are an important underlying cognitive skill in realistic geometric activities that allow children to understand the real space they interact with in their everyday life. Investigating spatial skills and their underlying cognitive processes, but also spatio-geometric activities in larger interaction spaces remain therefore important challenges for conceptual work and discussions in TWG4.

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