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Girls' spatial abilities: Charting the contributions of experiences and attitudes in different academic groups

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Background. Gender-related differences in spatial abilities favouring males are well established but have also generated a great deal of controversy. Cross-cultural research, meta-analyses and training studies could show the influence of socio-cultural and experiential factors on spatial-test performance. However, little is known about how experiences and gender-role stereotypes mediate performance differences in this area.

Aim. The relationship between specific experiences (spatial activities, computer experience), achievement-related attitudes, and spatial abilities, i.e., mental-rotation ability was investigated with males and females in different academic subgroups.

Sample. The sample comprised 112 female and 71 male undergraduates, majoring in arts, humanities and social sciences, sports, psychology and computational visualistics.

Methods. A redrawn version of the Vandenberg and Kuse Mental Rotations Test (MRT) was administered and the participants completed a questionnaire about their spatial activities, computer experience, self-ratings regarding everyday spatial abilities, and attitudes towards mathematics and physics.

Results. Mental Rotations Test performance was mainly affected by academic programme and gender, but the effect size of gender differences varied. It was largest with students majoring in arts, humanities and social sciences and smallest with those majoring in computational visualistics. Data analyses revealed statistically significant correlations with spatial activities and computer experience only for females. The relationship between test performance and scales of achievement-related self-concept also depended on gender.

Conclusions. Compared to males, females' spatial abilities are extremely vulnerable to and thus modifiable through attitudinal and experiential factors. This has

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considerable consequences for intervention programmes that could help to overcome the gender gap in spatial abilities.

Since the beginning of psychometric intelligence testing spatial tasks have been administered (Binet & Simon, 1905) in this domain and spatial abilities have been part of several intelligence models (e.g., Guilford, Fruchter, & Zimmerman, 1952; Thurstone, 1938). Also contemporary intelligence theories still point to the importance of spatial intelligence in contrast to, e.g., verbal or bodily-kinesthetic intelligence (Gardner, 1983). Very early, however, factor-analytic research and several meta-analyses also showed that spatial ability is not a global skill and should be divided into different subfactors. Linn and Peterson (1985), for example, proposed three spatial categories: *spatial perception*, the ability to determine spatial relationships with respect to the orientation of one's own body, affected by distracting information, *mental rotation*, the ability to mentally rotate a two or three-dimensional figure rapidly and accurately, and *spatial visualisation*, based on complicated multistep manipulations of spatially presented information.

Gender differences in spatial-ability test performance favouring males are well established (Harris, 1981; McGee, 1979) and are one of the main findings in the field of cognitive gender differences (Halpern, 1992; Maccoby & Jacklin, 1974). And spatial abilities – in particular spatial visualisation and mental-rotation ability – are important for technical professions (Smith, 1964) and for several academic subjects like mathematics (Burnett, Lane, & Dratt,1979), chemistry (Barke, 1993), computer sciences (Norman, 1994) and engineering (Sorby, Leopold, & Górska, 1999), in which occupational careers and academic programmes the largest sex segregation can be observed (Meinholdt & Murray, 1999; Vetter & Babco, 1986; White, 1985). On the other hand, studies revealed, for example, significant correlations between spatial visualisation and mathematics achievement (Fennema & Sherman, 1977) and an improvement of spatial-test performance through training of geometrical skills (Kirby & Boulter, 1998). Tartre (1990) found that gender differences in mathematics achievement can be partially explained by differences in spatial abilities.

Gender-related differences in spatial abilities have attracted considerable research attention, but have also generated a great deal of controversy concerning their size, importance and developmental course as well as their possible causes (Harris, 1981; Linn & Peterson, 1985; McGee, 1979). Similar to other domains of ability research, the theoretical discussion in this area for a long time could be described as an either-or-approach, arguing *for* the role of biological factors and *against* environmental influences as determinants for spatial abilities or vice versa, without considering the relationship between them. Authors favouring biological mechanisms point to genetic differences (e.g., genetic x-linkage, Bock & Kolakowski, 1973), different brain lateralization (Kimura, 1992), handedness (Annett, 1992), and to hormonal factors like the timing of puberty (Waber, 1977) or to pre- and postnatal exposure to sex hormones (Kerns & Berenbaum, 1991).

Those claiming environmental factors as the main determinants regard male superiority in spatial ability as a consequence of gender-typing parental child-rearing practices leading to different childhood activities such as hobbies or toy usage and to different achievement-related self-concepts for males and females. They have found support in the continuous decrease of the size of the sex differences in spatial abilities during the last decades (Feingold, 1988; Stumpf & Klieme, 1989), a trend that rather reflects changing gender roles and cannot be due to genetic differences: 'Females appear to be gaining in cognitive skills relative to males rather faster than the gene can travel' (Rosenthal & Rubin, 1982, p. 711). The results of training studies are other indicators of the importance of experiential factors in the spatial domain (Baenninger & Newcombe, 1989; Connor, Serbin, & Schackman, 1977; Peters, Chisholm, & Laeng, 1995; Vasta, Knott, & Gaze, 1996). And cross-cultural differences in spatial abilities (Berry, 1966; Munroe & Munroe, 1971) pointing to the role of socio-cultural factors in this area have brought into focus the importance of everyday activities and socio-cultural practices for spatial skills (Gauvain, 1993).

Instead of discussing biological and environmental factors as opponents, the issue of gender differences in spatial abilities has recently been addressed within a biological-environmental-interactionist framework (Casey, 1996). In contrast to other types of biological and environmental relations like gene-environment correlations, biological-environmental interactions are assumed to be particular combinations of biological and environmental relations resulting in consequences not predictable from the two considered separately (Wachs, 1992). In the field of spatial abilities this means that individuals with a specific biological disposition may benefit more when exposed to spatial experiences than individuals with a different biological disposition. Or in other words, some individuals (e.g., girls) profit more from specific environmental stimulation than others (e.g., boys). This 'bent-twig' model has been successfully tested for subgroups of females having a combination of a particular genetic potential – for example, familial handedness, and prior experiences, such as school major (Casey, Colon, & Goris, 1992).

The extent to which spatial activities and experiences influence spatial-test performance has often been examined in literature. Several studies and meta-analyses revealed a weak but reliable effect of spatial-activity experience on spatial-test performance (Baenninger & Newcombe, 1989; Newcombe, Bandura, & Taylor, 1983; Olson & Eliot, 1986). Thus, there is some empirical evidence for the hypothesis that females are less likely to have high spatial abilities because they have had less spatial experience than males. A still open question is, however, whether the experience itself and its spatial nature is important here, or the fact that the experience is gender-stereotyped. Spatial-activity research is in line with other studies focusing on the impact of academic instruction on spatial ability. A study supporting the 'differential-course-work hypothesis' revealed a significant correlation between spatial-test performance and the number of mathematics courses taken (Burnett & Lane, 1980). The enrolment in certain academic courses (mathematics, i.e., geometry, and physics, chemistry) leads to intensive exposure to abstract information processing – requiring mental imagery or other spatial tasks – and consequently improves spatial abilities.

Another research area relevant to gender differences in spatial abilities focuses on the influence of gender-role orientation on cognitive performance. Gender-schema theories, for example, try to explain gender differences through individual differences in gender-schematic processing of information (Bem, 1981; Martin & Halverson, 1981). According to these theories, individuals build up a gender schema in which knowledge of activities and interests, personality and social attributes, and scripts about gender-linked activities are successively included. Once formed, males and females behave consistently with the gender schema that reflects the cultural gender roles. Socio-cognitive theory of gender, however, assumes that gender-linked roles and conduct are acquired through 'enactive experience' and shaped by evaluative social reactions to gender-linked behaviour (Bandura, 1986; Bussey & Bandura, 1999). The complex and reciprocal relationship between culturally shaped achievement-related expectancies and self-selected experience have been outlined for mathematics achievement in Eccles' model of academic choice (Eccles, 1987, 1994). In Germany and other western societies certain spatial activities (e.g., technical activities) and engagement in specific areas like mathematics and physics as a kind of gender-linked behaviour are heavily socially sanctioned. Thus, according to theories considering the importance of gender roles in this context, engagement in and attitudes towards these areas are heavily influenced by gender-role orientation.

However, gender-role stereotypes have a profound effect on spatial-task performance. According to Nash's (1979) hypothesis concerning the gender-typing of tasks and Horner's theory of the fear of success (Horner, 1972), individuals perform better on cognitive tasks if their self-concept matches the gender-stereotyping of the task. This assumption has been supported in the field of spatial abilities in that higher masculine and lower feminine self-concept scores were related to better performance in spatial tests (Signorella & Jamison, 1978). Thus, there is strong evidence of a gender-role effect on both academic-course choice and spatial-test performance.

This paper focuses on differences in spatial abilities between different academic subgroups that are supposed to differ in specific experiential factors as well as in achievement-related attitudes. In addition, it addresses the differential role of experience and attitudes for mental-rotation ability with males and females. An academic major subgroup design, comparing students of arts, humanities and social sciences, sports students, psychology students, and computational visualistics students, was used to examine the following questions:

(1) Do the members of these academic subgroups remarkably differ in their spatial abilities?
(2) Do these academic groups differ in experiences and attitudinal variables that could be related to the differences in spatial ability?
(3) How are experiential as well as attitudinal variables and spatial abilities related to each other and does this relationship differ between males and females?

Method

Participants

The sample consisted of 183 (f = 112; m = 71) freshmen from Otto-von-Guericke-University Magdeburg, Germany, enrolled in different academic programmes: 53 (f = 38, m = 15) were students majoring in arts, humanities and social sciences, 19 (f = 11, m = 8) were sports students, 69 (f = 51, m = 18) were psychology students and 42 (f = 12, m = 30) were students of computational visualistics[1]. All students participated voluntarily.

Materials

Spatial ability tests. As recent studies have found the largest and most robust effect

[1] *Computational visualistics is a degree programme lately introduced at the Otto-von-Guericke-University of Magdeburg combining computer science knowledge with studies on pictures in the humanities and with applied knowledge, e.g., in medicine.*

sizes for mental rotation ability (Masters & Sanders, 1993; Voyer, Voyer, & Bryden, 1995), a redrawn version of the Mental Rotations Test (Vandenberg & Kuse, 1978) was used for the study (Peters *et al.*, 1995; German version: Quaiser-Pohl & Lehmann, 2002). The MRT consisted of 24 tasks, each presenting one standard drawing of a cube construction and four other drawings (an example item is shown in Figure 1). Participants had to identify the two drawings which were similar to the standard item. The tasks were given in two sets of 12, separated by a pause of 3 minutes. Students were allowed 3 minutes per set. Scoring was done by awarding a point only if both

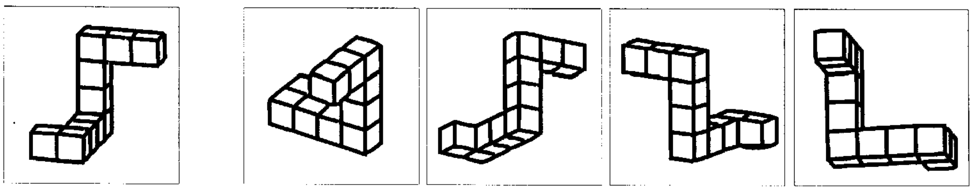

Figure 1. Mental Rotations Test (Peters *et al.*, 1995); item example

correct choices for each task had been identified.

Spatial activities questionnaire. This questionnaire was based on the Spatial Activities Experience Questionnaire used by Newcombe *et al.* (1983) and consisted of 58 items asking about leisure time activities requiring more or less spatial ability. The original 81-item questionnaire was transferred into German leaving out typical American activities like football and activities not being part of the daily life of German students of this age group. Participants had to indicate the frequency of doing each activity on a 5-point-Likert scale from 1 = *never done* to 5 = *very often done*. Factor analysis (principal component analysis) of the data revealed three rotated factors explaining 27% of the total variance. A scale-construction procedure following factor-analytic as well as content-analytic considerations revealed the subscales (1) '*technical activities*' (12 items, e.g., repairing a bike, doing electronic handicrafts: Cronbach's alpha = .819), (2) '*arts-and-needlework*' (21 items, e.g., drawing, taking photographs, knitting: Cronbach's alpha = .826) and (3) '*sports*' (22 items, e.g., tennis, soccer, skiing: Cronbach's alpha = .707). These scales differed from spatial-activity measures used in other studies (reported in Baenninger & Newcombe, 1989) insofar as spatial activities were not divided in groups of 'masculine', 'feminine' and not sex-typed items but with regard to their activity-specific content, which seemed more appropriate to the factor-analytic results. For each of the subscales sum scores were calculated.

Attitudes towards mathematics and physics. Another factor-analysed subscale consisted of 12 items in which students were asked about their general attitudes towards mathematics and physics (e.g., 'Physics was one of my favourite subjects at school') as well as about their achievement-related self-concept in this area (e.g., 'It is easy for me to solve mathematical problems'). Scale-reliability was satisfactory (Cronbach's alpha = .773, Guttman's Split-Half = .7914).

Attitudes towards maths and technical things as male domains. Another three items measured the gender-role orientation for mathematics and technical things. They asked about the attitudes towards mathematics and technical things as male domains ('Mathematics is rather a subject for boys than for girls' / 'Usually girls find mathematics more difficult than boys' / 'In my opinion technical professions are something for boys'). Although there was only a small number of items, scale homogeneity was extremely high: Cronbach's alpha was .6147.

Spatial ability in everyday life questionnaire. This scale consisted of 11 items. Participants had to judge whether they were 'better', 'similar' or 'worse' than other people of the same sex at doing several daily activities requiring spatial ability (e.g., 'drawing a map of the environs', 'finding one's way in an unknown building', 'interpreting figures and diagrams', 'reading a map'). Sum scores were distributed normally, reliability was satisfactory showing high homogeneity (Cronbach's alpha = .716, Guttman's Split-Half = .791)

Computer experience. In addition participants were asked with dichotomous items whether and how they had obtained computer skills and knowledge, and whether they had had computer science as a subject at school or acquired it at home.

Procedure

The whole testing took place as a group test during university seminars. The Mental Rotations Test was administered first, then the Spatial Activities, Attitudes Towards Math and Physics, Spatial Abilities in Everyday Life questionnaires were given in that order and finally questions about computer experience, handedness, and school marks were asked.

Results

Subgroup differences in MRT performance

Table 1 shows Mental Rotations Test results in each subgroup. Total mean differences between academic subgroups were not significant. But an ANOVA revealed significant main effects for gender favouring males ($F = 24.37$, d.f. = 1, $p \leqslant .001$) and significant academic subgroup-by-gender interactions ($F = 3.24$, d.f. = 3, $p = .024$). Looking at the measures of effect size η^2 and d (Hyde, 1981[2]) we found large gender differences with arts, humanities and social sciences and psychology majors, medium ones with sports students and small gender differences with students of computational visualistics[3]. Due to the sample (only psychology students and mostly females) for the mental-cutting test 'Schnitte', neither academic subgroup nor gender differences could be tested. MRT and 'Schnitte' test results were moderately correlated ($r = .595$[4], $p \leqslant .001$, $N = 45$).

As gender differences in variability in spatial abilities have been reported in the literature (Feingold, 1992), another measure of interest was the variation coefficient V, describing the standard deviation in mean units. Remarkable differences of variance between girls and boys were observed for all subgroups except sports and psychology students and for the whole sample, but in contrast to other studies both indicating greater female variability (see Table 1).

Subgroup differences in experience variables

Spatial activities. No significant main effect for academic subgroup membership was found, but post hoc tests showed that students of computational visualistics had more

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[2] $d = \frac{M_1 - M_2}{SD}$

[3] *According to Cohen (1977) d=.20 indicates a small, d=.50 a medium and d=.80 or more a large effect size.*

[4] *This and the following correlations are attenuated correlation coefficients.*

Table 1. MRT performance in different subgroups

		N	*M*	SD	Vin%	η^2	*p*	d
	Males:	15	16.60	3.4	20.5			
Arts, Humanities and Social Sciences	Total:	52	11.35	5.1		.440	.001	1.92
	Females:	37	9.22	4.0	43.5			
	Males:	8	14.87	5.8	39.2			
Sports	Total:	19	12.95	4.9		.114	n.s.	0.69
	Females:	11	11.55	4.5	38.8			
	Males:	15	13.07	5.1	38.9			
Psychology	Total:	55	10.29	4.7		.126	.01	0.84
	Females:	40	9.50	9.5	41.1			
	Males:	30	14.57	4.6	31.7			
Computational Visualistics	Total:	42	14.19	4.9		.015	n.s.	0.27
	Females:	12	13.25	5.7	43.1			
	Males:	68	14.72	4.6	31.7			
Total Sample	Total:	168	11.95	5.0		.132	.001	1.04
	Females:	100	10.07	4.4	43.1			

V = variation coefficient = *SD*/*M*

experience with technical activities, especially in contrast to students majoring in arts, humanities and social sciences (Scheffé test: $p \leqslant .001$) and to psychology students (Scheffé test: $p \leqslant .001$).

Means for the 'sports' subscale also differed between academic subgroups, with sports students, of course, having the most experience with sport activities and students majoring in arts and humanities the least ($F = 5.565$, d.f. = 3, $p \leqslant .001$, eta^2 = .091) (see Figures 2 and 3).

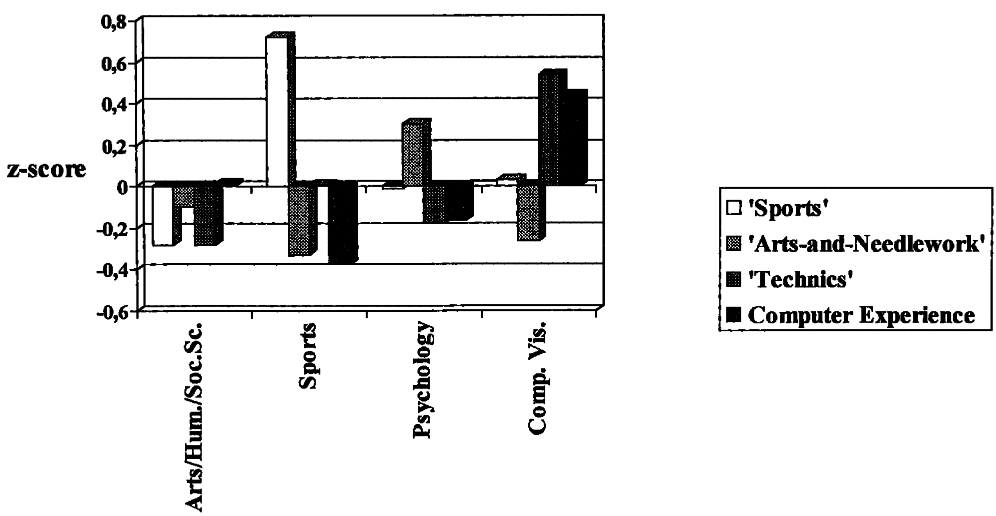

Figure 2. Academic group and self-ratings of experience; z-scores

For the subscale 'technical activities' ANOVA revealed a significant main effect for gender ($F = 23.11$, d.f. = 1, $p \leqslant .001$, $\text{eta}^2 = .12$) with boys having more often participated in technical activities, and a gender-by-academic-subgroup interaction in tendency ($F = 2.47$, d.f. = 3, $p = .064$, $\text{eta}^2 = .042$), with gender differences being the smallest with the computational-visualistics subgroup.

For the '*arts-and-needlework*' subscale again ANOVA revealed no difference between academic subgroups but significant gender differences ($F = 33.69$, d.f. = 1; $p \leqslant .001$, $\text{eta}^2 = .168$) with girls having more experience with arts and needlework activities.

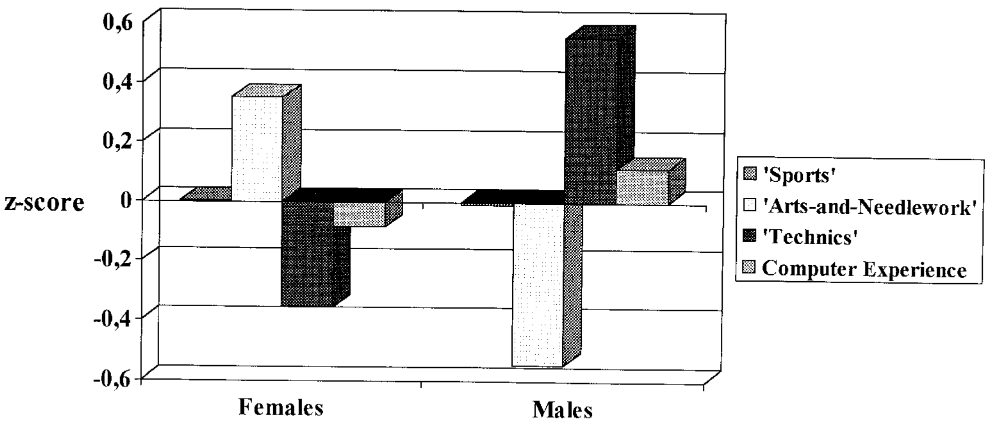

Figure 3. Gender and self-ratings of experience; z-scores

Computer experience. With regard to computer experience a significant main effect of academic subgroup ($F = 3.320$, d.f. = 3, $p = .021$, $\text{eta}^2 = .058$) could be observed. Sports and psychology students had less computer experience than students majoring in arts, humanities and social sciences and in computational visualistics (see Figure 2). But there was no gender difference: girls had as much computer experience as boys (see Figure 3).

Subgroup differences in achievement-related attitudes

Self-ratings of spatial abilities in everyday life. With regard to the self-ratings of spatial abilities in everyday life, academic subgroup as well as gender differences were found (see Figure 4). Students of computational visualistics rated these abilities higher than other students ($F = 6.208$, d.f. = 3, $p \leqslant .001$, $\text{eta}^2 = .10$; Scheffé-test: $p \leqslant .01$). Boys rated their everyday spatial abilities higher than girls ($F = 24.591$, d.f. = 1, $p \leqslant .001$, $\text{eta}^2 = .128$).

Attitudes towards mathematics and physics. There were large academic subgroup differences ($F = 41.720$, d.f. = 3, $p \leqslant .001$, $\text{eta}^2 = .138$), but no gender differences were observed concerning the attitudes towards maths and physics. Students majoring in computational visualistics and psychology students estimated maths and physics as more attractive and important, and their own abilities in this area as higher than sports students and students majoring in arts, humanities and social sciences (see Figure 4).

Maths and technical things as male domains. By contrast, there were neither academic subgroup nor gender differences in attitudes regarding maths and technical things as male domains. Girls and boys from all academic programmes estimated maths and technical things equally as gender-stereotyped.

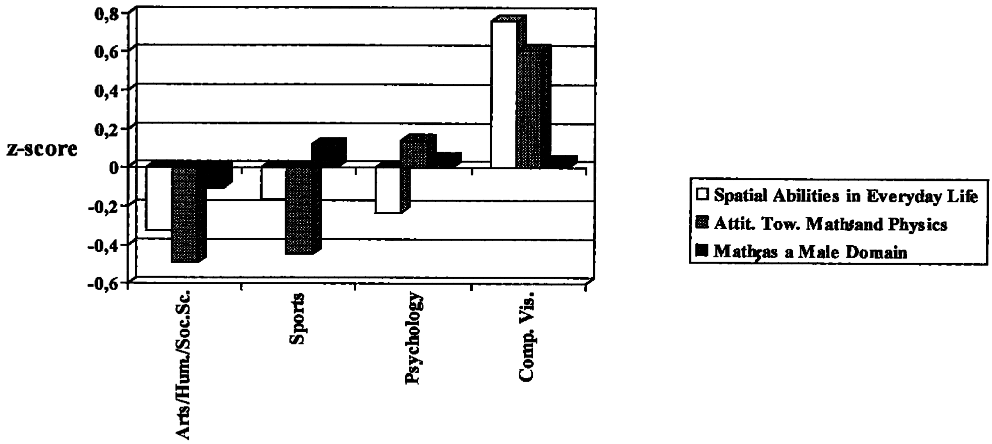

Figure 4. Academic group and achievement-related attitudes; z-scores

Relations between experience variables and spatial abilities

Spatial activities. Generally speaking, there was a different relation between experience with spatial activities and MRT performance for males and females (Figure 5). With females there was a significant positive correlation between MRT and the *technical activities* subscale (r = .375, p = .003, N= 98) and a significant negative correlation for the *arts and needlework* subscale (r = $-$.248, $p \leqslant$ .001, N= 98). For males, in contrast to that, there was a weak but not significant negative correlation for 'technical activities' and correlation around zero for arts-and-needlework. The more experience females had with technical activities and the less they had with arts-and-needlework activities, the better were their MRT results. But among the male students those with less experience with technical activities had better MRT results. With females there was also a positive correlation between sports activities and MRT performance (r = .253, p = .072, N= 97). The more experience females had with several sports activities, the better were their MRT results.

Computer experience. Computer experience was also related to MRT performance, but again statistically significant only with females. There was a significant positive correlation (r = .251, p = .036, N= 94): females who had acquired computer skills showed better MRT results than females who had not.

Relations between achievement-related attitudes and MRT performance

Spatial abilities in everyday life. There were significant positive correlations between this scale and MRT performance for the total sample (r = .522, p < .001, N= 164) and for the female subgroup (r = .488, $p \leqslant$ .001, N= 96). The higher females estimated their spatial abilities in everyday life, the better were their MRT results. With males there were zero-correlations between the two measures (see Figure 6). The correlation between self-ratings of everyday spatial abilities and performance in the mental-cutting test 'Schnitte' with females were even higher (r = .529, $p \leqslant$ .01, N= 43).

Attitudes towards mathematics and physics. A similar relationship was observed between attitudes towards maths and physics and spatial-test performance (see Figure 6). Both variables were significantly correlated with females (r = .286, p = .037, N= 92), while with males they were independent. An even higher correlation between

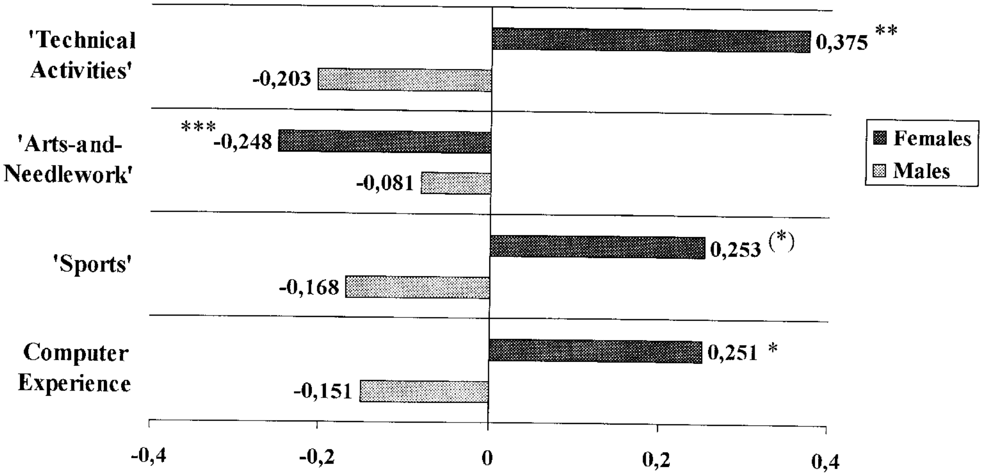

Figure 5. Correlations between MRT and specific experiences

females' attitudes towards maths and physics and test performance was observed for the mental-cutting test 'Schnitte' (r = .503, p = .003, N = 54).

Maths and technical things as male domains. Perceiving mathematics and technical things as gender-stereotyped, however, had no significant effect on MRT performance. But there was a weak tendency in that direction, females estimating maths and technical things as less gender-stereotyped had better MRT results. With males this aspect was not relevant for MRT performance.

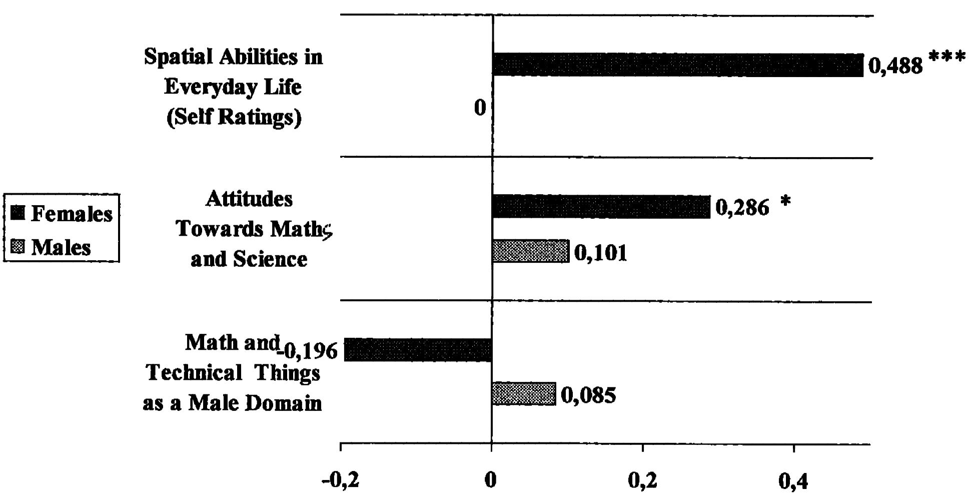

Figure 6. Correlations between MRT and achievement-related attitudes

Differential role of experience and attitude variables

In order to check the relative impact of variables that were related to MRT performance in univariate analyses, step-wise multiple regression analyses were computed separately for gender. In these analyses, MRT performance was the dependent variable, and academic subgroup, spatial activities, self-ratings of everyday spatial abilities, attitudes towards maths and physics were possible predictors. Self-ratings of everyday spatial abilities were revealed to be the best predictor and accounted for 29.2%of the variance. Another significant predictor was the experience with technical activities, which accounted for an additional 23.4% of the variance. For the male subgroup the combination of variables chosen did not fit a regression model.

Discussion

With regard to the three general questions this study was supposed to answer, 1) how students of different academic programmes differ in their spatial abilities, 2) how they differ in certain experiential and attitudinal variables, and 3) which experiential and attitudinal variables are related to spatial abilities, it has produced some interesting findings.

Looking at the different academic subgroups involved in the study (arts, humanities, and social sciences, psychology, sports, computational visualistics), differences in spatial abilities, i.e., mental-rotation ability could not be observed. This is not consistent with other studies considering abilities in general, and spatial abilities in particular to be central for academic major choice. Their self-rating of spatial-abilities-in-everyday-life, however, revealed significant subgroup differences with computational visualistics students rating their abilities higher than students following other academic programmes. So it seems to be the achievement-related self-concept that is related to career decisions.

Actual experiences, i.e., spatial activities and computer experience, and attitudinal variables, i.e., attitudes towards mathematics and physics, were revealed to be of further importance for academic programme choice. Significant academic subgroup differences were observed for almost all the variables studied here. Again, the computational visualistics students were the ones who, of course, excelled in computer experience and in their experience with technical activities. But it was also they who, besides their higher self-ratings of everyday spatial abilities, had the most positive attitudes towards maths and physics. A still open question, however, is, whether students chose the academic programme because of their attitudes and their experiences, or whether these attitudes are due to the academic programme they have chosen.

In contrast to that, gender differences were found for spatial abilities as well as for experiential and attitudinal factors. With regard to mental-rotation ability the well established differences favouring males (Harris, 1981; Linn & Peterson, 1985; McGee, 1979; Voyer *et al.*, 1995) could be observed. But the effect size of these mean differences was subgroup dependent: it was highest with arts, humanities and social sciences students, and lowest with computational visualistics students. Consequently, significant gender-by-subgroup interactions could be observed. Both facts taken together show that beside the subject's sex, as a biological variable, other variables seem to have considerable impact on spatial test performance. The unexpected results concerning variability in the MRT – which was higher with females than with males in all subgroups and in the whole sample – are in line with this and are incompatible with an often used argument claiming a biological origin of gender differences in spatial abilities, the supposed higher variability of males.

Self-ratings of spatial abilities in everyday life also revealed significant gender differences favouring males. The Spatial-Abilities-in-Everyday-Life-Scale proved to be a good self-rating scale for studying spatial abilities: scale means were sufficiently correlated with MRT performance, but only with females. In contrast to other studies, having found that girls are less able to estimate their own abilities in the mathematical and scientific area (Hannover, 1991), the achievement-related self-concept for spatial abilities obviously influences MRT performance, especially with females.

In addition, there were mean differences between males and females in experiential variables: males and females differed in their experiences with technical and arts-and-needlework activities, but they had similar computer experience. There were no principal gender differences in attitudes towards maths and physics or towards maths and technical things as male domains.

On the other hand, spatial abilities or rather spatial test performance, proved to be closely related to specific experiences and to one's achievement-related self-concept. Seeing that the amount of technical spatial activities was related to MRT results, this finding is not at all surprising. For a long time already, it has been assumed to be crucial for technical and mathematical studies and occupations (Smith, 1964), and earlier studies have already found a statistically significant but weak relationship between spatial activities experience and spatial test results (e.g., Baenninger & Newcombe, 1989). But the experience with specific activities in general is not as closely related to achievement. One can, for example, play tennis again and again, and never win a championship. On the other hand, if a person is good at something, he or she will probably keep doing it. Thus, these correlations rather reflect a close interdependence of certain variables instead of allowing causal explanations. A more striking finding in this context, however, is that spatial activities, i.e., technical activities, seem to improve only females' spatial abilities.

Although no gender differences were found in these variables, attitudinal factors as well as the experience with technical and arts-and-needlework activities were revealed to be related to females' mental rotation ability. A similar differential effect for males and females was found with regard to computer experience. Although male and female students had comparable computer experience, a higher measure of such experience led to better spatial test performance only with females.

In addition, there were significant correlations between the self-ratings of spatial abilities in everyday life and experiences with spatial activities. This means that practice and experience had an impact on the achievement-related self-concept. The more experience females had with any spatial activity (technical things, arts-and-needlework, sports), the higher did they estimate their spatial abilities in everyday life, which, in turn, improved actual MRT performance.

Although the study did not focus on the 'causes' of gender differences in spatial abilities, it investigated whether factors like spatial activities, achievement-related attitudes and the choice of academic courses or majors mediate or increase them. In this context it has produced a number of interesting findings. First, females had definitely less experience with activities crucial for the development of spatial skills (i.e., with technical activities). Second, experiences were related to MRT performance only with females. Third, females rated their spatial abilities in everyday life lower than males in all academic subgroups, although this did not correspond with their actual MRT performance. Fourth, females' spatial test performance was closely related to attitudinal factors, especially to the achievement-related self-concept with regard to spatial abilities in everyday life. Fifth, more computer experience of females resulted in better spatial test performance. And sixth, although boys surpassed girls in MRT performance, no significant gender difference was observed with students of computational visualistics, which can be regarded as a particularly selected subgroup.

All these observations are consistent with gender schema theories (Bem, 1981; Martin & Halverson, 1981) and social cognitive theories of gender development (Bandura, 1986; Bussey & Bandura, 1999). Thus, these results can be interpreted as reflecting the influence of socio-culturally shaped gender role stereotypes regarding mathematics, technical skills and tasks measuring spatial abilities as male domains. Similarly, they support the assumption (Horner, 1972; Nash, 1979) that spatial test performance is influenced by whether a person regards a task (e.g., mathematics, technical things) as corresponding to his or her gender role. Results show that attitudes, especially achievement-related attitudes, have an impact on test performance. These attitudes proved to be the best predictor of test performance: female participants with good test results had better achievement-related attitudes than females with worse test results. And this was true even for high performance subgroups. With computational-visualistic majors, females' performance was affected by their achievement-related attitudes, while the zero correlations within the males' subgroup indicate that males' test performance is not influenced by their achievement-related self-concept.

Thus, although we cannot make causal explanations grounded on correlational data, these results help to answer a question that matters from an educational-psychological point of view. How can girls' deficits in spatial abilities that lead to females' under-representation in certain professions and academic areas be overcome? As our results show, females' achievement-related attitudes seem to be a good frame of reference here. In addition, specific experiences like playing with technical toys, practising technical hobbies and using and getting used to computers seem to be good means to improve spatial abilities.

Our results have several implications for intervention programmes. Besides increasing girls' experiences in spatial ability relevant areas, females should be supported in their actual skills and encouraged in their view of the importance of these skills. This is in line with the bent-twig model explaining gender differences in spatial abilities as an interaction of biological and environmental factors (Casey, 1996). According to this approach, some individuals or groups of individuals (e.g., girls) profit more from certain environmental influences like education and training programmes than others do. So, it is still important, of course, that from early childhood on girls should be encouraged by parents and teachers to improve their technical skills, for example, by doing technical things, like repairing a bike, as well as by choosing mathematical and technical subjects at school. This could help girls to modify their achievement-related self-concept with regard to technical abilities through enactive experience (Bussey & Bandura, 1999). Moreover, there could be special intervention programmes for females giving them the opportunity to close their experience gap. This could be done, for instance, by offering computer courses for girls, which take into account females' specific experiences as well as their interests.

Another focus of intervention should be females' achievement-related attitudes themselves, which develop in the course of their lives in a complex interaction between aptitude factors, gender role orientations, and the experience of social sanctions or social rewards for a specific behaviour. Achievement-related attitudes based on gender role stereotypes, however, are difficult to change. And only to a small degree is it the individual person himself or herself that is the motor of development and change, because the social environment (parents, teachers, peers) plays the main role here. With regard to Eccles's model explaining how gender role stereotypes influence academic course choice (Eccles, 1994), however, it can be assumed that successful experience with certain leisure time activities, i.e., technical activities, can motivate girls to choose an academic subject like computational visualistics. And according to social-cognitive approaches (Bandura, 1986; Bussey & Bandura, 1999) a reciprocal relationship between spatial activity experience, achievement-related gender-role attitudes and choice of academic subjects can be assumed. By changing one of the constituents the whole system will change.

A future purpose of research in educational psychology could be to create and evaluate intervention and training programmes considering gender differences in spatial abilities from a more differential perspective and thus taking into account the particular experiences and attitudes of males and females. Another concern of future studies will be to determine in which way computer activities are related to spatial abilities, and thus can improve them.

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