Determinants of the neuropsychological development of schoolchildren and adolescents

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2018

document version
Publisher's PDF, also known as Version of record

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Sex differences in the performance of 7–to 12–year olds on a mental rotation task: A large cross-sectional study

Under review:
Van Tetering, M.A.J., van der Donk, M.L.A., de Groot, R.H.M., & Jolles, J. Sex Differences in the Performance of 7–12–Year Olds on a Mental Rotation Task: A Large Cross-Sectional Study. *Brain and Cognition.*

ABSTRACT

It has been amply documented that from the age of ten years, boys perform better than girls on mental rotation tasks. It is, however, not clear whether this sex difference exists in younger children. This is because there are no tasks suitable for evaluating mental rotation performance in young children. We therefore developed a renewed task: the Mental Rotation Task – Children (MRT-C). This task is suitable for investigating mental rotation performance in children below the age of ten years. The MRT-C has a binary response approach in which children indicate whether two graphic representations of three-dimensional cuboid figures are the same or not. This task was applied to a large sample of 729 children aged 7–to 12-years old in a cross-sectional study. Results revealed a sex difference in the number of correct judgments made in the MRT-C. Post hoc analyses revealed that this sex difference was confined to 7– to 9-year-old children. Boys performed better than girls. A closer look at the distribution of boys and girls in this age group showed that boys were overrepresented in the top performance quartile, whereas girls were overrepresented in the lowest performance quartile. This is the first study to provide evidence that by the age of 7–9 years, boys are outperforming girls at mental rotation.

INTRODUCTION

There is ample scientific evidence that there are sex differences in performance on mental rotation tasks in adolescence (e.g., Hahn, Heil, & Jansen; 2010; Hoyek, Collet, Fargier, & Guillot, 2011; Johnson & Meade, 1987; Quinn & Liben, 2008; Titze, Jansen, & Heil, 2010; Voyer, Voyer, & Bryden, 1995). Boys outperform girls from the age of ten onwards and this sex difference persists throughout adulthood (e.g., Miller & Halpern, 2014; Voyer et al., 1995). It is, however, not clear whether sex differences in mental rotation are present before the age of ten years (Hoyek et al., 2011; Titze et al., 2010). There are several explanations why sex differences are not consistently reported in young children. One is that differences in the learning experiences of boys and girls emerge over the course of childhood and gradually influence their cognitive development (Baenninger & Newcombe, 1995; Cherney & London, 2006; Jirout & Newcombe, 2015; Miller & Halpern, 2014; Uttal et al., 2013) According to this notion, sex differences are only detectable from the age of ten onwards (Hoyek, et al., 2011; Neuburger, Jansen, Heil, & Quaiser-Pohl, 2011; Titze et al., 2010). Another possibility is that sex differences do exist in younger children, but the mental rotation tasks used to date are too difficult and therefore not sensitive to sex differences in children under the age of ten (Hoyek et al., 2011). The present study aimed to clarify the inconsistent findings of previous studies with respect to the existence of sex differences in mental rotation in young children. A cross-sectional study was performed, which involved more than 700 children aged 7–12 years. Mental rotation was assessed using a renewed procedure that is more sensitive to sex difference in young children than the methods used in earlier research.

It is important to get a better understanding of sex differences in mental rotation - especially of the age at which sex differences emerge - because it may improve our understanding of differences between males and females in success and achievement in the field of Science, Technology, Engineering and Mathematics (STEM; e.g., Lubinski, 2010; Wai, Lubinski, & Benbow, 2009). Males more often than females pursue careers in STEM (e.g., Hango, 2013). This sex difference can – theoretically – be the consequence of the superior spatial abilities of males as compared to females, which have extensively been reported (e.g., Hahn, Heil, & Jansen; 2010; Hoyek, Collet, Fargier, & Guillot, 2011; Johnson & Meade, 1987; Quinn & Liben, 2008; Titze, Jansen, & Heil, 2010; Voyer, Voyer, & Bryden, 1995). These sex differences can either be inborn or arise at later ages. If they arise at later ages, it could be the case that the preference of young boys for spatial play makes them more experienced in STEM-related skills. This would indicate that spatial abilities of girls just lag behind because they lack experiences with spatial play. It is of special importance to find out whether sex differences in spatial abilities are already present in young children, because spatial processes are actively developing and specializing at early ages. This suggests that they are especially malleable and susceptible to environmental influences in young children (see also Zelazo and Carlson, 2012). When research finds that the sex difference is present at early ages, spatial intervention and enrichment programs could be developed in order to enhance the development of spatial abilities including mental rotation of young girls. This type of intervention programs would thereby indirectly reduce the sex differences in successes and achievement in STEM at later ages.

Mental rotation is an example of a spatial process that involves the ability to imagine how an object would look if rotated away from the orientation in which it is actually presented (Jansen & Heil, 2010; Shepard & Metzler, 1971). Mental rotation tasks typically require the participant to compare two or three-dimensional images of objects. The objects may be identical, but rotated around a vertical or horizontal axis or they may be mirror images of each other (Shepard & Metzler, 1971). The participant is asked to determine as quickly as possible which of the images represent the same object but from another rotation. Performance is evaluated in terms of the speed and accuracy with which participants differentiate between identical but rotated pairs and non-identical pairs (e.g., Hahn et al., 2010; Hoyek et al., 2011; Peters et al., 1995; Rüsseler, Scholz, Jordan, & Quaiser-Pohl, 2005; Titze et al., 2010; Voyer et al., 1995). Amongst various tasks that administer cognitive abilities, the largest performance difference between boys and girls has been reported on such mental rotation tasks (Voyer et al., 1995).

Earlier studies on sex differences in relatively young children have been inconclusive about the age at which sex differences on mental rotation tasks at first emerge (e.g., Hahn et al., 2010; Titze et al., 2010; Hoyek et al., 2011; Voyer et al., 1995). In reviewing this literature, it is important to distinguish research dealing with children aged 5-7 years old and research dealing with children aged 7 years and older, because there are substantial differences in the methods used to evaluate mental rotation in younger and older children. For instance, Hahn and colleagues (2010) investigated sex differences in 5-year-old children using colored drawings of animals. Children were asked to indicate whether drawings were 'identical' or 'mirror-reversed'. They found that boys outperformed girls. A potential disadvantage of this approach, however, is that it may prompt children to engage primarily in recognition of object features rather than mentally rotating them (Hoyek et al., 2011). Another disadvantage of the use of concrete objects as stimuli is that they may elicit an emotional reaction based on the child's positive or negative experiences with that object. This emotional reaction may facilitate or hinder mental rotation performance. For these two reasons, another approach – such as the well-established Vandenberg and Kuse Mental Rotation Task (VMRT) – is better suitable to administer mental rotation ability without confounding by object recognition and emotional factors.

The VMRT has been used by Titze and colleagues (2010) and Hoyek and colleagues (2011) to investigate sex differences in 7– to 12-year-old children (Peters et al., 1995; Vandenberg & Kuse, 1978). This task requires children to mentally rotate three-dimensional cuboid figures (see Figure 1, Shepard & Metzler, 1971). Participants are asked to work out which two out of the four test figures are rotations of the target figure, rather than mirror versions of it. Both studies reported sex differences in children aged ten years and older, but not in children under the age of ten (Hoyek et al., 2011; Titze et al., 2011). They therefore concluded that ten is the age at which sex differences in mental rotation emerge.

Close examination of the version of the VMRT as used by Titze and colleagues (2010) and Hoyek and colleagues (2011), however, shows why administering it to young children is problematic. The task may not be comprehensible enough to children under the age of ten because it is a highly complex task, which requires a high working memory capacity. Working memory is required because (1) the participant needs to remember the task instructions and the target stimulus, (2) to mentally rotate the various alternative stimuli one by one and (3) to remember responses to earlier test stimuli whilst mentally rotating the remaining test stimuli. This also necessitates a proper executive functioning (e.g., Anderson; 2001; Diamond, 2013; Jolles, 2016; Kelly, 2010). Accordingly, (4) planning and prioritizing are necessary, as well as (5) high levels of selective attention in order not be distracted by other options. In addition, the participant needs to (6) suppress the tendency to act before thinking (impulsivity). The VMRT is thus a highly complex task for children, which involves numerous of executive functions. Tasks that depend heavily on executive functions can be difficult for 8– to 10-year-old children, and even for many 10– to 14-year-old children. The reason is that executive functions are still immature in childhood, as they continue to develop in childhood until at least early adulthood (Diamond, 2013; Jolles, 2016), (Diamond, 2013). If the task is too difficult for children aged less than 19, it is possible that sex differences in VMRT performance have gone unnoticed. This notion is substantiated by the finding in the study of Hoyek and colleagues (2011), which revealed low mean performances amongst 7– to 8-year-old children; The mean number of correct responses was similar for the young boys and girls and they performed equally bad on the task. This floor effect could have masked potential sex differences. We conclude from this body of research that studying mental rotation in young children requires the use of an age-appropriate task that is not too difficult in order to be sensitive to group differences in performance.

For this reason, we developed a modified version of the VMRT that is more suitable for assessing mental rotation in children under the age of ten; the Mental Rotation Task – Children (MRT-C). Our renewed version is easier because it relies less on functions such as working memory, planning and prioritizing and sustained attention. Children are asked to indicate whether two stimuli are the same or not. They only have to compare one stimulus with the target, not several, as in the standard VMRT. This binary response approach has been shown to be productive in other research on childhood sex differences in mental rotation (e.g., Hahn et al., 2010; Heil & Jansen-Osmann, 2008). This modification has also been performed by Peters & Battista (2008) who studied sex differences in mental rotation in adults. In addition to reducing the complexity of the response options, we also reduced the complexity of the stimuli. We limited the stimuli to three-dimensional cuboid figures rotated around a vertical axis by 0 to 180 degrees relative to the target stimulus, whilst the VMRT test stimuli can be rotated around either the horizontal or vertical axis between 0 and 360 degrees (Peters & Battista, 2008). The stimuli for our modified task were thus more homogeneous than those for the VMRT and the instructions were easier to understand. This reduced the possibility that children would make procedural mistakes

In short, the aim of this study was to determine whether there are sex differences in performance on a mental rotation task in children under the age of ten. A second aim was to evaluate the development of mental rotation by a comparing the performance of 7–10-year-old children to that of children aged 10–12 years. We planned a large, cross-sectional study as we wanted to have sufficient power to detect sex differences. The sample consisted of 729 children, and is thereby much larger than that of any previous study (e.g., Hoyek et al., 2011; Titze et al., 2010; Voyer et al., 1995). Our sample was limited to children who could be considered to show normal cognitive development.

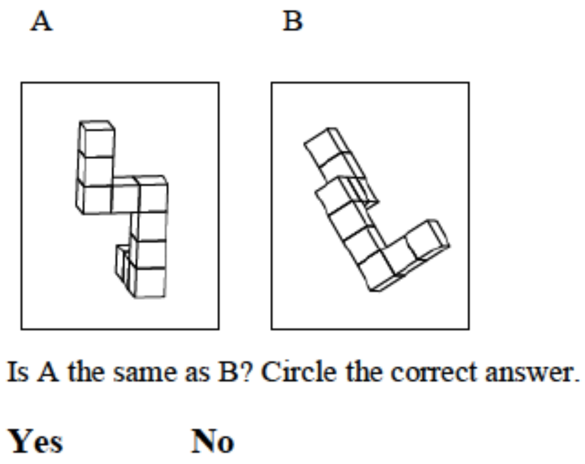

Figure 1. This figure shows an item of the MRT-C. The participant has to mentally rotate the figure on the right to decide whether it matches the target item on the left.

METHOD

Participants

The study was part of a large-scale cross-sectional research program called BrainSquare (in Dutch: 'BreinPlein'), which took place in the period of January to June 2016. BrainSquare was aimed at improving knowledge about child-related determinants of learning performance and neurocognitive development of children and young adolescents aged 7 to 12 years (i.e., grades 2 to 6). A total of 1,081 participants were recruited from nine mainstream primary schools in a rural area in the greater Amsterdam region of the Netherlands. Schools were part of the same board and provided roughly equivalent numbers of children from low, middle and high socio-economic status (SES) families. This was done to homogenize our sample with respect to SES. Accordingly, the nine schools were matched on their SES. The SES of the school was established using a composite score that was calculated based on the mean educational levels, incomes, and positions on the labor market of all habitants in the neighborhood of the school in 2016 (Status scores, 2016). The SES of the schools gives a suitable approximation of the SES of the family in which children grow up in the Netherlands (Proximity of Neighborhood Facilities, 2016). As the study sample included roughly equivalent numbers of children from low, middle and high SES, it is prevented that SES differences between children influenced our main outcomes.

In total, N = 1,081 children participated in the study. Participants were excluded based on the following criteria: (a) skipping or repeating a class (*n* = 231), (b) missing data about the participants age (*n* = 46) or sex (*n* = 4), (c) missing data on the mental rotation task (*n* = 54), and (d) unreliable data because the child did not understand the task-instructions (*n* = 17). This resulted in a final sample of *n* = 729 individuals (48.8% girls). Of these participants, 137 subjects were in grade 2 (50.4% girls; *M* age = 7.75, *SE* = 0.02), 123 participants were in grade 3 (41.5% girls; *M* age = 8.82, *SE* = 0.03), 156 participants were in grade 4 (52.6% girls; *M* age = 9.84, *SE* = 0.02), 132 participants were in grade 5 (47.7% girls, *M* age = 10.76, *SE* = 0.03), and 181 participants were in grade 6 (50.3% girls, *M* age = 11.88, *SE* = 0.03). An Analysis of Variance (ANOVA) revealed that the average age of boys and girls in each grade did not significantly differ between the sexes (*p*-values between .28 - .96).

For statistical analyses, the participants were analyzed in two age groups: one group consisting of 416 participants with a mean age of 8.9 years (grades 2, 3 and 4; 46.2% girls; age range = 7.3 - 10.4, *SE* = 0.05) and one group consisting of 313 participants with a mean age of 11.4 years (grades 5 and 6; 50.3% girls; age range = 10.3 - 12.9, *SE* = 0.04). Again, ANOVA revealed that the average age of girls and boys did not significantly differ in the younger age group (F (1, 414) = 0.06, p = .81, η_p = 0.00), and in the older age group (F (1,311) = 0.16, p = .69, η^2 = 0.00).

Procedure

First, the collaborating schools agreed to include the testing procedure into their regular school schedule. Then, parents or caregivers (referred to as caregivers in the rest of the paper) of the participating schools received an information letter about the study and gave written informed consent. Participation was voluntary. All caregivers were informed that no personalized data would be used in the analyses and that no personalized results would be obtained, since all data were assembled on group level. The Ethical Committee of the Faculty of Behavioral and Movement Sciences of the Vrije Universiteit Amsterdam approved the study protocol.

The children were tested at their own school during normal class time. Questionnaires and neuropsychological tests were administered by means of group administration. This was procedurally identical for every class. A maximum of 30 children was tested together in the classroom. Administration of the total protocol took approximately 60 minutes. All schools were tested within three weeks. Tests were administered by the same two neuropsychologists. One of them gave instructions to the participants and kept track of time.

The other walked around in the classroom to help with potential problems. Additionally, a teacher supported with task administration and kept order in the class.

The data of the present study are part of a larger study protocol consisting of eight neuropsychological tests. Participants first filled in their sex, handedness and their date of birth. The mental rotation task was the sixth task within this protocol and took about five minutes to administer.

Measure: the Mental Rotation Task - Children.

Participants had to solve the Mental Rotation Task - Children (MRT-C), which is a newly made, modified version of the VMRT. The VMRT is a well-established and frequently used task to administer mental rotation ability (Peters et al., 1995; Vandenberg and Kuse, 1978). Both the VMRT and the MRT-C have a similar experimental approach. They are both paper-and-pencil tests that use the 10-block, three-dimensional cuboid figures (i.e., originally introduced by Shepard & Metzler, 1971).

The MRT-C consists of 26 items of three-dimensional-objects, with one reference figure on the left and one figure on the right (see Figure 1). Only figures with rotations in space ranging from 0 to 180 degrees around the vertical axis were selected. The participants had to mentally rotate the target figure and indicate whether the figure on the right matched the reference figure. Children thus need to answer a question with binary answer approach: yes or no.

The task-instructions of the MRT-C were explained classically by the researchers using an example item. Then, participants were instructed to solve another item themselves. The answers given by the participants were checked for their accuracy by the researchers. It was then asked whether the task-instructions were completely understood. The total test was divided into two sets, each containing 13 items. Each set consisted of five pages. Three items were presented on one page in a booklet (sized 210 by 297 mm). The last page of each set contained only one item. Participants were allowed two minutes to complete each set; a short pause of approximately one minute was given in between. This pause was devised to reduce possible mental fatigue effects. Credit was given for each item that was correctly marked as being the same as the target figure or different. Total score for an individual participant could thus range from 0 to 26. Also, the number of mistakes was counted for each individual.

Statistical analyses

All analyses were performed using SPSS version 23. Eta squared were reported as a measure for effect sizes.

Two (age group: younger aged 7–to 9-years old vs. older participants aged 10–to 12-years old) x two (sex: boys vs. girls) analyses of variances (ANOVAs) were performed with MRT-C performance (total number of correctly identified items) as dependent variable. A *p*-value of < .05 was considered statistically significant. Because of the significant interaction between grade and sex, post-hoc one-way ANOVAs were performed to investigate sex differences in each age group separately. Modified Hochberg correction was used to control for multiple testing issues when assessing sex differences in the two separate age groups. A *p*-value of $\leq$ .04 was considered critical for assigning statistical significance (Rom, 2013).

In addition, analyses were performed to take a closer look at the distribution of boys and girls in the overall sample. Accordingly, MRT-C performance was divided into quartiles from lowest to highest performance (according to a procedure published in Dekker, Krabbendam, de Groot, & Jolles, 2013). This was done per grade to control for the age effect which was needed, because MRT-C performance was expected to improve with grade. These analyses provide more insight into the distribution of boys and girls in a group of low, medium, good and excellent performers. This reflects a real-life situation, since each class includes performers of various levels.

Additional analyses were performed using a one-way ANOVA to investigate whether boys and girls (independent variable: sex) differed in their total number of mistakes (dependent variable) per age group. These analyses were performed to control for the possibility that boys performed better because they used a different strategy that prioritized speed above accuracy and achieved a higher number of correct responses because they guessed responses to some items. According to the Modified Hochberg correction that was used to control for multiple testing issues, a *p*-value of $\leq$ .04 was considered critical for assigning statistical significance (Rom, 2013).

Finally, to investigate more precisely at what age possible sex differences emerge, post-hoc one-way ANOVAs were performed to investigate sex differences in each study grade. Again, Modified Hochberg correction was used to control for multiple testing issues; a *p*-value of < .01 was considered critical for assigning statistical significance (Rom, 2013).

RESULTS

Sex Differences in Younger and Older Participants

Differences between boys and girls, younger and older children, and the possible interaction between sex and age group on MRT-C performance were investigated. Table 1 presents the number of correct substitutions on the MRT-C by age group and sex. Results revealed significant main effects of sex (F (1, 725) = 14.80, p < .01, η_p = 0.02) and age group (F (1, 725) = 92.28, p <.01, η_p = 0.11) on MRT-C performance. Boys (M = 6.6, SE = 0.26) showed better performance than girls (M = 15.2, SE = 0.26), and the older participants (M = 17.8, SE = 0.26) showed better performance than the younger participants (M = 14.5, SE = 0.23). The interaction between sex and age-group on MRT-C performance was significant as well (F (1, 725) = 5.22, p = .02, η_p = 0.01), indicating that the difference in the performance of boys and girls is different in the older age group than in the younger age group.

Post hoc analyses were performed to investigate sex differences within each age group because of the significant interaction. Results showed an effect of sex on MRT-C performance in the younger age group (F (1, 414) = 22.01, p < .01, η_p = 0.05), but not in the older age group (F (1, 311) = 1.06, p = .30, η_p = 0.00). More specific, younger boys (M = 15.5, SE = 0.33) outperformed younger girls (M = 13.4, SE = 0.31), whereas in the older age group boys and girls performed equally.

Table 1. Mean performance on the MRT-C for younger and older participants, and for boys and girls.

	Total sample	Boys	Girls		
	M (SE)	M (SE)	M (SE)	η_p	*p*-value
Total sample	15.9 (0.19)	16.6 (0.26)	15.2 (0.26)	0.02	.01*
Younger	14.5 (0.23)	15.5 (0.33)	13.4 (0.31)	0.05	<.01*
Older	17.8 (0.26)	18.1 (0.40)	17.5 (0.34)	0.00	.30

Note: *$p \leq .01$

Distribution Boys and Girls in the Total Study Population

In addition, analyses were performed to take a closer look at the distribution of boys and girls in the overall sample. The distribution of boys and girls significantly differed between the quartiles (χ^2 (3) = 21.87, p < .01). It appeared that students within the highest quartile were predominantly boys (boy: girl ratio = 2: 1; boys: z = 2.7). There were no significant differences in the boy: girl ratio in the first (boy: girl ratio = 3:4; boys: z = -1.3), second (boy: girl ratio = 1: 1; boys: z = -0.6) and third quartiles (boy: girl ratio = 3: 4; boys: z = -1.2) (see Figure 2).

Distribution Boys and Girls in the Younger and Older Age Groups

In addition, the distribution of boys and girls was investigated in the younger and older age group. Within the younger age group, we found that the relative number of boys and girls significantly differed between the quartiles (χ^2 (3) = 19.052; p < .01). It appears that students within the lowest quartile were predominantly females (boy: girl ratio = 2:3; boys: z = -2.8), and within the highest quartile were predominantly boys (boy: girl ratio = 7: 3; boys: z = 2.4). There were no significant differences in the boy: girl ratio for the second (boy: girl ratio = 1: 1; boys: z = -1.0) and third (boy: girl ratio = 1: 1; boys: z = -0.8) quartiles.

Within the older age group, we found that the differences in the distribution of boys and girls approached significance (χ^2 (3) = 7.159; p = .067). It appeared that students within the third quartile were predominantly females (boy: girl ratio = 2: 3; boys: z = -2.1), and within the highest quartile were predominantly boys (boy: girl ratio = 3: 2; boys: z = 2.3). There were no significant differences in the boy: girl ratio for the first (boy: girl ratio = 1: 1; boys: z = -0.2) and second (boy: girl ratio = 1: 1; boys: z = -0.3) quartiles.

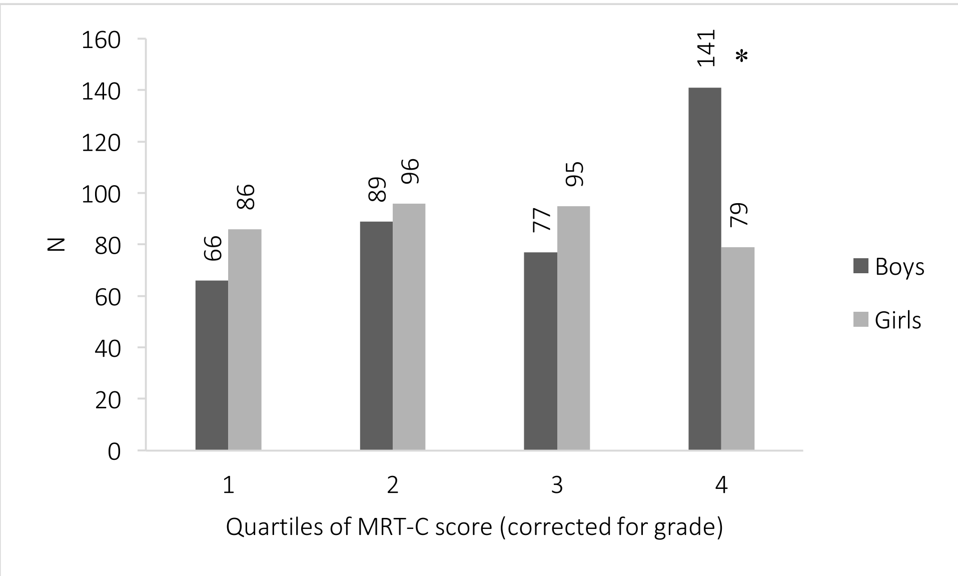

Figure 2. Sex differences in MRT-C performance in the total population divided over quartiles.
Note: Quartile 1 = 25% lowest MRT-C scores: Quartile 4 = 25% highest MRT-C scores. *p-value $\leq$ .01.

Additional Analyses: Sex Differences on the Number of Mistakes

Additional analyses were performed to investigate whether boys and girls differed in their total number of mistakes. Results showed that within the younger group, girls (*M* = 7.1, *SE* = 0.29) made significantly more mistakes than boys (*M* = 6.0, *SE* = 0.34), F (1, 414) = 6.10, p = .01, η_p = 0.02). In the older group, no significant difference in the total number of mistakes was found between boys (*M* = 4.8, *SE* = 0.31) and girls (*M* = 5.2, *SE* = 0.29), F (1, 311) = 0.69, p = .41, η_p = 0.02.

Post-hoc Analyses: Sex Differences per Grade

Post hoc analyses were conducted in which sex differences on MRT-C performances were investigated in each grade separately. Results showed an effect of sex on MRT-C performance in grade 2 (F (1, 135) = 9.15, p < .01, η_p = 0.06) and in grade 4 (F (1, 154) = 11.82, p < .01, η_p = 0.07), to the advantage of boys. The sex-difference on MRT-C performance approached significance in grade 3 (F (1, 122) = 4.61, p = .034, η_p = .03), to the advantage of boys. No sex differences were found in grade 5 (F (1, 130) = 0.77, p = .38, η_p = 0.01), and 6 (F (1, 179) = 0.44, p = .51, η_p = 0.00). Means, standard errors, *p*-values and effect sizes are presented in Table 2.

Table 2. Mean performance on the MRT-C and results of the analyses for boys and girls per grade.

	Sex			
	Boys	Girls		
	M (SE)	M (SE)	η_p	*p*-values
Grades 2	13.5 (0.50)	11.4 (0.52)	0.06	<.01*
Grades 3	15.8 (0.60)	13.8 (0.66)	0.03	.03
Grades 4	17.1 (0.53)	14.8 (0.41)	0.07	<.01*
Grades 5	17.6 (0.61)	16.8 (0.58)	0.01	.38
Grades 6	18.4 (0.53)	18.0 (0.41)	0.00	.51

Note: *p-value $\leq$ .05

DISCUSSION

This study evaluated whether there were sex differences in mental rotation in 7– to 12-year-old children using a renewed task (the MRT-C). The MRT-C has been developed for investigating mental rotation performance in children below the age of ten years. Results revealed that there were sex differences in MRT-C performance; Boys performed better than girls. This sex difference was confined to the younger group (aged 7 – 9 years old). Inspection of the sex distribution of performance in the younger group revealed that boys were over-represented in the top quartile, whilst the lowest quartile was predominantly made up of girls. Also in the older group, there were more boys than girls in the top performance quartile. Additional analyses showed that girls made more mistakes than their male peers at the ages of 7–to 9-years, but not at the ages of 10– to 12-years. These findings imply that younger girls have more difficulties with the task than younger boys. These analyses were performed to control for the possibility that boys performed better because they used a different strategy that prioritized speed above accuracy and achieved a higher number of correct responses because they guessed responses to some items. This alternative hypothesis was not supported by the data as boys made fewer mistakes than girls.

Our findings support the possibility that the original VMRT is too complex for young children. This possibility is supported by the finding that boys aged 7–to 9-years perform somewhat better at the MRT-C than their female peers, while studies using the standard VMRT did not detect sex differences in performance of children this age (Hoyek et al., 2011; Titze et al., 2010). As noted in the introduction of this paper, the regular VMRT could be insensitive to sex differences in young children, because it is too complex. This hypothesis is supported by the fact that the adjusted VMRT (i.e., the MRT-C) is less complex in both the answer approach and the nature of the stimuli used. MRT-C performance is therefore less dependent on executive functions such as working memory, planning and prioritizing and selective attention than performance on the VMRT. This is important for research in young children, given the existence of individual differences in executive functions in 7–12-year-old children (e.g., Anderson, 2001; Diamond, 2013; van Tetering & Jolles, 2017; Wassenberg et al., 2008). For instance, there is evidence that the child's sex is a relevant factor contributing to individual differences in executive functions (see van Tetering & Jolles, 2017). When difficult tasks – such as the VMRT – are used to assess mental rotation, sex differences in executive functions may interfere with task performances. This unwanted contamination of performance on the target skill can be avoided by using a more straightforward task such as the newly developed MRT-C.

An important strength of the MRT-C is the use of three-dimensional cuboid figures. These stimuli are unlikely to elicit emotional reactions that could influence mental rotation performance. This is one of the reasons that these figures have been used in many earlier studies (e.g., see Hoyek et al., 2011; Titze et al., 2010; Voyer et al., 1995). Another reason why previous studies used these figures is that there is much evidence that participants actually mentally rotate stimuli of this type into an upright position in order to determine whether pairs of stimuli are identical or mirror images (Hoyek et al., 2011). Cuboid figures thus seem to be highly appropriate stimuli to administer mental rotation ability, and they are useful in young children.

An additionally relevant finding of this study pertains to the fact that sex differences in mental rotation are present in the best performing older children: Boys are overrepresented in the upper performance quartile, whereas there was no sex difference in mean MRT-C performance of children aged 10–to 12-years old. The fact that we did not find a sex difference in MRT-C performance on a group level can be explained by the difficulty level of the MRT-C; It could be that the MRT-C is too easy for use with older children (adolescents). When a task is too easy, performance can be subject to a ceiling effect given the time individuals have to perform the task in relation to their information processing speed (i.e. all groups perform nearly perfectly within the time they have to perform the task, and so there is no scope for detection of group differences). Our finding that the mean performance of boys and girls is similar in the older group is substantiated by the additional analyses showing that older boys and girls made an equivalent number of mistakes. This is an important finding and implies that age-appropriate tasks should be used when assessing cognitive abilities such as mental rotation. Future investigation of potential sex differences in MRT-C performance in children aged nine years and older should be done, using a more difficult version of the task. Task difficulty could be increased by expanding the range of possible rotations (e.g. to between 0 and 360 degrees around the vertical or horizontal axis, as in the VMRT).

Practical implications & conclusion

This study has a practical implication with regard to the stimulation of mental rotation skills and related spatial activities in young girls. It is known that spatial activities - such as spatial navigation and experiences in spatial play - could stimulate the maturation of brain networks underlying mental rotation ability (e.g., Dunst et al., 2013; Haier et al., 2009; Hausmann et al., 2009; Jaušovec & Jaušovec, 2012; Jolles & Crone, 2013; Krendl et al., 2008). Upon the structural changes in the brain, also the function of the brain areas involved improve (Jolles & Crone, 2013). Performing spatial activities thus both improves brain maturation and mental rotation skills. This “experience-based hypothesis” indicates that learning experiences are important for the cognitive development of children, and moderate the contribution of innate (genetic) factors. On the basis, it can be hypothesized that boys and girls develop similar mental rotation abilities when they are equally exposed to relevant spatial activities and encouraged to perform such activities. Teachers and caregivers should therefore encourage girls to engage in a variety of spatial activities inside and outside of school. This is important because of the importance of spatial abilities for many daily life activities, such as finding one's way in three-dimensional space (e.g. to go to school, sports and playing games, see Newcombe & Frick, 2010). In addition, children's mental rotation abilities are fundamental to quantitative reasoning, such as in mathematics and geometrics, which requires the use of spatial cues, making comparisons and mentally visualizing, rotating and calculating the sides two- and three-dimensional figures (Jirout & Newcombe., 2015; Nuttall, Casey, & Pezaris, 2005; Rosselli, Ardila, Matute & Inozemtseva, 2009). Improving girls' mental rotation performance may lead to later success and achievement in the domain of STEM.

In conclusion, this study has demonstrated that 7– to 9-year-old boys outperform girls on a renewed mental rotation task, the MRT-C. Based on the findings presented here, we showed that sex differences in mental rotation emerge at least at the age of seven years. Major advantage of our study is its very large sample size. Due to the size and homogeneity of the study sample, our study had sufficient power to detect relatively small but substantial sex differences in mental rotation in two age groups. Based on our results, we conclude that MRT-C is suitable for young children. Nevertheless, our results highlight the need to use age-appropriate tasks when assessing cognitive abilities, as we did not find sex differences in mean performance of children aged 10– to 12-years old. Future research is needed to fine-tune the MRT-C to make it suitable to both younger and older children.

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Acknowledgements

We gratefully thank Mathilde van Gerwen and Zita de Snoo for their assistance and their important contribution to the organization and execution of the BrainSquare study.