



Sports and mathematical abilities in primary school-aged children: How important are spatial abilities? An explorative study

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Abstract

It is well known that sports and mathematical abilities are related to spatial abilities, also a relation between sport and mathematical abilities is assumed. However, the relation between all three aspects has not been investigated until now. Therefore, the main goal of the study is to examine the relationship between sport, spatial and mathematical ability in elementary school aged children. 50 boys and 42 girls from third grade solved spatial and sport tasks, which can be differentiated into the following: intrinsic-dynamic, intrinsic-static and extrinsic-static. Furthermore, their performances in mathematical (separated into numerical/arithmetical and geometrical) abilities were analyzed. The results showed significant correlations between the static spatial and sporting activities. This correlation is due to the strong correlation within the group of girls. Furthermore, a good performance in the intrinsic-spatial ability was related to a high geometrical ability of the children, especially in boys. However, the geometrical ability could not be predicted by sport abilities.

Keywords Primary school-aged children · Intrinsic and extrinsic spatial abilities · Sport performance · Numerical knowledge · Geometrical abilities

Introduction

There is often anecdotal evidence that children who are good at mathematics are also good at sports, however there are only a few studies investigating this relationship (Beck et al., 2016). Furthermore, it is well known that mathematical as well as sports abilities are related to spatial abilities at least in adults (e.g. Voyer & Jansen, 2017). Therefore, the main goal of this study is to investigate the relation between sports, mathematical and spatial abilities in primary school-aged children. Until now the relations between all three aspects have not been investigated. Before presenting the possible relationships, the main aspects of spatial, mathematical and sports abilities will be discussed.

Main Aspects of Spatial, Mathematical and Sports Abilities

Spatial abilities can roughly be differentiated between three factors: spatial orientation (perception of the position of various objects in space), mental rotation (imagining the rotation of objects) and spatial visualization (perception of complex spatial patterns) (Mix & Cheng, 2012). A new theoretically motivated typology of spatial abilities was presented by Uttal et al. (2013) who analyzed the spatial training literature: They differentiate between an intrinsic versus extrinsic and a dynamic versus static dimension. Intrinsic is related to the specification of the parts of an object and the relation between different parts of the object. Extrinsic refers to the relation of an object within a group of objects. The second dimension relates to static or dynamic tasks, where the object either stays stable or might be moved. According to this, the following four abilities can be identified: intrinsic-static, intrinsic-dynamic, extrinsic-static and extrinsic-dynamic. The intrinsic-static ability can be described as the ability to perceive, for example, an object amid distracting background information (test example: embedded figure test). An intrinsic dynamic ability requires, for example, the piecing together of objects or the mental transformation of them (possible test: paper folding and mental rotation). Spatial perception, which means the understanding of

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abstract spatial principles such as horizontal invariance (possible test: water level task) is classified as extrinsic-static. Finally, perspective is an extrinsic-dynamic ability, Piaget's three mountains task serves as an example (see also Newcombe & Shipley, 2015).

Regarding the investigation of mathematical abilities, Mix et al. (2016) described the long history of investigating different mathematical abilities, from early distinction between conceptual and procedural factors, or standards of mathematical topics, such as the number concepts, operations/algebra, measurement, fractions, ratios and geometry. These fundamental tasks can be subdivided further: Campbell (2004) has differentiated between numerical ability, which included number representation and number comparison, and mathematical problem-solving abilities (e.g. abstract representations of mathematical relations from context problems). Gaber and Schlimm (2015) identified numerical and geometric abilities as basic mathematical abilities. Currently, Xie, Zhang, Chen, and Xin (2019) summarized four mathematical abilities: numerical ability (counting, number sense), arithmetical ability (fraction, algebra, calculus), geometric ability (geometry) and logical reasoning (word problem solving, mathematical reasoning).

With regard to the classification of sports abilities, a prominent taxonomy is that between "open skills" (permanent adaptation of movement to a dynamic environment) and "closed skills" (movement in a relatively stable environment), which was extended to a multidimensional classification scheme of sport skills depending on the degree of variability of movement exercise and environment (Gentile, 2000). Other taxonomies distinguished between movement patterns with mainly energetic (cardiovascular or muscular) processes or movement patterns that are controlled and regulated by the central nervous system. Concerning the complexity of the movement pattern, discrete, continuous and serial types of sport regarding the specific structure of movement were described (Sewell, Griffin, & Watkins, 2005).

However, Pietsch (2018) provided a visual-spatial taxonomy of types of sport in accordance with the taxonomy provided by Uttal et al. (2013) for visual-spatial abilities. The intrinsic-static motor or sport ability¹ allows athletes to keep their body or the sports equipment in a steady balanced state – examples are sports with cyclical movements (e.g. running). With the help of intrinsic-dynamic sport abilities, the balance during body rotations around one or more body axes can be achieved and athletes are able to perform coordinated interactions of the body's limbs during complex non-cyclical movements (like jumping). Extrinsic-static sport abilities allow the recognition of the position of the athletes' own bodies, or the differential positioning of different parts of the body compared to the

sports equipment (e.g. the position of the ball relative to the position of the shoulders or the twisted upper body in the throwing position). With extrinsic-dynamic sport abilities, the athlete is able to perceive the relationship between objects (opponents, team members) and his or her own body, if the athlete or the objects (or both) are in motion.

Because it is not possible to classify most sports to only one category, basic forms of movement (running, jumping, throwing) were chosen in this study. Running, where athletes have to keep their body in a steady balanced state is graded as an intrinsic-static sport ability. The top speed depends on inter- and intramuscular coordination, nervous conduction speed, fine motor skills, attention and especially on movement execution that has to be as accurate as possible (Li, Van den Bogert, Caldwell, Van Emmerik, & Hamill, 1999). Most important for an excellent long-jump performance (except jumping ability) is to convert horizontal velocity into vertical velocity by way of a perfectly timed takeoff and the coordinated interaction of arms and swinging leg, to support the takeoff and prepare the landing (Jaitner, Mendoza, & Schöllhorn, 2001). Additionally, during the takeoff and flight phase, the athlete has to control his or her body position (Seyfarth, Friedrichs, Wank, & Blickhan, 1999). Therefore, long jump is rated as mainly intrinsic-dynamic. Important for throwing performance with an 80 g ball, a mainly extrinsic-static sport ability, is a correct throwing position with a differential positioning of legs, upper body and the throwing arm for an ideal utilization of biomechanical principles, e.g. an optimal acceleration distance or a chronological coordination of single pulses (Bartlett & Robins, 2008).

The Relation between Sports and Mathematical Abilities

The effect of sports or motor activity on mathematical achievement has already been investigated. Beck et al. (2016) examined the effect of motor-enriched mathematical teaching in Danish pre-adolescent children with a mean age of 7.5 years. One group (gross motor maths group, GMM) received mathematical teaching with gross motor activity (skipping, crawling, throwing, etc.), one group (fine motor maths group, FMM) with fine motor activity (playing with LEGO bricks) and a control group without any activity over six weeks. Children had to complete a maths test with 50 tasks before (T0) and immediately after the programme (T1) and 8 weeks after the intervention (T2). Whereas all groups improved their maths performance from T0 to T1, the improvement was higher in the gross motor group compared to the fine motor group. However, only the normal maths performers benefitted from GMM not the low maths performers. Visual-spatial short-term memory accounted for approximately 35% of the intervention on maths performance. This result was in

¹ In this taxonomy the use of sport ability and motor abilities is exchangeable.

line with a study of Hraste, De Giorgio, Jelaska, Padulo, and Granić (2018) demonstrating better mathematical learning when the maths teaching was accompanied by motor activity compared to a control group who learned through traditional teaching.

The Relation between Spatial and Mathematical Abilities

The investigation of the relation between spatial and mathematical abilities (see for example Rutherford, Karamarkovich, & Lee, 2018) is important because, among other factors, spatial abilities predict performance in STEM (Mix & Cheng, 2012). One explanation for the relation is the use of overlapping brain regions for some parts of mathematical and spatial manipulations (Hubbard, Piazza, Pinel, & Dehaene, 2005). Mix et al. (2016) conducted a large cross-sectional study with 845 children from kindergarten, third and sixth grades between five and 13 years. They chose a range of tasks that represented the various classes of spatial abilities (mental rotation, visual spatial working memory, block design, map reading, perspective taking) and of mathematical abilities (word problems, calculation, place value, missing term problems and algebra, number line estimations and fractions). Additionally, the performances of the 6th graders in two subtests from the Comprehensive Mathematical Ability Test (CMAT), charts and graphs and geometry were recorded. In third grade, which is the relevant age group for the study presented here, mental rotation (MR), visuo-spatial working memory (VSWM), visuo-motor integration (VMI) and perspective taking (PT) had a significant effect for mathematical ability. MR and VSWM predicted the performance on both new and familiar mathematics contents, whereas VMI and PT were predictive for familiar content only. Mix et al. (2016) concluded that there is a great amount of overlapping variance in these two domains. Reasons for this might be either general ability or basic shared processing. The spatial factor, which overlapped most with mathematics, was spatial visualization, but also spatial tasks with a high VSWM and VMI had relatively strong relations to mathematics in third grade.

Recently, Xie et al. (2019) demonstrated in a meta-analysis with respect to the four spatial categories intrinsic-static, intrinsic-dynamic, extrinsic-static and extrinsic-dynamic and the category of visual spatial memory that only the category of extrinsic-dynamic was not significantly associated with mathematical ability. Each of the other four categories was associated with mathematical ability to a comparable extent. There was no moderating effect for the age or the developmental status of the participants in the studies. The authors assumed that the relationship between spatial and mathematical ability was moderated by the complexity of spatial tasks.

The Relation between Spatial and Sports Abilities

In studies with athletes, it has been demonstrated that sports students performed better in spatial tasks than physically inactive people (Pietsch & Jansen, 2012). More precisely, Voyer and Jansen (2017) investigated the motor expert effect in spatial abilities while comparing, in a meta-analysis, the spatial abilities of motor experts and non-experts in such activities. They analyzed a final set of 62 effect sizes and their results showed an overall advantage in spatial tasks in favour of motor experts. There were several moderator variables and the largest effect size was shown for participants in combat sports. Medium size effects were found for gymnasts/dancers and musicians. Regarding the test categories, the largest effect sizes could be seen with spatial perception in comparison to mental rotation and spatial visualization tasks. Especially measurements of spatial perception and spatial visualization produced reliable effect sizes. However, there are some training studies with children demonstrating that motor coordination training can improve especially mental rotation performance (Blüchel, Lehmann, Kellner, & Jansen, 2013; Pietsch, Böttcher, & Jansen, 2017).

Goals and Hypotheses

The main goal of the paper is to investigate the relation between sports, spatial and mathematical performance in a field study. Because external validity was important in this study, we decided to use the performance tests for sport and mathematical ability that are used in the school context. The following hypotheses were analyzed:

1. According to the meta-analysis of Voyer and Jansen (2017), we hypothesize a relation between spatial and sport ability. According to the taxonomy of Pietsch (2018), the following variables should correlate: a) sprinting as an intrinsic-static motor ability with the intrinsic-static spatial ability measured with the visual figure test, b) throwing as an extrinsic-static motor ability with the extrinsic-static spatial ability measured with the water level test and c) jumping as an intrinsic-dynamic motor ability with the intrinsic-dynamic spatial ability measured with a mental rotation test.
2. According to the review of Xie et al. (2019), we assume a correlation between the three spatial domains of intrinsic-static, intrinsic-dynamic and extrinsic-static especially with the mathematical ability that is related to geometry.
3. We would like to investigate, if mathematical ability can be predicted by spatial and motor ability. Furthermore, gender was considered as a possible influencing factor regarding motor abilities because, in children between five and 11 years, girls were better than boys in balancing backward, in the stand-and-reach test and jumping

sideways. Boys were faster than girls in running (Roth, Schmidt, Seidel, Woll, & Bös, 2018).

4. Also, gender differences in spatial abilities, especially in mental rotation, should be investigated. Former studies show no gender differences favouring boys in second grade, but they are observed in fourth graders (Neuburger, Jansen, Heil, & Quaiser-Pohl, 2011).

Methods

Participants

50 boys and 42 girls from third grade (mean age boys: 9.08, $SD = .60$; girls: 8.98, $SD = .60$) of one elementary school in Bavaria, Germany participated. Because hypothesis 2 requires three correlations, p was set to .017. The required sample size was estimated using the software G*power (Faul, Erdfelder, Lang, & Buchner, 2007). To ensure a sufficient sample size, a moderate effect correlation (one-tailed) of $r = .3$, a power of .8 and an alpha value of .017, a sample size of 91 children was estimated for this study. All children and their parents gave their written consent for participation. The experiment was conducted according to the ethical guidelines of the Helsinki Declaration. Ethical approval for this study was not required because research that carries no additional risk beyond daily activities does not require Research Ethics Board Approval. We communicated all considerations necessary to assess the question of the ethical legitimacy of the study.

Apparatus and Stimuli

To emphasize external validity, we decided to use the performance tests for sports and mathematical ability that are used in Germany for primary school-aged children.

Mathematical tests (Institut zur Qualitätsentwicklung im Bildungswesen, 2018). The mathematical tests (see Fig. 1) were part of the standardized German school-performance test for grade 3 for the school subjects Mathematics and German (VERA). VERA is an abbreviation for “VERgleichsArbeiten”, comparison studies for different classes in different schools. The VERA tasks require a Germany-wide standard of education with a medium sized degree of abstraction concerning the anticipated performance. The demanded standard of education contains a general content-related component (according to the traditional curriculum), a procedural-formal component (general specialized competence), and a more cognitive component (e.g. application, transfer). They are focused on the core area of the subject and aim for cumulative, networked learning and mainly process-related not only content-related competences (Lankes, Rieger, & Pook, 2015).

Every pupil has to complete this test in the third grade. The mathematical test consisted of 32 tasks, split into two parts. Thereby, general as well as content-related mathematical competences are tested. General mathematic competences comprise specialized abilities, that are important for all content areas of mathematics, e.g. technical basic skills or problem solving. The different tasks could be divided into the following mathematical aspects: a) collecting, structuring, presenting; b) tables and graphs, c) probability, d) estimating odds, e) combinatorial analysis, f) area and mathematical body g) volume and range, and h) spatial imagery. According to the test instruction, collecting, structuring, presenting (a), probability (c), estimating odds (d) and combinatorial analyses (e) were summarized in the variable math 1 (data, frequency and probability), while tables and graphs (b), area and mathematical body (f), volume and range (g) and spatial imagery (h) were combined in the variable math 2 (space and form). The test had to be completed in 40 min (20 min for each of the two parts).

Spatial tests. According to the classification of Uttal et al. (2013), extrinsic-static (water level test), intrinsic-dynamic (mental rotation test) and intrinsic-static (visual figure test) spatial abilities tests were applied. Extrinsic-dynamic tests were not applied due to the lack of relationship between extrinsic-dynamic and mathematical abilities (Xie et al., 2019). One example of each test item is given in Fig. 2.

Mental rotation (Neuburger et al., 2011). The mental rotation test with pictures of drawn animals consisted of two practice and 16 non-practice tasks. Each task consisted of one standard drawing on the left side and four items on the right side. The children had to cross out those two pictures from the right side that are a non-mirror version of the standard item. To solve this task, children were asked to cross out those two pictures of the animals that look in the same direction as the standard animal. Children were asked to solve the task as quickly and accurately as possible. The time limit was two minutes for the 16 tasks. One point was awarded if both pictures of animals were marked correctly. Before the test began, the tasks were explained with the help of two identical stuffed animals. The time limit was chosen in accordance with the original instructions.

Water level (Piaget & Inhelder, 1956). In this test, children were first shown a transparent and closed upright container that is half-full of water. Using this example, the children were instructed to draw the water surface in each of the following containers. Then, 16 containers on four different sheets were presented. The first eight containers were identical to the test container but tilted in different positions. The other eight tasks contained various vessels, also presented in tilted positions. There was no time limit for this task.

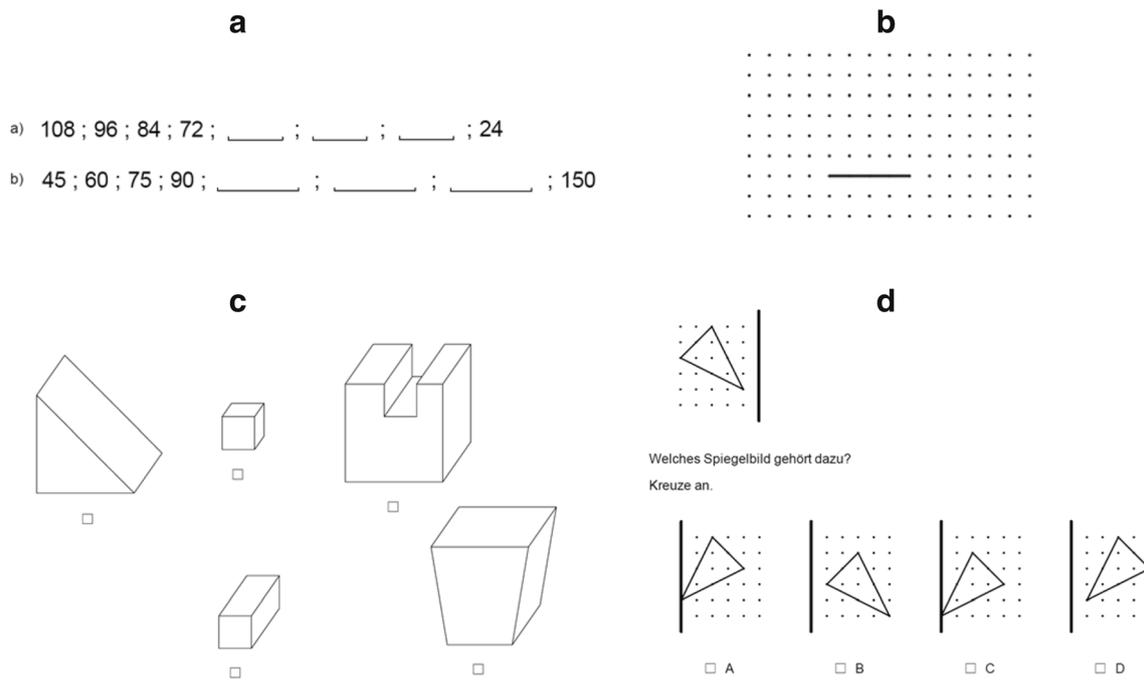


Fig. 1 Examples of the VERA math test: **(a)** Complete the row; **(b)** Complement to a rectangle; **(c)** Which two of these pieces can be composed to a cube?; **(d)** Which mirror image is the right one? (Projekt VERA, 2008)

Visual figure (TVPS-R, Gardner, Brown, Rodger, Davis, & Klein (1996)). In the Test of Visual-Perceptual Skills (non-motor) Revised, Subtest Visual Figure Ground, the children were shown one single figure at the top of the page. Beneath this single figure, four complex comparison figures were shown. Children were told that they could find the single figure in only one of the four larger figures. It was their task to mark the correct figure out of the four figures given. The test was explained to the children using the exercise on page

one. Children could take up to ten minutes to complete the whole test.

Motor tests. For the motor test the basic sporting abilities of throwing, jumping and sprinting were examined. For sprinting, the time of a 50 m race was recorded. For the measurement of throwing, a ball (80 g) was thrown three times from a short run-up, for jumping, three long jump attempts were allowed. For both measurements, the best of the three attempts was recorded. All results were measured during a

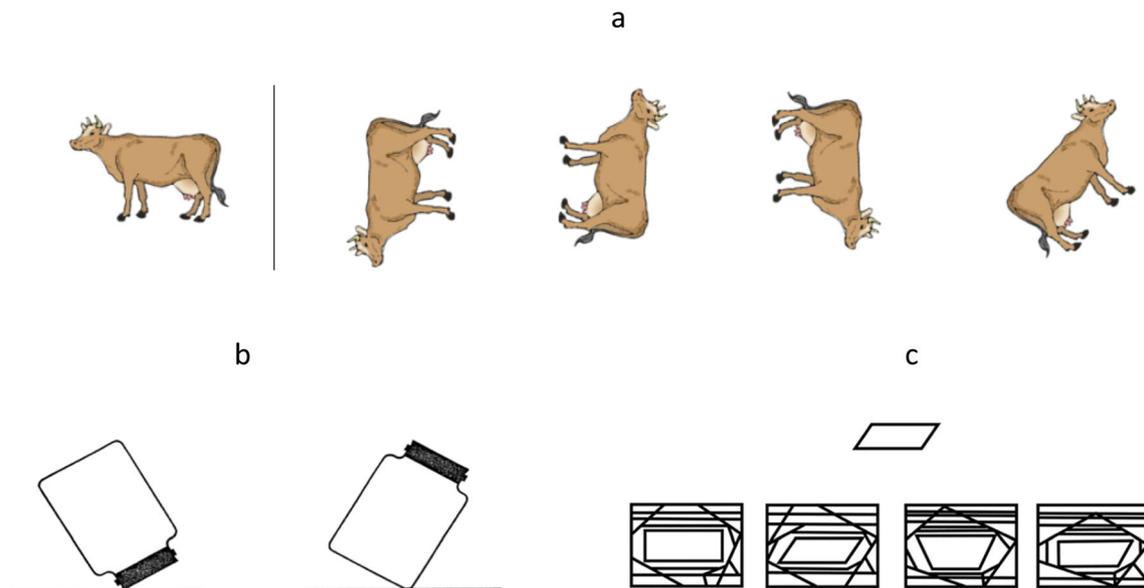


Fig. 2 Examples of the spatial tests used: **(a)** mental rotation (Neuburger et al., 2011); **(b)** water level test (based on Piaget & Inhelder, 1956); **(c)** visual figure test (based on Gardner et al., 1996)

school competition by experienced physical education teachers, who were trained in these tasks.

Demographics questionnaires. The children completed a questionnaire regarding their age, gender, sporting activity per week in hours and their last grades in sports education and mathematics.

Procedure and Research Design

Each of the three test groups was conducted on three different days between June and July 2019 in the following order: maths, sports and spatial tests. The maths and spatial test were conducted as a group test with the children of one class (around 23 children in each class). A correlation research design was used.

Statistical Analysis

According to our hypotheses, a correlational analysis between sprinting and intrinsic-static spatial ability (visual figure test), throwing and extrinsic-spatial ability (water level test) and jumping and intrinsic-dynamic spatial ability (mental rotation) was conducted. Furthermore, the spatial abilities were correlated to the math 1 and math 2 variables. Because three correlations were conducted with each of the two math variables, the significance level was Bonferroni corrected, and p was set to .017. The significant correlations were also presented for boys and girls separately. In addition, possible sex differences were calculated with univariate analyses of variance for the relevant motor, spatial and mathematical variables with sex as a between subject factor. Lastly, a regression of the mathematical ability of working with space and form with the predictors of the intrinsic-spatial and the sprinting ability was conducted.

Results

Table 1 describes the mean and standard deviations of all measurements for boys and girls separately.

With regard to our first hypotheses, we found a significant negative correlation between sprinting and the performance in the visual figure test ($r = -.248, p = .017$). The faster the children were able to run the more items were solved by them. Analyzing this correlation separately for boys and girls, the correlation remained significant for girls ($r = -.377, p = .014$) but not for boys ($r = -.125, p = .386$).

Furthermore, there was a significant positive correlation between throwing and the performance in the water level task ($r = .372, p < .001$). The more items they solved, the further they threw the ball. Again, this correlation was significant only for girls ($r = .423, p = .005$), but not for boys ($r = .277, p = .054$). Our data did not show a significant correlation

Table 1 Means and standard deviations of sports abilities, spatial abilities and mathematical abilities

task	boys	girls	significance-level, p
sprint (sec.)	9.30 (.69)	9.29 (.76)	.959
long-jump (metres)	2.89 (.37)	2.74 (.40)	.069
throwing (metres)	18.38 (6.00)	14.51 (4.44)	.001
mental rotation	8.02 (5.72)	7.93 (5.53)	.938
visual figure	13.88 (1.69)	14.17 (1.75)	.427
water level	5.7 (5.68)	3.40 (4.18)	.033
math: numbers	10.52 (2.86)	11.00 (2.40)	.391
math: geometry	11.92 (3.39)	11.95 (2.98)	.962

between jumping and the mental rotation performance ($r = .046, p = .665$).

From the correlations between the spatial and the mathematical variables (data, frequency and probability and space and form), only the correlation between the mathematical ability of working with space and form and the performance in the visual figure test reached significance ($r = .265, p = .011$). A good performance in the intrinsic-spatial ability was related to a high geometrical ability of the children. This relation was significant for boys ($r = .305, p = .031$) but not for girls ($r = .217, p = .168$).

Regarding sex differences, only two significant effects could be detected: first, boys ($M = 5.7, SD = 5.68$) showed a better performance than girls ($M = 3.4, SD = 4.18$) in the water level task, $F(1, 90) = 4.704, p = .033$, partial $\eta^2 = .05$. Second, the performance of the boys ($M = 18.38$ m, $SD = 5.99$) in the throwing task was better than that of the girls ($M = 14.51$ m, $SD = 4.44$), $F(1, 90) = 11.95, p = .001$, partial $\eta^2 = .117$.

Due to the fact that sprinting relates to the visual figure test, the question arises if the mathematical ability of working with space and form can be predicted by the intrinsic-spatial ability and the sprinting ability. The multiple regression indicated that 7% of the variance ($R = .265, R^2 = .070$) is explained by the predictor intrinsic spatial ability ($\beta = .264, p = .014$).

Discussion

Regarding the first hypothesis, our data revealed that sprinting correlates to the intrinsic-static ability that was measured with the visual figure test and throwing to the extrinsic-static ability, measured with the water level test. Interestingly, the correlations were significant for girls but not for boys. However, there was no correlation as assumed between jumping and the mental rotation performance. In relation to our second hypothesis, the correlation between the mathematical ability of working with space and form and performance in the intrinsic spatial test

reached significance. This correlation was significant for boys but not for girls. However, the mathematical relation could not be predicted by the sprinting ability of the children.

Relation between Sports and Spatial Abilities

Our results show a relation between running and the visual figure test: running as an intrinsic-static ability allows athletes and children to keep their body in a steady balanced state. During a 50 m run, children have to control their posturokinetic activities to retain an unperturbed natural balance. This relates to the affordance of the visual figure test, where spatial configurations have to be perceived with distracting background information. According to Uttal et al. (2013), this intrinsic-static ability relates to the classification of Carroll (1993) who describes the visual spatial perceptual speed in more detail. Here the speed component is important and for this it seems plausible that the sprinting ability is related.

Due to motor learning related to the horizontal and vertical orientation, it is quite feasible that throwing performance is related to the performance in the water level test, which is a test for understanding abstract spatial principles such as horizontal invariance or verticality (Uttal et al., 2013). Interestingly the correlations hold true for girls but not for boys. Because girls show a worse performance than boys in both the throwing and the water level task, one might assume that girls especially might profit from a specific motor training to improve at least their extrinsic static spatial skill.

However, contrary to the third part of our first hypotheses, we found no correlation between intrinsic-dynamic visual spatial-ability (mental rotation) and the respective sporting performance (long jump) according to the taxonomy of Pietsch (2018). One reason for this result might be that the technical abilities of long jumping are not highly developed in primary school-aged children (Panteli, Theodorou, Pilianidis, & Smirniotou, 2014). At this point, they might not be able to shift their body's centre of gravity during takeoff or the position of their upper body during the landing but remain in an upright position during the whole jump (Bridgett & Linthorne, 2005). For this, the assumed relation might be detectable in adolescents who have received track- and field training for a considerable time. In contrast, the relation between sprinting and intrinsic-static spatial abilities and throwing and extrinsic-static abilities is identifiable even in primary school-aged children. Children at the age of 12 years are supposed to already achieve the level of balance of an adult (Ying-Shuo, Chen-Chieh, & Yi-Ho, 2009), because a sensorimotor organization of locomotor balance and a concept of the position of one's own body is already developed in primary school-aged children independent of a specific sport technique. Also, our results did not demonstrate gender differences in mental rotation performance favouring boys, which is in line with a study of

Titze, Jansen, and Heil (2009). They found a large significant advantage of boys in an older group of fourth graders (mean age: 10.3 years) but not in a group of younger fourth graders (mean age: 9.3 years).

Relation between Spatial and Mathematical Abilities

Our results only demonstrated a correlation between the intrinsic-static spatial performance measured with the visual figure test and the mathematical ability related to geometry. This correlation holds true especially for boys. It contradicts our assumption according to the review of Xie et al. (2019) and formulated in hypothesis 2 that intrinsic-dynamic and extrinsic-static spatial abilities are also correlated with the part of mathematical ability related to geometry. However, the results are in line with the study of Mix et al. (2016) who showed that the factor of spatial visualization is the one that mostly overlapped with mathematics in third grade children. Uttal et al. (2013) considered spatial visualization defined by Linn and Petersen (1985) as an intrinsic-static spatial performance. Battista (1990) has already shown that spatial visualization predicts success in geometric reasoning. Furthermore, Gilligan, Hodgkiss, Thomas, and Farran (2019) suggested that at approximately 8 years there is a transition period regarding the relation of spatial skill and mathematical ability. In their study, mental rotation was a significant predictor for mathematics at 6 and 7 only.

One reason for the lack of other correlations might be the design of the German mathematical test. The second part of this test defined as the mathematical ability of forms and space consisted of the ability to work with tables and graphs, area and mathematical body, volume and range and the ability of spatial imagery. These tests were not included in the study of Mix et al. (2016) for kindergarten children and pupils in the third grade. Instead they investigate performance in word problems, calculation, missing term problems/algebra and number line estimation. These tests are also different from those used in the first part of the mathematical test. In this part, the abilities of collecting, structuring, presenting, understanding of probability, estimating odds and combinatorial analyses were investigated. Results are difficult to compare because tests of mathematical abilities seem to differ by country, even if American and German pupils are both educated in a Western country. Similar results were revealed by a visual spatial training study, in which elementary students' mathematics performance could be improved (Lowrie, Logan, & Ramful, 2017). In this study the MathT test from the Australian National Assessment Program, where six items covered geometry measurement concepts and non-geometry tasks, was used. Thus, this mathematical test, applied to Australian pupils who are also raised in a Western country, differs from the one in this study and the one in the study of Mix et al. (2016). This gives a hint that the concept of

mathematical ability should be regarded with caution due to the country in which the test was applied.

No prediction of mathematical ability by sports ability

Our results further failed to show a prediction of maths ability by sport ability. This is the first study, to the best of our knowledge to investigate the relation between these aspects. Furthermore, the variance, which is explained by the spatial ability, is very low. The question arises, of what is the relevant factor for the development of different aspects of mathematical ability. One possibility might be the general cognitive processing speed and working memory. Formoso et al. (2018) demonstrated that working memory and cognitive processing speed have a significant impact on maths cognition in an investigation with 4–6-year-old children. The role of working memory for specific mathematical exercises (arithmetic story problems and measurement skills) has also been proven for third grade pupils (Campos, Almeida, Ferreira, Martinez, & Ramalho, 2013). That working memory is a basic cognitive ability in young children has also been demonstrated with a study of pre-school children. Also motor ability and mental rotation were highly correlated, only working memory predicted the performance in a mental rotation task (Lehmann, Quaiser-Pohl, & Jansen, 2014). Thus, working memory ability should be considered in all further studies investigating the relation between motor, spatial and mathematical performance. This assumption fits well with the idea of Cheung, Sung, and Lourenco (2019) that spatial training may have benefitted symbolic arithmetic performance by (among others) increasing the capacity of the visuo-spatial working memory. Furthermore, Kahl, Grob, Segerer, and Möhring (2019) demonstrated that the effect of visual-spatial skills on mathematical achievement were stronger in adolescents than in children, whereas the effect of executive functions was linear and age-invariant.

Practical Implications

The results of the study give a hint that the relation between mathematical, spatial and sports ability has to be regarded with caution with respect to the specific tests which were applied to the boys and girls. The three aspects are not related per se, but only in specific aspects. This result should discourage teachers and parents from establishing general sport programmes to enhance mathematical abilities. Instead the mathematical ability of working with space might be trainable through intrinsic-spatial tasks. Within groups of girls, it might be useful to train spatial skills through the sports activity of sprinting and throwing. Enhancing the spatial abilities of girls is an important point due to the relation between spatial abilities and the preference for the so-called STEM (Science, Technology, Engineering, Mathematics) degrees and

professions, where girls and women are underrepresented (Moè, Jansen, & Pietsch, 2018). Interestingly, in both (sports and spatial) extrinsic-static domains, girls showed a worse performance compared to boys. To raise the performance of girls, the development of a gender typed training programme might be useful.

Limitations and Conclusions

To the best of our knowledge, this is the first study to investigate the relation between sports, spatial and mathematical ability. Even if the single relations are well known, the relations of all three aspects have not been considered until now. The results indicate that further studies integrating other concepts like working memory are necessary. Further, the socio-economic status of the parents of the participating children should be considered as well. The limitations of a rather specific age group (third grade) should be overcome, as well as the choice of long-jump as extrinsic-static motor ability. The technical demand of long-jump for primary school-aged children is very high, so that they are not able to complete the technical affordance of this task very easily. It might also be reasonable to investigate the relation between sports, spatial and mathematical performance along with the consideration of working memory in adults, where motor abilities are trained. Such studies could overcome the explorative, albeit interesting, nature of the study presented here.

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Availability of the Data The data can be retrieved from the first author by request.

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Compliance with Ethical Standards

Conflict of Interest none.

Ethical Approval and Consent to Participate All children and their parents gave their written consent for participation. The experiment was conducted according to the ethical guidelines of the Helsinki declaration. Ethical approval for this study was not required because research that carries no additional risk beyond daily activities does not require Research Ethics Board Approval. We communicated all considerations necessary to assess the question of ethical legitimacy of the study.

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References

- Bartlett, R., & Robins, M. (2008). *Biomechanics of throwing*. In: *Routledge handbook of biomechanics and human movement science*. (Hrsg. Y. Hong and R. Bartlett). 285-294. Abingdon: Routledge.
- Battista, M. T. (1990). Spatial visualization and gender differences in high school geometry. *Journal for Research in Mathematics Education*, 21(1), 47–60. <https://doi.org/10.2307/749456>.
- Beck, M. M., Lind, R. R., Geertsen, S. S., Ritz, C., Lundbye-Jensen, J., & Wienecke, J. (2016). Motor enriched learning activities can improve mathematical performance in preadolescent children. *Frontiers in Human Neuroscience*, 10, article 645. <https://doi.org/10.3389/fnhum.2016.00645>.
- Blüchel, M., Lehmann, J., Kellner, J., & Jansen, P. (2013). The improvement of mental rotation performance in school-aged children after a two weeks motor-training. *Educational Psychology*, 33, 75–86. <https://doi.org/10.1080/01443410.2012.707612>.
- Bridgett, L. A., & Linthorne, N. P. (2005). Changes in long jump take-off technique with increasing run-up speed. *Journal of Sports Sciences*, 24, 889–897. <https://doi.org/10.1080/02640410500298040>.
- Campbell, J. I. D. (Ed.). (2004). *Handbook of mathematical cognition*. New York, NY: Psychological Press.
- Campos, I. S., Almeida, L. S., Ferreira, A. I., Martinez, L. F., & Ramalho, G. (2013). Cognitive processes and math performance: A study with children at third grade of basic education. *European Journal of Psychology of Education*, 28, 421–436. <https://doi.org/10.1007/s10212-012-0121-x>.
- Carroll, J. B. (1993). *Human cognitive abilities. A survey of factor-analytic studies*. New York, NY: Cambridge University Press. <https://doi.org/10.1017/CBO9780511571312>.
- Cheung, C.-N., Sung, J. Y., & Lourenco, S. F. (2019). Does training mental rotation transfer to gains in mathematical competence? Assessment of an at-home visuospatial intervention. *Psychological Research*, 84, 2000–2017. <https://doi.org/10.1007/s00426-019-01202-5>.
- Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39, 175–191. <https://doi.org/10.3758/BF03193146>.
- Formoso, J., Injoque-Ricle, I., Barreyro, J.-P., Calero, A., Jacobovich, S., & Burin, D. (2018). Mathematical cognition, working memory and processing speed in children. *Cognition, Brain, Behavior*, 22, 59–86. <https://doi.org/10.24193/cbb.2018.22.05>.
- Gaber, D., & Schlimm, D. (2015). Basic mathematical cognition. *Wiley Interdisciplinary Cognitive Science*, 6, 355–369. <https://doi.org/10.1002/wcs.1351>.
- Gardner, M. F., Brown, G. T., Rodger, S., Davis, A., & Klein, S. (1996). TVPS, test of visual-perceptual skills (non-motor): Manual. Revised Edition. Hydesville: Psychological and Educational Publications.
- Gentile, A. M. (2000). Skill acquisition: Action, Movement, and neuromotor processes. In J. H. Carr, R. B. Shepherd, J. Gordon, A. M. Gentile, & J. M. Held (Eds.), *Movement science: Foundations for physical therapy in rehabilitation* (pp 111–180). Gaithersburg, MD: Aspen.
- Gilligan, K. A., Hodgkiss, A., Thomas, M. S. C., & Farran, E. K. (2019). The developmental relations between spatial cognition and mathematics in primary school children. *Developmental Science*, article e12786. <https://doi.org/10.1111/desc.12786>.
- Hraste, M., De Giorgio, A., Jelaska, P. M., Padulo, J., & Granić, I. (2018). When mathematics meets physical activity in the school-aged child: The effect of an integrated motor and cognitive approach to learning geometry. *PLoS One*, 13(8), e0196024. <https://doi.org/10.1371/journal.pone.0196024>.
- Hubbard, E. M., Piazza, M., Pinel, P., & Dehaene, S. (2005). Interactions between number and space in parietal cortex. *Nature Reviews Neuroscience*, 6, 435–448. <https://doi.org/10.1038/nrn1684>.
- Institut zur Qualitätsentwicklung im Bildungswesen. (2018). Vergleichsarbeiten 3. und 8. Jahrgangsstufe (VERA-3 und VERA-8). Didaktische Handreichung. Modul B. [Comparison tasks 3. and 8. grade (VERA-3 and VERA-8). Didactic handbook. Modul B.].
- Jaitner, T., Mendoza, L., & Schöllhorn, W. I. (2001). Analysis of the long jump technique in the transition from approach to takeoff based on time-continuous kinematic data. *European Journal of Sport Science*, 1, 1–12. <https://doi.org/10.1080/17461390100071506>.
- Kahl, T., Grob, A., Segerer, R., & Möhring, W. (2019). Executive functions and visual-spatial skills predict mathematical achievement: Asymmetrical associations across age. *Psychological Research Psychologische Forschung*. <https://doi.org/10.1007/s00426-019-01249-4>.
- Lankes, E.-M., Rieger, E., & Pook, M. (2015). *VERA-3 in Bayern. Ein Instrument für die Schul- und Unterrichtsentwicklung [VERA-3 in Bavaria. An instrument for school and lesson development]*. Amorbach: Volkhardt Caruna Medien GmbH & Co. KG.
- Lehmann, J., Quaiser-Pohl, C., & Jansen, P. (2014). Correlation of motor skill, mental rotation and working memory in 3- to 6 years old children. *European Journal of Developmental Psychology*, 4, 1–14. <https://doi.org/10.1080/17405629.2014.888995>.
- Li, L., Van den Bogert, E. C. H., Caldwell, G. E., Van Emmerik, R. E. A., & Hamill, J. (1999). Coordination patterns of walking and running at similar speed and stride frequency. *Human Movement Science*, 18, 67–85. [https://doi.org/10.1016/S0167-9457\(98\)00034-7](https://doi.org/10.1016/S0167-9457(98)00034-7).
- Linn, M. C., & Petersen, A. C. (1985). Emergence and characterisation of sex differences in spatial ability: A meta-analysis. *Child Development*, 56, 1479–1498. <https://doi.org/10.2307/1130467>.
- Lowrie, T., Logan, T., & Ramful, A. (2017). Visuospatial training improves elementary students' mathematics performance. *British Journal of Education Psychology*, 87, 170–186. <https://doi.org/10.1111/bjep.12142>.
- Mix, K. S., & Cheng, Y.-L. (2012). The relation between space and math: Developmental and educational implications. *Advances in Child Development Behavior*, 42, 197–243. <https://doi.org/10.1016/B978-0-12-394388-0.00006-X>.
- Mix, K. S., Levine, S. C., Cheng, Y.-L., Young, C., Hambrick, D. Z., Ping, R., & Konstantopoulos, S. (2016). Separate but correlated: The latent structure of space and mathematics across development. *Journal of Experimental Psychology: General*, 145(9), 1206–1227. <https://doi.org/10.1037/xge0000182>.
- Moè, A., Jansen, P., & Pietsch, S. (2018). Childhood preference for spatial toys. Gender differences and relationships with mental rotation in STEM and non-STEM students. *Learning and Individual Differences*, 68, 108–115. <https://doi.org/10.1016/j.lindif.2018.10.003>.
- Neuburger, S., Jansen, P., Heil, M., & Quaiser-Pohl, C. (2011). Gender differences in pre-adolescents' mental rotation performance: Do they depend on grade and stimuli? *Personality and Individual Differences*, 50, 1238–1242. <https://doi.org/10.1016/j.paid.2011.02.017>.
- Newcombe, N., & Shipley, T. F. (2015). Thinking about spatial thinking: New typology, new assessments. In N. J. S. Gero (Ed.), *Studying visual*

- and spatial reasoning for design creativity (pp. 179–192). Heidelberg: Springer. https://doi.org/10.1007/978-94-017-9297-4_10.
- Panteli, F. N., Theodorou, A., Pilianidis, T., & Smirniotou, A. (2014). Locomotor control in the long jump approach run in young novice athletes. *Journal of Sports Sciences*, 32, 149–156. <https://doi.org/10.1080/02640414.2013.810344>.
- Piaget, J., & Inhelder, B. (1956). *Child's conception of space: Selected works*. London: Routledge.
- Pietsch, S. (2018). The different point of view – As visual-spatial taxonomy of sports. *Journal of Athletic Enhancement*, 7, 3. <https://doi.org/10.4172/2324-9080.1000294>.
- Pietsch, S., & Jansen, P. (2012). Different mental rotation performance in students of music, sport and education science. *Learning and Individual Differences*, 22(1), 159–163. <https://doi.org/10.1016/j.lindif.2011.11.0127>.
- Pietsch, S., Böttcher, C., & Jansen, P. (2017). Cognitive motor coordination training improves mental rotation performance in primary school-aged children. *Mind, Brain, and Education*, 4, 176–180. <https://doi.org/10.1111/mbe.12154>.
- Projekt VERA (2008). *Vergleichsarbeiten in 3. Grundschulklassen. Mathematik (Aufgabenheft 1+2/2008) [Comparison test for third graders. Mathematics (Exercise book 1+2/2008)]*. Universität Koblenz-Landau.
- Roth, A., Schmidt, S. C. E., Seidel, I., Woll, A., & Bös, K. (2018). Tracking of physical fitness of primary school children in trier: A 4-Year longitudinal study. *BioMed Research International*, 1–10. <https://doi.org/10.1155/2018/7231818>.
- Rutherford, T., Karamarkovich, S. M., & Lee, D. S. (2018). Is the spatial/math connection unique? Associations between mental rotation and elementary mathematics and English achievement. *Learning and Individual Differences*, 62, 180–199. <https://doi.org/10.1016/j.lindif.2018.01.014>.
- Sewell, D., Griffin, M., & Watkins, P. (2005). *Sport and exercise science: An introduction*. London: Routledge.
- Seyfarth, A., Friedrichs, A., Wank, V., & Blickhan, R. (1999). Dynamics of the long jump. *Journal of Biomechanics*, 32, 1259–1267. [https://doi.org/10.1016/S0021-9290\(99\)00137-2](https://doi.org/10.1016/S0021-9290(99)00137-2).
- Titze, C., Jansen, P., & Heil, M. (2009). Mental rotation performance and the effect of fourth graders and adults. *European Journal of Developmental Psychology*, 7, 432–444. <https://doi.org/10.1080/1740560802548214>.
- Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin*, 139, 352–402. <https://doi.org/10.1037/a0028446>.
- Voyer, D., & Jansen, P. (2017). Motor expertise and performance in spatial tasks: A meta-analysis. *Human Movement Science*, 54, 110–124. <https://doi.org/10.1016/j.humov.2017.04.004>.
- Xie, F., Zhang, L., Chen, X., & Xin, Z. (2019). Is spatial ability related to mathematical ability: A meta-analysis. *Educational Psychology Review*. published ahead of print, 32, 113–155. <https://doi.org/10.1007/s10648-019-09496-y>.
- Ying-Shuo, H., Chen-Chieh, K., & Yi-Ho, J. (2009). Assessing the development of balance function in children using stabilometry. *International Journal of Pediatric Otorhinolaryngology*, 73, 737–740. <https://doi.org/10.1016/j.ijporl.2009.01.016>.

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