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MENTAL ROTATION IS SUPPORTED BY BLOCK PLAY IN BOYS AND GIRLS

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ABSTRACT

Mental rotation in adults can be supported by spatial activities and shows sex differences in favor of males. Yet, whether these results apply to young children and whether possible early sex differences in mental rotation might be alleviated through spatial play remains unclear. Thus, we investigated whether play with different levels of guidance (high guidance vs. medium guidance vs. low guidance) would affect girls' and boys' mental rotation in a sample of 183 German 5- and 6-year-olds. Any play form fostered children's mental rotation. However, girls profited less from high guidance than boys. Play can foster mental rotation, but different levels of guidance seem to have differential effects on girls and boys.

Introduction

An important goal of early childhood research is to investigate how children's educational environment can support their cognitive development. Spatial skills are an integral part of cognitive development and have received growing attention from the research community due to their later importance for success in science, technology, engineering, and mathematics (STEM; Borriello & Liben, 2018; Newcombe & Frick, 2010; Webb, Lubinski, & Benbow, 2007.) Uttal and colleagues have even referred to spatial skills as the gatekeepers to STEM, as students with high spatial skills have higher STEM attainment and are more likely to focus on a STEM career than students with low spatial skills (Uttal et al., 2013; Uttal & Cohen, 2012). Moreover, spatial skills might be especially important for novices because they facilitate STEM learning. Additionally, Uttal et al. (2013) concluded from their meta-analysis that spatial skills are malleable and are thus a viable target for intervention. Following these important results, Li, Sun, and Zhang (2021) called for the investigation of interventions to foster spatial skills in early childhood.

Spatial skills include, among others, mental rotation (Newcombe, Uttal, & Sauter, M., 2013), that is, the ability to imagine the rotational movement of an object or an array of objects (Frick, Möhring, & Newcombe, 2014). This ability allows an individual to recognize that two pictures depict the same object or figure rotated by different angles (Shepard & Metzler, 1971). Mental rotation emerges in children as young as 4 years (Newcombe et al., 2013), and fostering mental rotation early in life may be critical for future academic performance, due to its involvement in STEM (Uttal & Cohen, 2012; Yang, Liu, Chen, Xu, & Lin, 2020). Most studies have focused on the role of mental rotation in

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mathematics. Research shows that mental rotation is related to mathematical reasoning skills in primary school students (Geer, Quinn, & Ganley, 2019) and mathematics performance in kindergarten and third-grade students (Mix et al., 2017). Moreover, a study with undergraduate chemistry students suggests that mental rotation might play a role in recognizing molecular representations from different angles (Stieff et al., 2018). Given the importance of mental rotation for STEM, investigating ways to foster mental rotation at an early age is an important research goal. With this study, we aim to contribute to knowledge about mental rotation and playful approaches that can be used to support mental rotation in girls and boys in an experimental design with three points of measurement, employing a sample of 5- to 6-year-old preschool children. In addition, we explored how sex and cognitive variables are related to mental rotation.

MENTAL ROTATION

Along with perspective-taking, mental rotation belongs to the family of spatial skills (Newcombe et al., 2013; Newcombe & Frick, 2010). Spatial skills in general allow individuals to mentally transform spatial information (e.g., shapes, locations, paths, and the relationships between them) to navigate the environment and manipulate 2D and 3D objects (Newcombe et al., 2013; Newcombe & Frick, 2010; Newcombe & Shipley, 2015; Yang, Liu, et al., 2020). Mental rotation is often viewed as a primary indicator of spatial visualization and is critical for object manipulation because it allows individuals to plan, perform, and adjust relevant manual actions in their own minds, instead of performing erratic object manipulation directly and physically in the environment (Frick, Hansen, & Newcombe, 2013). Thus, children can apply mental rotation when building with blocks by rotating the blocks mentally and putting them in the correct place in their minds instead of having to manually experiment with how a certain block needs to be placed and risking the collapse of a building.

Although studies on mental rotation in toddlers and young children have produced mixed results, studies that have implemented tests with low cognitive demands, which are arguably more suited for young children than the tests commonly used for adults, have suggested that mental rotation begins to develop early in life (Frick, Hansen, & Newcombe, 2013; Hespos & Rochat, 1997; Newcombe & Frick, 2010; Quaiser-Pohl, Rohe, & Amberger, 2010; Rochat & Hespos, 1996). Moreover, mental rotation undergoes considerable development in toddlerhood as well as in the preschool years (Cai, Luo, Zhang, & Ying, 2020; Frick et al., 2014; Yang, Liu, et al., 2020). Thus, investigating mental rotation at this critical age can fill a gap in the literature as well as inform ways of supporting mental rotation skills in children's everyday lives.

RELATIONSHIP WITH FLUID INTELLIGENCE AND SEX DIFFERENCES IN MENTAL ROTATION

Interindividual differences in the development of mental rotation might be explained by taking a closer look at research on potential relations to other cognitive variables as well as sex differences. Both the relationship between mental rotation and individual differences in general cognitive abilities (Newcombe, Booth, & Gunderson, 2019; Newcombe & Frick, 2010; Varriale, van der Molen,

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& Pascalis, 2018; Yang et al., 2020) as well as sex differences in mental rotation are strongly established (Lauer, Yhang, & Lourenco, 2019).

Despite the diversity in theories of intelligence (Newcombe & Frick, 2010), many theories link spatial visualization—which is nonarguably key for mental rotation—with cognitive abilities such as working memory (Yang, Wu, et al., 2020) and fluid intelligence (Varriale et al., 2018). Fluid intelligence refers to the ability to solve problems for which prior knowledge is unnecessary or not useful (Varriale et al., 2018), and thus seems to be an important prerequisite for mental rotation, since prior knowledge is not helpful when solving mental rotation tasks. Despite a recent study that investigated the relationship between working memory capacity and mental rotation in 5-year-olds (Yang, Wu, et al., 2020) and multiple reports of a relationship between fluid intelligence and mental rotation in adults (Tachibana, Namba, & Noguchi, 2014; Varriale et al., 2018), the relationship between fluid intelligence and gains in mental rotation in preschool children remains unstudied.

Sex differences in mental rotation are commonly found in adolescents and adults (Geiser, Lehmann, & Eid, 2008), yet the results from early childhood research have been mixed. Some findings indicate that the sex differences in mental rotation, with advantages for males commonly found in adults, first arise in early childhood (e.g., Moore and Johnson, 2008, Moore and Johnson, 2011; Quinn and Liben, 2008, Quinn and Liben, 2014), but others have not found such early differences (Frick et al., 2014; Frick & Möhring, 2013; Möhring & Frick, 2013). A meta-analysis by Lauer et al. (2019) suggests that, from 6 years of age, males have a small advantage that increases even more as children age. Sex differences in play preferences may partly account for the early advantage that boys show in mental rotation (Desouza & Czerniak, 2002; Early et al., 2010; Freeman, 2007; Ruble, Martin, & Berenbaum, 2006), since exercising mental rotation in block play may boost children's spatial skills and given that boys are typically more likely to engage in block play than girls. Since mental rotation is malleable and shaped by experience, any potential early advantages for males do not necessarily have to translate into overt performance differences in preschool and primary school (Newcombe & Frick, 2010) and might be alleviated through targeted interventions. Thus, engaging girls and boys in spatial play with different levels of guidance might foster their mental rotation and therefore alleviate the sex differences that tend to arise.

In general, studies on interventions targeting mental rotation in preschool children are scarce at best. The few existing studies have suggested that mental rotation can be fostered with interventions. For example, Fernández-Méndez, Contreras, and Elosúa (2018) implemented an intervention in which 3- to 5-year-olds were asked to find the correctly rotated version of a 2D picture. A control group received no intervention. The results suggested that the intervention was successful, as the children in the intervention group performed better on a second measure of mental rotation than the control group. In another study, Frick, Ferrara, and Newcombe (2013) implemented a similar intervention with 4- and 5-year-olds and found relevant improvements in mental rotation for the 5-year-old children. A somewhat different way of fostering mental rotation might be through play involving construction (e.g., block play). Block play is an everyday activity that children engage in during the time they spend in day care facilities or at home (Borriello & Liben, 2018; Ferrara, Hirsh-Pasek, Newcombe, Golinkoff, & Lam, 2011), and it has a strong relationship with

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spatial skills (e.g., Cai et al., 2020; Ferrara et al., 2011; Pruden, Levine, & Huttenlocher, 2011). In addition, links between children's spatial skills and block play have been reported (Jirout & Newcombe, 2015). During block play, children can learn different spatial principles, such as height, width, and the correct placement of blocks (Borriello & Liben, 2018; Ferrara et al., 2011). Given that an adult's guidance might be implemented into children's play through scaffolding (Klahr, Zimmerman, & Jirout, 2011; Zosh et al., 2018), children's mental rotation might be further supported through spatial play, e.g., block play, that focuses on children's experiences and encompasses an adult's support. Different degrees of such guidance might have different effects on children's mental rotation and their investigation could inform ways to support mental rotation during spatial play.

CAN SPATIAL PLAY FOSTER MENTAL ROTATION?

The concept of play is fundamental for many aspects of children's development. Definitions of play contain a wide range of characteristics that sometimes contradict each other. However, most researchers agree that an activity has to feature five criteria to be considered play; thus, play is an activity that is voluntary, motivating, child-directed, process-oriented, and contains elements of choice (Danniels & Pyle, 2018; Pellegrini, 2013; Rubin, Fein, & Vandenberg, 1983; Trawick-Smith, 2012). Moreover, play is often viewed as the required form of pedagogy in early interventions.

In fact, previous studies have consistently shown that play can foster spatial skills. For example, in a large-scale study, Jirout and Newcombe (2015) found that frequency with which children engage in block play was related to their spatial skills. Moreover, Seo and Ginsburg (2003) observed preschool children during everyday play and found that children included spatial concepts in their play. Thus, the children explored spatial forms and spatial relationships (e.g., positions). Similarly, Verdine et al. (2019) found that joint shape play between parents and children increased how much children talked about geometrical and spatial concepts during play, indicating that their knowledge in these two areas increased as well. In consequence, block play as a form of spatial play might foster children's spatial skills.

Play can be enriched with an adult's guidance and Zosh et al. (2018) conceptualized play as a continuum. In their view, play that meets all criteria, i.e., is voluntary, motivating, child-directed, process-oriented, and contains elements of choice, is considered free play, whereas play with a learning goal is viewed as guided play. In guided play, an adult might have a learning goal in mind, but the child does not necessarily need to achieve that goal or even be aware of it, thus ensuring that the activity remains joyful and child-directed (Weber & Leuchter, 2022). During guided play, the adult can gently encourage the child to engage with the play materials in a manner that is consistent with the learning goal, thus guiding the activity (Borriello & Liben, 2018; Fisher, Hirsh-Pasek, Newcombe, & Golinkoff, 2013; Verdine et al., 2019; Weber & Leuchter, 2022; Weisberg, Hirsh-Pasek, Golinkoff, Kittredge, & Klahr, 2016). Research has suggested that scaffolding during guided play might be necessary to help children learn from the activity (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011; Fisher et al., 2013; Weber, Reuter, & Leuchter, 2020; Weisberg & Zosh, 2018).

During spatial play (e.g., block play), an adult's guidance can take the form of material support (i.e., learning materials, e.g., photographs of block buildings that the children can rebuild) and verbal

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scaffolds (i.e., verbal support measures; Leuchter & Naber, 2019; van de Pol, Volman, & Beishuizen, 2010). Material scaffolds can draw children's attention toward the learning content, for example, they can motivate children to rebuild the block buildings, encouraging them to rotate the blocks correctly in the process (e.g., Borriello & Liben, 2018; Casey et al., 2008). Moreover, verbal scaffolds can be used to model behavior, link new information to prior knowledge, provide explanations, encourage comparisons, and ask for the reasoning behind a child's actions (e.g., Hsin & Wu, 2011; Richey & Nokes-Malach, 2013; van de Pol et al., 2010; Weber et al., 2020).

Studies show that guidance during play can increase the effect of playful interventions. For example, Fisher et al. (2013) compared the spatial knowledge of children who received guided play, free play, or direct instruction. They found that children in the guided play group showed the highest spatial knowledge compared with the other two groups after the intervention and at the follow-up test 1 week later. Other studies have also shown that guided play with adult scaffolds was more beneficial for a child's learning than free play. For example, Borriello and Liben (2018) examined parents and children who engaged in guided play with photographs or in free block play. Parents in the guided play condition were also given a brief introduction on how to foster children's spatial skills during play. Children in the guided play condition produced more spatial language than children in the free play condition, and this result was considered an indication of spatial knowledge. Ferrara et al. (2011) had similar results in their study. Finally, another study found that guided play with higher levels of adult guidance was more beneficial for children's learning than either free play or guided play with low adult guidance. In Weber et al.' (2020) study on the effect of block play on children's causal reasoning regarding spatial properties, guided play with material and verbal scaffolds increased children's spatial reasoning compared with free block play and guided play with only material scaffolds.

In a recent study on 4-year-old children's mental rotation, Casasola, Wei, Suh, Donskoy, and Ransom (2020) found that a guided spatial play with spatial language fosters mental rotation as compared to a free spatial play. However, Casey et al. (2008) found that neither guided play nor free block play fostered preschoolers' mental rotation. Note that the authors stated that the mental rotation test implemented in their study was rather complex, as the child needed to mentally rotate and flip the picture. As block play might not be related to such complex tasks, studies using easier mental rotation tasks that are better suited to young children (Fernández-Méndez et al., 2018; Frick, Ferrara, & Newcombe, 2013; Quaiser-Pohl et al., 2010) might uncover different results.

In conclusion, these studies indicate that play as a general feature might foster spatial skills (e.g., mental rotation) and that additional adult support might be especially worthwhile. However, it remains an open and yet not sufficiently investigated research question whether the different degrees of guidance during play are better or equally suited for girls and boys when it comes to fostering their mental rotation skills.

SEX DIFFERENCES IN THE EFFECTS OF SPATIAL PLAY

Finding ways that best support boys' and girls' spatial skills, such as mental rotation, may potentially have far-reaching practical implications and may be critical to support children's future academic performance (e.g., Uttal & Cohen, 2012). Several studies have investigated whether girls and boys differ in how their spatial skills benefit from spatial play. One study suggested that fathers' spatial support during block building supported their daughters' spatial knowledge but not their sons' (Thomson, Casey, Lombardi, & Nguyen, 2018). However, other studies have found that girls and boys profited from the playful activities to a similar degree. In their study on the effects of shape play on spatial skills, Fisher et al. (2013) found no sex differences in verbalizations about spatial concepts during play. Similarly, Verdine et al. (2019) did not uncover sex differences in their study. However, parents were more likely to support their sons' spatial play compared with their daughters'. Ferrara et al.'s (2011) results on children's block play suggested that girls and boys produce a similar number of verbalizations about spatial concepts. Thus, spatial play might support girls' and boys' mental rotation to similar degrees as well and might help decrease the sex differences that tend to arise.

To conclude, we identified three gaps in the research on mental rotation in early childhood. It remains unclear (a) which intraindividual differences are related to change in mental rotation in young children, (b) whether different degrees of guidance during play can foster mental rotation in young children, and (c) whether girls and boys profit from the different degrees of guidance during play.

RESEARCH QUESTIONS

In this study, we addressed these three research gaps by investigating the relation of mental rotation to two interindividual variables, fluid intelligence and potential sex differences without accounting for the playful intervention (Research Question 1). Moreover, we examined the effects of different degrees of guidance during play—guided block play with material and verbal scaffolds (high guidance), guided block play with material scaffolds (medium guidance), and free block play (no guidance)—on young children's mental rotation in an experimental design with three points of measurement (Research Question 2). Furthermore, we were interested in possible sex differences in the effects of these forms of play on mental rotation (Research Question 3).

Thus, in this study, we addressed the following research questions:

1.) Which intraindividual differences are related to change in mental rotation in young children?

a. Fluid intelligence is positively related to change in mental rotation.

b. There are sex differences in favor of boys in change in mental rotation.

2.) Are there differences in change in mental rotation between play groups that receive different amounts of guidance?

a. The amount of guidance is positively related to change in mental rotation.

3.) Does change in mental rotation depend on children's sex and the amount of guidance received during play?

a. The amount of guidance is not related to sex differences in change in mental rotation.

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Method

PARTICIPANTS

A total of 183 children from Germany (88 girls) between the ages of 5 and 6 years (*M* = 5.55, *SD* = 0.50) participated in the study. Socioeconomic background was indicated by the standard land value of the children's residences, determined via municipal documentation. The standard ground value ranged from 83 €/m^2 to 460 €/m^2 with a median of 230 €/m^2, indicating that a broad socioeconomic spectrum was represented in the sample.

The children were enrolled in 23 preschools (*n* = 2 to 13 participants per preschool), which were located either in villages (700 to 3000 inhabitants; *n* = 83 children), small cities (fewer than 20,000 inhabitants; *n* = 10 children), or medium-sized cities (approximately 50,000 inhabitants; *n* = 91 children). Seven of the preschools were public, 13 Catholic, and three Protestant. In German preschools, regardless of whether they are public or private, free play is the most common practice (Anders, 2015), and none of the children in the sample had received any formal education. Prior to the beginning of the study, the children were informed about the goals of the study in appropriate words and asked whether they wanted to participate in accordance with APA's recommendations on research with children and the ethical standards of the German Research Foundation. All children participated voluntarily and with their parents' written consent.

PROCEDURE

This study was part of a larger study that investigated young children's playful learning. The children were interviewed at three points of measurement. T1 took place approximately 2 weeks before the playful intervention. T2 took place directly after the intervention. T3 took place 10 weeks after T2. A relatively long delay was introduced between T2 and T3 in order to investigate whether potential effects of the playful interventions remained stable. This procedure was also requested by the funding agency.

The intervention design consisted of three different block playgroups. One group received material support in the form of photographs of block structures (Material group; *n* = 59; 32 girls; age, *M* = 5.53 years, *SD* = 0.49). The second group received the same materials and additional verbal support (Verbal group; *n* = 64; 27 girls; age, *M* = 5.60 years, *SD* = 0.54). The third group played with building blocks freely (Free Play group; *n* = 61; 29 girls; age, *M* = 5.53 years, *SD* = 0.49). The playful intervention lasted for about 1 h, and the children played with the experimenter in mixed-sex groups of two to six children, depending on the size of the preschool. The average size of the intervention groups did not differ between the three play conditions, $F(2,102) = 6.88$, $p = .082$. Moreover, the proportions of girls, $\chi^2 = 0.45$, $df = 2$, $p = .798$, and boys, $\chi^2 = 1.45$, $df = 2$, $p = .483$, did not differ between the three play conditions. To prevent effects of verbal ability, we implemented a test on verbal ability. This helped us ensure that verbal ability was similarly distributed across all three playgroups, and verbal ability was used as a matching variable. Thus, the children were randomly assigned to one of the playgroups while accounting for their verbal ability. To account for verbal

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ability, they were matched with two other children who had a similar proficiency in language. Afterwards, out of each triplet that was matched on language proficiency, one child was assigned to the Material group, one to the Verbal group, and one to the Free Play group.

The playgroups were led by one of six female experimenters who were blind to the study's hypotheses, and each experimenter led all intervention groups according to a systematic intervention plan in order to avoid experimenter effects. Thus, the play sessions were videotaped or audiotaped with the parents' and children's permission to ensure that the activity remained playful, and as an additional manipulation check, to ensure that no experimenter effects were present. Unfortunately, video- and audio-recordings are not available for all sessions, due to frequent lack of consent by either parents or children or technical failure. Therefore, the recordings were not analyzed further.

In all three playgroups, the children were allowed to take a break whenever they liked or to stop playing completely. However, analyses of the available video- and audio-recordings and the experimenters' notes showed that approximately 95% of the children played with the blocks for the full 1 h of play time, and most of the children in the guided play groups used the material scaffolds for their play.

A baseline group that did not play with blocks at all was not implemented, because in the German preschool system block building is a regular activity that many children engage in on a daily basis. It would be impossible to prevent children from doing so and thus, the Free Play group was implemented to ensure that all children played with building blocks for the intervention.

MEASURES

MENTAL ROTATION

Mental rotation was assessed with the Picture Rotation Test (PRT;Quaiser-Pohl, 2003; Quaiser-Pohl et al., 2010) at pretest (T1), posttest (T2), and follow-up (T3) in a standardized single interview and in accordance with the manual. The PRT takes about 10 min to complete. The test consists of 16 items that each contain four colored pictures. Half of the items show humans, and the other half show animals. The picture on the left side is the reference picture, and the children are asked to choose the correctly rotated version of the picture out of three possible pictures on the right side of the page. The other two pictures are mirrored and rotated versions of the reference picture. An example item is presented in Fig. 1. Children receive credit for each item they solve correctly ranging from 0 (*all items solved incorrectly*) to 16 (*all items solved correctly*).

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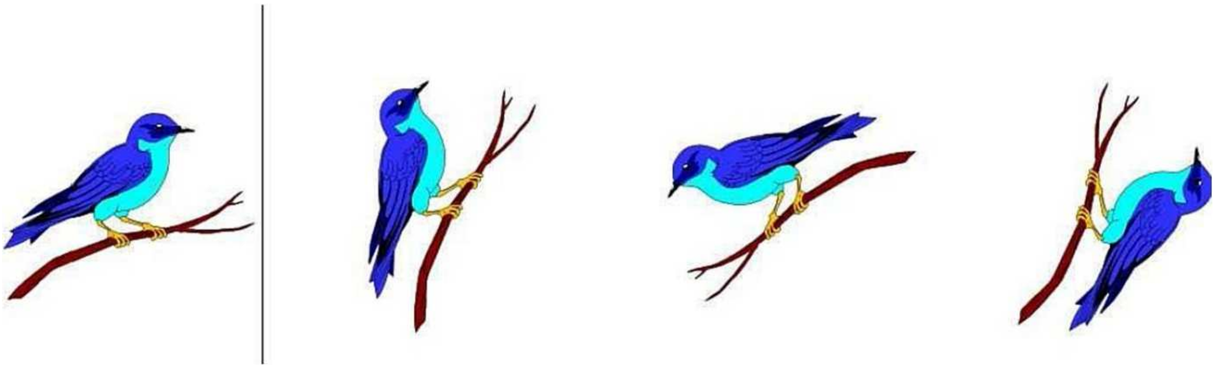

Fig. 1. *Example Item of the PRT (*Quaiser-Pohl, 2003*;* Quaiser-Pohl et al., 2010*).*

FLUID INTELLIGENCE

Fluid intelligence was assessed with the labyrinths and matrices subtests from the Culture Fair Test (CFT 1-R; Weiß & Osterland, 2013) at T1 and administered in group settings of up to six children per group. We specifically chose these two subtests for their spatial nature. The group test took about 10 min. For the group test, the children were prevented from copying from each other by either seating them back-to-back or having a small screen between them. The labyrinths subtest indicates children's navigation skills, and the matrices indicate their figural reasoning. According to the scoring procedure described in the CFT 1-R handbook, children receive 1 point for each correctly solved labyrinth and matrix. Thus, the total score ranges from 0 (*no items solved correctly*) to 24 (*all items solved correctly*). T-values as reported in the manual were not available, as only two subtests were administered (for more information on test parameters, see the CFT 1-R handbook).

VERBAL ABILITY

Verbal ability was measured as a matching variable that was used to sort the children into the three playgroups. It was assessed with the German version of the Peabody Picture Vocabulary Test (PPVT 4; Dunn et al., 2015) at T1, a standardized single-interview procedure. The PPVT takes about 40 min to complete. It consists of 19 picture-based sets, with 12 items per set and four pictures per item. Children at the age of 5 begin with Set 4, and children at the age of 6 begin with Set 5. For all items, the experimenter provides a word, and the child points to the correct picture that shows the word. This procedure is maintained until the child answers eight out of 12 items in one set incorrectly (see the PPVT 4 handbook for more information). The PPVT 4 was administered to ensure that all children understood the German language sufficiently so that they could understand the instructions and the scaffolds provided in the guided play with verbal support. *T*-values are available for the PPVT 4 with a value of $T = 50$ indicating an average verbal ability score at the 50th percentile. The sample had a mean value of $M = 52.67$, which implies an average level of verbal ability.

Testing took approximately 1 h at T1 and 10 min each time at T2 and T3. Breaks were possible whenever the child or the experimenter considered them necessary during testing.

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PLAYFUL INTERVENTION

For the block play session, the children in all three groups played with blocks for approximately 1 h. The intervention consisted of three different playgroups with varying degrees of guidance. The Verbal group received material and additional verbal scaffolds; thus, they received the largest amount of adult guidance. The Material group received only materials scaffolds. The Free Play group played with blocks freely. The Verbal and Material groups received material scaffolds in the form of photographs, and they could freely decide which structure they wanted to rebuild first. In the Free Play group, children were free to build whatever they wished. Thus, the children directed the play and were offered elements of choice (Pellegrini, 2013; Rubin et al., 1983; Zosh et al., 2018). The two guided play groups played five activities that were presented in a standardized order (examples are presented in Fig. 2):

1.) Black block (11 photographs): You can build the structure shown in the photograph. Build the structure and guess whether the blocks remain stable or tumble.

2.) Add-a-block (eight photographs): These blocks in the photos were bewitched so they would remain stable. Can you rebuild the structure so that it is stable? (If a child failed, the experimenter provided a green block in both guided play groups): Look, here is a green block. Try to stabilize the structure with it.

3.) Sliding (nine photographs): This is sliding play. You rebuild the structure in the photograph. Then, you slide the upper block along the lower block until it falls (experimenter models it). That's noisy, isn't it?

4.) Rebuild (11 photographs): You can just rebuild the structure in these photographs and see how well you are doing. Some structures are very easy to rebuild; others are more difficult. However, every one of them will remain stable if built correctly.

5.) Stable/Tumble (eight photographs): The structures in the photographs will sometimes remain stable, but at other times, the blocks are bewitched. Look at the photograph and predict whether it will remain "stable" or "tumble," and then try them out to see whether you were correct.

Fig. 2. Example pictures from the playful activities. *Note*. From left to right: black block, add-a-block, sliding, rebuild, and stable/tumble.

The five activities were developed based on a previous project investigating children's stability knowledge (Plöger, 2020) as well as the materials used for spatial play by Borriello and Liben (2018) and Krist (2010). Since building stable constructions is a large part of block play, it was decided to focus on activities highlighting stability, as it was something the children were familiar with from their everyday lives. The photographs that served as material scaffolds in the two guided play groups showed block structures that varied in the number of blocks, complexity, block shapes, block sizes, and block colors. The children needed to place the blocks correctly to rebuild the structures shown

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in the pictures; thus, it was necessary for the children to mentally rotate the blocks. The material scaffolds were developed prior to the study and piloted with children to ensure that they could rebuild the structures and had a sufficient level of fun in doing so to stay engaged.

The children in the Material group did not receive any further support. The children in the Verbal group received additional verbal scaffolds to foster their cognitive processes. Five verbal scaffolding measures were implemented in the Verbal group: (a) modeling (Leuchter & Naber, 2019), (b) referring to children's prior knowledge (Leuchter & Naber, 2019; Richey & Nokes-Malach, 2013), (c) encouraging comparisons (Hsin & Wu, 2011; Richey & Nokes-Malach, 2013), (d) providing explanations for spatial concepts, such as rotation or stability (Richey & Nokes-Malach, 2013), and (e) asking for reasons (Hsin & Wu, 2011). Modeling was implemented by, for example, the experimenter showing behaviors that the children could imitate, such as looking closely at the pictures or the structures. Children's prior knowledge about mental rotation was addressed by referring to prior experiences with mental rotation (e.g., by asking, "Have you ever seen something like this?"). The children were asked to make comparisons to encourage them to mentally rotate the blocks or block structures (e.g., "Your building looks different than [another child's building], doesn't it? What is different? Is something similar?"). Experimenters provided explanations of spatial principles more broadly (e.g., "This side of the structure is heavier than the other side. This is why the structure remains stable."). Finally, the experimenters asked for the children's reasoning (e.g., "Can you explain this in more detail?"). The experimenters were trained by the lead author of the study in the use of the verbal scaffolds. After the training, they received a script detailing the different guidance measures and examples for each of the measures. The experimenters were asked to use all the presented scaffolding measures with each child but were free to apply them flexibly when playing with the children to make the situation as natural and playful as possible.

Children in the Free Play group did not receive any support but were left to play with the blocks freely. For this free play, they were given a large wooden box containing the same building blocks used in the two guided play groups. The experimenter asked the children to play with the blocks in whatever way they liked and did not provide further instructions or ideas about what to build.

In all three groups, the experimenter praised the children's efforts. Sometimes, the children asked the experimenter for help while building. She provided the requested help only in the Verbal group. In the Material and Free Play groups, she declined in a friendly manner and suggested that the child could ask another child for help with building.

DATA ANALYSIS

The statistics program R, version 4.0.3 (R Core Team, 2023), was used to analyze the data. First, we computed descriptive statistics and autocorrelations of mental rotation at the three points of measurement as well as correlations between mental rotation, fluid intelligence, and verbal ability. To address the three research questions, we investigated changes in mental rotation from T1 to T3 using mixed-effects models. First, we tested whether a random intercept or random slope model could better explain the data. Then we addressed Research Question 1 regarding the relation of fluid intelligence with mental rotation and sex differences in mental rotation by adding fluid intelligence

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as a main effect and an interaction of sex and change to the mixed-effects model. Verbal ability was added as a control variable. To address Research Question 2 concerned with the impact of play on mental rotation, we added the play intervention to the model as a new predictor, which allowed us to analyze differences between the playgroups in mental rotation across the three points of measurement. Last, to address Research Question 3 about sex differences in these playgroups, we added the interaction between change, playgroup, and sex.

Missing data occurred when children missed the test dates that had been agreed upon with their preschools (e.g., because of illness). A total of 134 children had complete data sets, and 49 children had missing values on single items or subtests at one point of measurement. Because mixed-effects models can handle missingness by using all the data available for analyses instead of listwise deletion (Singer & Willett, 2003), we did not take specific measures to handle missingness. However, to ensure that missingness would not affect the results, we ran all the analysis only with the children who had a complete data set. The results are the same for the complete data sets and the data sets with missing data.

RESULTS

Descriptive statistics at each timepoint are presented separately for each of the three conditions and for sex in Table 1. Cronbach's α for mental rotation was good at each timepoint. With 16 items and three possible answers per item, a mean of 5.33 would indicate the level of chance. The mean in the current sample was $M = 11.32$ at T1. A one-sample *t*-test suggested that children performed above the level of chance on average, $t(174) = 21.56$, $p < .001$.

Table 1. Descriptive statistics by sex and condition.

	Overall			Verbal						Material						Free Play						
				Girls			Boys			Girls			Boys			Girls			Boys			
	n	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*	α
MR T1	175	11.32	3.68	25	11.20	3.45	37	11.00	3.97	32	11.41	3.98	24	11.46	3.92	27	11.33	3.23	30	11.60	3.58	0.82
MR T2	165	12.72	4.65	25	12.20	3.63	34	12.38	3.28	30	13.03	3.55	24	12.79	3.39	26	12.46	2.90	26	13.46	2.20	0.80
MR T3	137	13.75	2.80	23	12.17	3.75	23	14.04	2.46	23	14.04	2.44	18	13.72	2.78	24	13.54	3.04	26	14.85	1.52	0.81
FlI	179	11.65	4.65	25	11.68	5.02	36	12.61	4.20	32	11.28	5.57	26	11.23	3.56	29	11.00	4.04	31	11.87	5.28	–
VA	163	52.67	8.67	26	53.15	9.99	35	52.66	8.34	26	52.42	6.78	22	50.50	10.74	24	51.04	8.62	30	55.37	7.50	–

Note. MR = mental rotation. FlI = Fluid intelligence. VA = Verbal ability. α = Cronbach's α for the whole sample.

Correlations between the different measures are presented in Table 2. Mental rotation showed high autocorrelations between the three points of measurement. Moreover, fluid intelligence was positively correlated with mental rotation at each timepoint.

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Table 2. Manifest correlations between the constructs at each timepoint.

	Mental rotation T1	**Mental rotation T2**	**Mental rotation T3**	**Fluid intelligence**
Mental rotation T2	0.71***			
Mental rotation T3	0.58***	0.76***		
Fluid intelligence	0.43***	0.40***	0.27***	
Verbal ability	0.18*	0.17*	0.13	0.22*

* $p < .05$.

*** $p < .001$.

Then we checked for group differences in mental rotation, fluid intelligence, and children's age between the three playgroups (the Verbal, Material, and Free Play groups) at T1. ANOVAs showed no group differences for any of the variables at T1: mental rotation, $F(2, 172) = 0.20$, $p = .816$; fluid intelligence, $F(2, 176) = 0.73$, $p = .482$; age of the participating children, $F(2, 179) = 0.50$, $p = .609$; verbal ability, $F(2, 160) = 0.64$, $p = .531$. Moreover, we investigated possible sex differences at T1. The *t*-tests showed no sex differences for any of the measures at T1: mental rotation, $t(173) = 0.00$, $p = .996$; fluid intelligence, $t(172) = 0.97$, $p = .334$; age of the participating children, $t(179) = 0.13$, $p = .899$; verbal ability, $t(160) = 0.60$, $p = .553$.

RESEARCH QUESTION 1: WHICH INTRAINDIVIDUAL DIFFERENCES ARE RELATED TO CHANGE IN MENTAL ROTATION IN YOUNG CHILDREN?

The first research question was concerned with the relation of fluid intelligence with mental rotation as well as possible sex differences between girls and boys. We addressed this and all other research questions with mixed-effects models. In a first step, we tested whether a multilevel structure was necessary. Thus, a mixed-level model was specified with children on Level 2 and timepoint on Level 1. The intraclass correlation was $\rho = 0.58$. Thus, 58% of the variance in mental rotation could be traced back to differences on the child level, making a second level necessary. Next, we tested for whether mental rotation changed over time by including time in a random intercept model and in a random slope model. The results are presented in Table 3. Tests of deviances implied that the random slope model showed the best fit to the data compared with the other two models, $\chi^2 = 25.40$, $df = 2$, $p < .001$. Therefore, we added all other variables to the random slope model.

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Table 3. Mixed-effects models for change in mental rotation.

	Null model		**Random intercept**		**Random slope**	
Fixed effects	**γ**	***SE***	**γ**	***SE***	**γ**	***SE***
MR T2	12.42***	0.22	12.56***	0.22	12.56***	0.22
Time	–	–	1.22***	0.11	1.24***	0.12
Random effects	*Var*	*SD*	*Var*	*SD*	*Var*	*SD*
Person	6.82	2.61	7.31	2.70	7.40	2.72
Time	–	–	–	–	1.11	1.05
Level 1 residuum	4.92	2.22	3.49	1.87	2.42	1.55
Fit indices	*AIC*	*BIC*	*AIC*	*BIC*	*AIC*	*BIC*
	2394	2406	2291	2308	2274	2299

Note. MR = Mental rotation.

*** $p < .001$.

To investigate the relation between fluid intelligence and change in mental rotation as well as potential sex differences in this change, we added fluid intelligence as a predictor and an interaction between sex and time to the random slope model. Verbal ability was added as a control variable (R code: lmer(mental rotation ~ time*sex + fluid intelligence + verbal ability + (time | child))). The results are presented in Table 4 and Fig. 3.

Table 4. Mixed-effects models for the effects of fluid intelligence and sex differences in change in mental rotation.

	Fixed effects	**γ**	***SE***
Intercepts	MR T1 Boys	11.16***	0.36
	MR T1 Girls	11.64***	0.38
	ΔMR T1 Boys–Girls	0.48	0.51
Slopes	Change in MR Boys	1.46***	0.18
	Change in MR Girls	0.96***	0.18
	ΔChange in MR Boys–Girls	−0.49	0.26
	Fluid intelligence	0.22***	0.04
	Verbal ability	0.03	0.02
	Random effects	*Var*	*SD*

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	Person	8.16	2.86
	Time	1.07	1.04
	Level 1 residuum	2.37	1.54
	Fit indices	*AIC*	*BIC*
		1980	2020

Note. MR = Mental rotation.

*** $p < .001$.

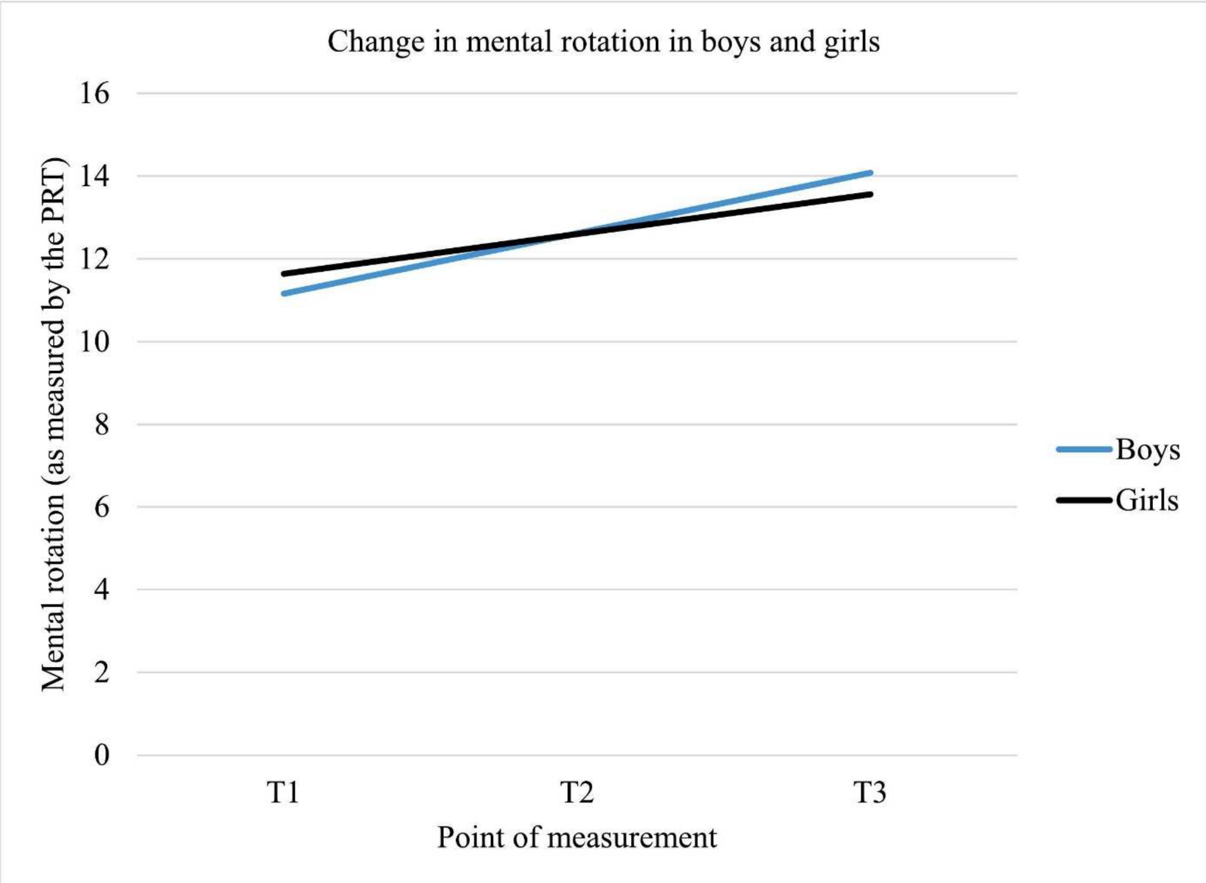

Fig. 3. Change in mental rotation across all three measurement points in boys and girls.

Results showed that, in line with expectations, fluid intelligence was positively related to change in mental rotation, $\gamma = 0.22$, $p < .001$. Moreover, mental rotation increased in girls and boys over the three points of measurement. Contrary to our expectations, we did not find sex differences in change in mental rotation, but the difference in change between boys and girls approached significance, $\Delta\gamma = -0.49$, $p = .058$.

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RESEARCH QUESTION 2: ARE THERE DIFFERENCES IN CHANGE IN MENTAL ROTATION BETWEEN PLAY GROUPS THAT RECEIVE DIFFERENT AMOUNTS OF GUIDANCE?

To address the second research question on the effects of the playgroups on mental rotation, we added the playgroup variable as well as fluid intelligence and verbal ability as control variables to the random slope model (R code: lmer(mental rotation ~ time*playgroup + fluid intelligence + verbal ability + (time | child))). By adding the interaction between time and playgroup, we were able to investigate group differences in change in mental rotation, i.e., in slopes. The results are presented in Table 5. We recentered the time variable to investigate playgroup differences at T2 directly after the intervention, but we found no differences between the playgroups in mental rotation at T2.

Table 5. Mixed-effects models for differences between the playgroups in change in mental rotation.

	Fixed effects	**γ**	***SE***
Intercepts at posttest	MR T2 Verbal	11.95***	0.34
	MR T2 Material	13.06***	0.37
	MR T2 Free Play	12.88***	0.35
	ΔMR T2 Verbal–Material	−1.11*	0.50
	ΔMR T2 Verbal–Free Play	−0.93	0.48
	ΔMR T2 Material–Free Play	−0.18	0.51
Slopes	Change in MR Verbal	1.13***	0.22
	Change in MR Material	1.17***	0.24
	Change in MR Free Play	1.32***	0.22
	ΔChange in MR Verbal–Material	−0.05	0.33
	ΔChange in MR Verbal–Free Play	0.20	0.31
	ΔChange in MR Material–Free Play	0.16	0.33
	Fluid intelligence	0.23***	0.04
	Verbal ability	0.03	0.02
	Random effects	*Var*	*SD*
	Person	5.35	2.31
	Time	1.22	1.06
	Level 1 residuum	2.39	1.55
	Fit indices	*AIC*	*BIC*

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	1981	2029

Note. MR = Mental rotation.

* *p* < .05.

*** *p* < .001.

To address the change in mental rotation over time, we examined the slopes of the three playgroups from T1 to T3 and found increases in mental rotation in all three groups (see Fig. 4). Descriptively, the increase in the Free Play group was the largest, $\gamma = 1.33$, $p < .001$, whereas the increase in the two groups with guidance was lower, Verbal $\gamma = 1.13$, $p < .001$, Material $\gamma = 1.17$, $p < .001$. However, contrary to our expectations, the differences in change between the playgroups were nonsignificant.

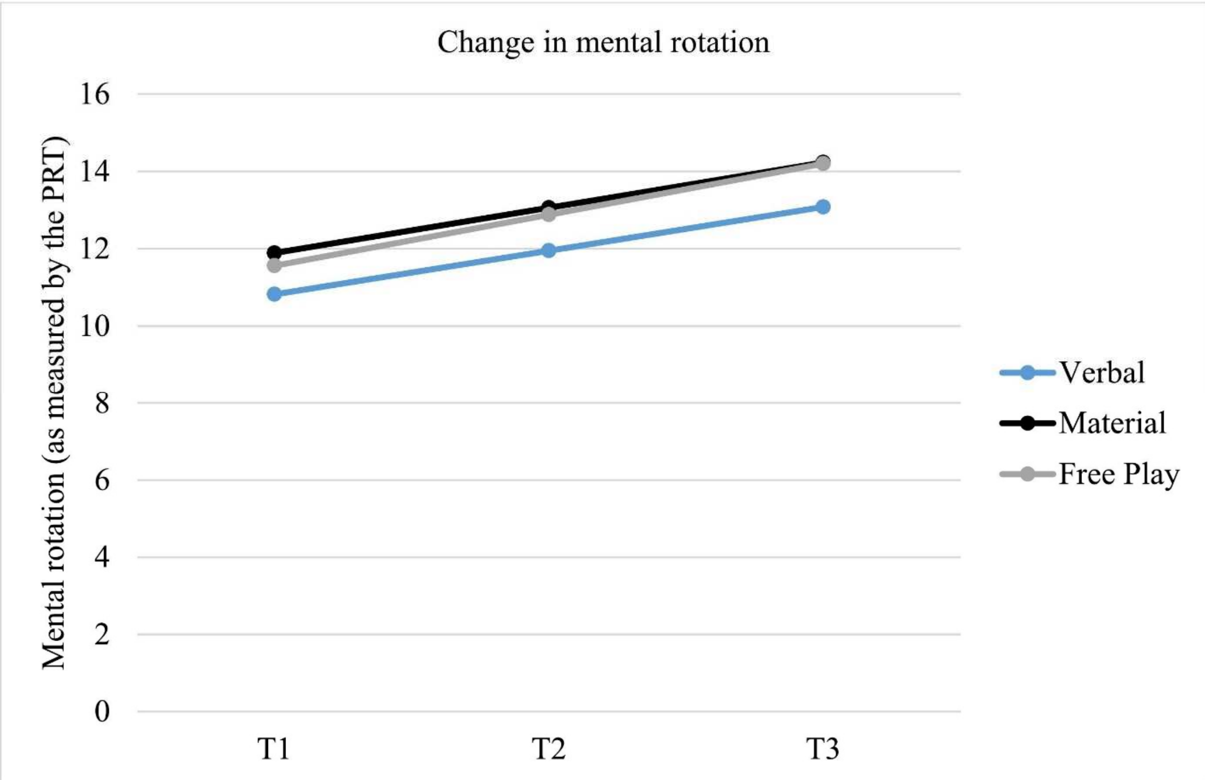

Fig. 4. Change in Mental Rotation Across All Three Measurement Points in the Three Playgroups.

Nevertheless, the model implied group differences in mental rotation scores at T2 directly after the intervention. The Material group showed higher mental rotation skills than the Verbal group at T2, $\Delta\gamma = 1.11$, $p = .028$. Moreover, the difference between the Free Play and the Verbal group at T2 was approaching significance as well, $\Delta\gamma = 0.93$, $p = .055$.

RESEARCH QUESTION 3: ARE THERE SEX DIFFERENCES IN CHANGE IN MENTAL ROTATION IN RELATION TO AMOUNT OF GUIDANCE RECEIVED DURING PLAY?

To address the third research question on possible differences between boys and girls in the effects of the different forms of play on mental rotation, we added an interaction effect of play group and sex with time into the random slope model. Fluid intelligence and verbal ability were kept in the

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model as control variables (R code: lmer(mental rotation ~ time*sex*playgroup + fluid intelligence + verbal ability + (time | child))) The results are presented in Table 6.

Table 6. Mixed-effects models for playgroup and sex differences in change in mental rotation.

Fixed Effects	γ	***SE***
Change in MR Verbal girl	0.66*	0.32
Change in MR Verbal boy	1.52***	0.29
Change in MR Material girl	1.23***	0.32
Change in MR Material boy	1.09**	0.37
Change in MR Free Play girl	1.00**	0.32
Change in MR Free Play boy	1.60***	0.29
ΔChange in MR Verbal girl–Verbal boy	0.86	0.44
ΔChange in MR Verbal girl–Material girl	0.57	0.45
ΔChange in MR Verbal girl–Material boy	0.43	0.49
ΔChange in MR Verbal girl–Free Play girl	0.34	0.46
ΔChange in MR Verbal girl–Free Play boy	0.94*	0.44
Fluid intelligence	0.22***	0.04
Verbal ability	0.03	0.02
Random effects	*Var*	*SD*
Person	5.40	2.32
Time	1.12	1.06
Level 1 residuum	2.38	1.54
Fit indices	*AIC*	*BIC*
	1981	2054

Note. MR = Mental rotation. Only slopes are presented.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

We found that mental rotation increased for girls and boys in all three playgroups (see Table 6 and Fig. 5). Next, we examined differences between girls and boys in change in mental rotation in the three playgroups. To do so, we compared the change for all groups, but for matters of conciseness,

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we present only the differences between the girls in the Verbal group and the other groups in Table 6 because this group had the lowest increase in mental rotation, $\gamma = 0.66$, $p = .044$. Group comparisons showed that the girls in the Verbal group had smaller gains in mental rotation than the boys in the Free Play group. This implies that girls in the group with the highest degree of guidance had the lowest gains in mental rotation, while boys in the group with no guidance showed the highest gains of all groups. Moreover, differences to boys in the Verbal group approached significance, $\Delta\gamma = 0.86$, $p = .052$. Furthermore, results implied a difference between girls in the Verbal group and girls in the Material group in state mental rotation at T2, $\Delta\gamma = 1.56$, $p = .030$. There were no sex differences between the other playgroups. Thus, girls profited less from a large amount of guidance and more from a medium degree. However, in the groups with no guidance (Free Play group) or a medium amount of guidance (Material group), girls and boys benefitted to the same extent with respect to their mental rotation.

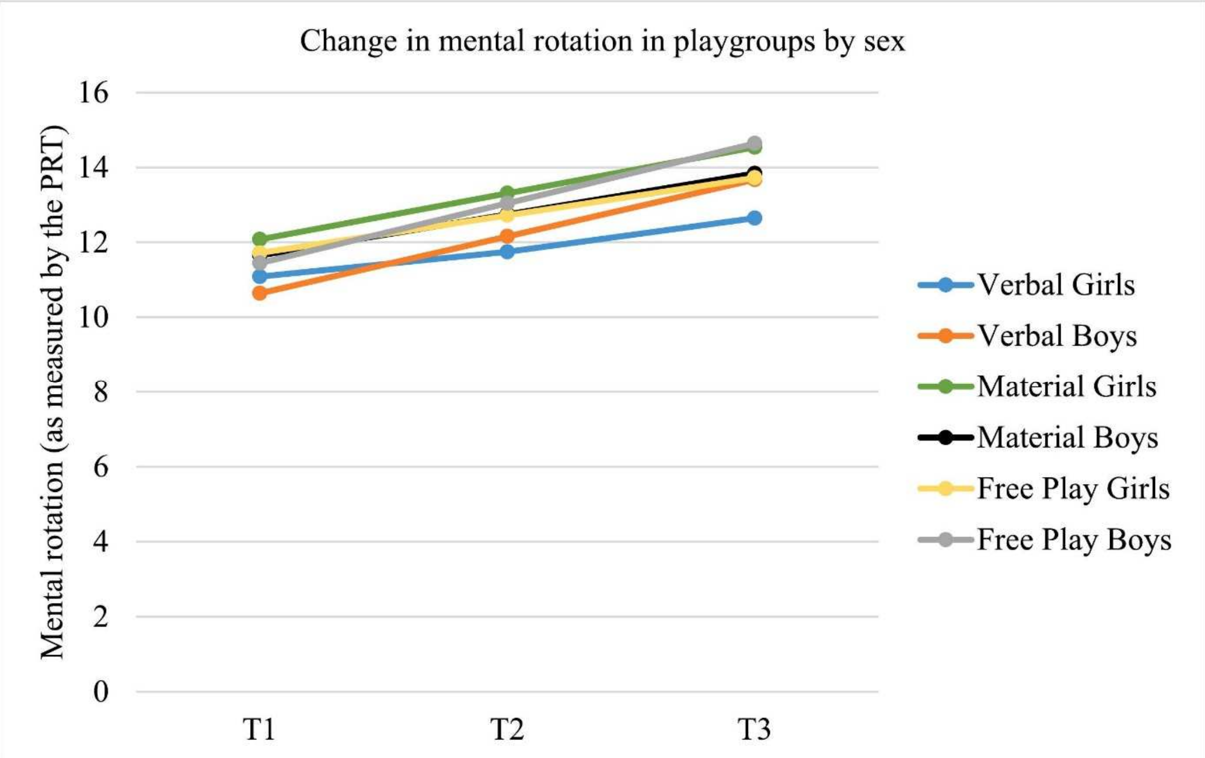

Fig. 5. Change in mental rotation across all three measurement points in the three playgroups by sex.

Discussion

Mental rotation, as one of the core facets of spatial ability, plays an important role in cognitive development. With this study, we set out to investigate mental rotation in $N = 183$ preschool children in a pre-, post- follow-up-test design with two guided play groups (Verbal and Material groups) and a free play group. On the backdrop of three research questions, we found that (a) fluid intelligence was related to mental rotation but sex differences were not, (b) different degrees of guidance during block play did not affect children's change in mental rotation differently, and (c) girls profited the

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least from high degrees of guidance, while boys profited from the play regardless of degree of guidance. Our findings contribute to the literature on spatial skills and how to support preschool students by shedding light on how to foster the early emergence of mental rotation with play, how to address the emergence of early sex differences, and how fluid intelligence is related to mental rotation.

Fluid intelligence was related to the development of mental rotation. Studies have reported links between fluid intelligence and mental rotation in adults (Tachibana et al., 2014; Varriale et al., 2018), but research on the relationship in young children remains sparse. The results of this study indicate that fluid intelligence might be related to the development of mental rotation in young children. The tests used for assessing fluid intelligence were also spatial in nature as children needed to navigate through a labyrinth and spatial skills might be helpful when solving matrices. We specifically decided to apply these measures due to their spatial nature, since we did not aim to map out the contributions of different subfactors of fluid intelligence, but were specifically interested in the spatial component.

Moreover, we did not find sex differences in mental rotation, which is in line with other studies on young children (Frick et al., 2014; Frick & Möhring, 2013; Möhring & Frick, 2013). Lauer et al. (2019) suggest that sex differences start to arise at around six years of age and the children in our study fall into this age group or were only slightly younger. The difference between boys and girls was approaching significance in our study. At the ages of 5 and 6, sex differences might be on the verge of developing. Yet, when other cognitive constructs, such as fluid intelligence and verbal ability are considered, sex differences do not seem to play an important role in mental rotation skills at this young age, yet. Still, one reason for the arising differences between girls and boys might be differences in play preferences, as boys on average tend to spend more time with spatial play such as block play compared to their female peers (Desouza & Czerniak, 2002; Early et al., 2010; Freeman, 2007; Ruble et al., 2006). Therefore, in our next research question, we investigated whether different degrees of guidance during spatial play can foster mental rotation.

Play as a voluntary, motivating, child-directed, and process-oriented activity that contains elements of choice is a promising way to engage children in spatial activities (Danniels & Pyle, 2018; Pellegrini, 2013; Rubin et al., 1983; Trawick-Smith, 2012). Mental rotation increased in all three playgroups (i.e., guided play with material and verbal support, guided play with material support, and free play). Previous studies on children's free block play found that, in line with the findings from the present study, children incorporate spatial concepts (e.g., rotation) into their play without an adult's intervention (Seo & Ginsburg, 2003) and that spatial play (e.g., block play) is related to children's spatial skills (Jirout & Newcombe, 2015).

In this study, an adult's guidance in guided play did not facilitate mental rotation more than free play. Results on the effects of spatial play on mental rotation have been mixed (Casasola et al., 2020; Casey et al., 2008). However, previous literature on fostering spatial skills through guided versus free block play came to different results when reporting on the importance of an adult's guidance during play (Borriello & Liben, 2018; Casasola et al., 2020;Ferrara et al., 2011; Fisher et al., 2013; Verdine et al., 2019). There are two potential reasons for this difference. First, most of the previous literature

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used children's verbalizations about spatial concepts during play as an indicator of their spatial skills, whereas we implemented a mental rotation test as a pre-, post- and follow-up measure. The different assessment methods might provide an explanation for the different results, as we investigated change in a spatial skill, whereas the other studies focused on the state of children's spatial skills in the play situation. While Casasola et al. (2020) investigated mental rotation in a pre- and posttest, they did not investigate change over an extended period of time either. The difference in results to our study might also stem from the extended period of time over which we investigated mental rotation and which might have allowed children in the other three groups to develop their mental rotation skills further through maturation effects. Thus, the verbalizations might indicate the process through which children acquire spatial knowledge, whereas the mental rotation measure in the present study provided a way to operationalize children's performance. Second, spatial vocabulary and mental rotation are different subconstructs of spatial skills. An adult's support for spatial vocabulary might be necessary for children to learn spatial terms and use them adequately, but such support might not be necessary for mental rotation. Instead, mental rotation might develop through engaging in activities that stimulate the cognitive processes involved in mental rotation without an adult's support.

Regarding sex differences in change in mental rotation in the three playgroups, girls in the group with the most guidance (i.e., the Verbal group) showed the lowest gains in mental rotation of all the groups. Moreover, they showed significantly lower gains than boys in the Free Play group, and a lower mental rotation at T2 directly after the intervention than girls in the Material group. However, girls in the groups with no or a medium degree of guidance performed just as well as the boys. We did not find any differences between boys in the three play groups. Apparently, girls profited more from medium degrees of guidance during spatial play. Research has suggested that boys tend to prefer spatial toys compared to girls (Early et al., 2010). Thus, girls might not be as familiar with spatial play as boys. Consequently, girls in the Verbal group with the highest amount of guidance might have been overwhelmed with the combination of spatial play that they on average do not engage in as often as boys and the highly cognitively demanding verbal guidance. This might be the reason that girls in the group with the highest degree of guidance showed the least gains in mental rotation.

Previous studies did not find sex differences in changes in spatial skills via different types of play (Ferrara et al., 2011; Fisher et al., 2013; Verdine et al., 2019). The sex differences in this study could also be attributed to the assessment of mental rotation compared with spatial vocabulary. Previous results indicate that sex differences are more profound for mental rotation than for other spatial skills (Tian et al., 2022). Perhaps our study, but not other studies, tapped into these sex differences, as we assessed mental rotation and not spatial vocabulary. Moreover, previous studies assessed spatial skills as a state variable and did not investigate change scores. The different assessment methods may have contributed to the different results as well, as sex differences begin to surface around the age of 6 (Tian et al., 2022). Our results are in line with other studies that also found more pronounced gains in males than females at different age groups, ranging from 7-year-old children to adults (e.g., Geiser et al., 2008; Terlecki, Newcombe, & Little, 2008).

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PRACTICAL IMPLICATIONS

The results of this study have practical implications. Fluid intelligence was related to spatial skills. Identifying children with lower fluid intelligence and offering them additional support at an early age may allow them to catch up to children with higher fluid intelligence. Thus, providing early support for these children may prevent them from falling behind early in their education, and consequently, in their later education.

Moreover, in line with the literature (Lauer et al., 2019), we found that sex differences in mental rotation were not present in children between 5 and 6 years of age if fluid intelligence and verbal ability were considered in the analysis. However, the sex difference approached significance in favor of boys. Considering the literature on sex differences in mental rotation (Lauer et al., 2019), it is possible that sex differences would have arisen shortly after. Given the importance of mental rotation for later STEM achievement (Geer et al., 2019), it might be worthwhile to foster girls' mental rotation skills at age 5 to 6 or younger, so they do not fall behind their male peers.

Spatial play is one possibility of an early support of mental rotation and can be enriched with guidance. Our results suggest that there might be differences in the benefits boys and girls can reap from such guidance. We carefully suggest that to foster girls' mental rotation, forms of play with less or no guidance might be more beneficial than high degrees of guidance. Perhaps play with medium degrees of guidance or no guidance provides girls with the opportunity to implement their block building in a setting that is more suited to their play preferences than a guided activity. For example, girls tend to prefer story-based play over simply building, and free play allows them to integrate elements of pretend play (Desouza & Czerniak, 2002; Early et al., 2010; Freeman, 2007; Ruble et al., 2006). Research on the underlying reasons could be conducted in the future.

LIMITATIONS

This study has several limitations, primarily concerning the playful intervention. First, the amount of playtime was relatively brief, as the children played for only 1 h. However, other studies on spatial skills have implemented interventions that were similar in length or even shorter (e.g., Borriello & Liben, 2018; Ferrara et al., 2011; Fisher et al., 2013).

Second, the interventions were only partly video recorded, as some parents or children did not give their consent for filming or because there were technical errors. Therefore, the children's play could not be analyzed in detail, and differences in the children's and the experimenters' behaviors could not be detected. It is possible that the children engaged differently with the provided materials. Some children might have constructed more complex block structures or rotated the blocks more frequently, whereas other children may have preferred to watch others build. Moreover, the verbal support measures were not assessed to see if they met the learning needs of the individual child. These behaviors might have affected children's mental rotation ability and could be investigated in a future study.

Third, the video recordings might be especially valuable when it comes to girls' behavior in the mixed-sex playgroups. Other studies on mixed-sex classrooms have found that girls often tend to watch, whereas boys engage with the materials more frequently in science and math activities of which spatial skills are an integral part (e.g., Borriello & Liben, 2018; Newcombe & Frick, 2010; Webb et al., 2007). The experimenters in this study were tasked to interact with all the children and engage every child in play. However, as the activity was supposed to remain playful, every child was free to engage with the materials as they wished. It is possible that the girls would have interacted with the materials in a different way if the groups had consisted of only girls (Moè, 2018). Differences between girls-only and mixed-sex playgroups should be investigated in a future study.

Fourth, a baseline group that did not play with blocks at all was not implemented in the study, because it was deemed impossible to prevent children from playing with blocks in their free time or in their preschool. Therefore, instead a free play group was implemented. The study was conducted to compare effects of different degrees of guidance during play on mental rotation. Nevertheless, a baseline group would have allowed us to examine the effects of play compared to developmental effects further and rule out possible test-retest effects. Fernández-Méndez et al. (2018) found a marginal increase in performance on the same measure used in this study that was much lower than the increase in the training group. Given this result, a test-retest effect cannot be ruled out completely in this study. Therefore, a baseline group would allow for a more detailed investigation of developmental trajectories and possible test-retest effects.

Despite these shortcomings, this study provides valuable insights that highlight possibilities for fostering children's mental rotation, an important part of spatial learning and thus early cognitive development, by engaging them in everyday playful activities. Spatial play offers an easy approach for facilitating the acquisition of spatial skills as an important part of later STEM achievement.

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CRediT authorship contribution statement

Anke Maria Weber: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. **Katarzyna Bobrowicz:** Conceptualization, Writing – original draft, Writing – review & editing. **Samuel Greiff:** Writing – review & editing. **Miriam Leuchter:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Data availability

Data will be made available on request.

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