Learning and Instruction 18 (2008) 30–41

Learning and Instruction

www.elsevier.com/locate/learninstruc

Manual training of mental rotation in children

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Received 30 January 2006; revised 19 September 2006; accepted 23 September 2006

Abstract

When deciding whether two stimuli rotated in space are identical or mirror reversed, subjects employ mental rotation to solve the task. In children mental rotation can be trained by extensive repetition of the task, but the improvement seems to rely on the retrieval of previously learned stimuli. We assumed that due to the close relation between mental and manual rotation in children a manual training should improve the mental rotation process itself. The manual training we developed indeed ameliorated mental rotation and the training effect was not limited to learned stimuli. While boys outperformed girls in the mental rotation test before the manual rotation training, we found no gender differences in the results of the manual rotation task.

Keywords: Gender differences; Manual rotation training; Mental rotation

1. Introduction

Extant studies have shown that mental rotation abilities are sensitive to training in children. However, these training procedures affected only previously learned objects indicating that the mental rotation process itself was not improved but the task was solved by retrieval of memory representations (e.g., Kail, 1986; Kail & Park, 1990). Due to the close relation between motor and mental rotation we assumed that manual rotation training could improve the process of mental rotation. Mental rotation ability was measured before and after manual rotation training and compared to a control group which did not receive any manual training but received a non-spatial filler task. A successful training of mental rotation by manual training would have broad implications for instructional and learning settings. Furthermore, it could give new insights in the cognitive processes underlying mental rotation and provide possibilities in educational research when taking into account the relation between the ability to mentally rotate and, for example, mathematical skills (e.g., Casey, Nuttal, & Pezzaris, 1997) or orientation behaviour in a large-scale space (Hegarty & Waller, 2005).

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doi:10.1016/j.learninstruc.2006.09.009

1.1. Mental rotation ability of children

The paradigm of mental rotation was established by Shepard and Metzler (1971). Participants had to decide whether two block stimuli rotated in space were the same or were mirror reversed. Reaction time increased linearly with increasing angular disparity between the stimuli. Marmor (1975) was the first to study mental rotation in children in a systematic way. Her aim was to disprove the assumption of Piaget and Inhelder (1971) that children are not able to represent kinetic images until after the age of 7 or 8. Marmor could show that even 5 years old children use mental rotation to solve the task with two-dimensional figures. However, 5-year-olds were about twice as slow as 8-year-olds in their speed of mental rotation (defined as the inverse slope of the mental rotation regression line between reaction time and angular disparity). In a further study the performance of 4 years old children was shown to conform to a linear function between angular disparity and reaction times typically found in mental rotation (Marmor, 1977). Again, the mental rotation speed was slower than that of older children and much slower than that of adults. Other studies confirmed these results and indicate that young children posses mental rotation abilities by the age of 5 (e.g., Kosslyn, Margolis, Barrett, & Goldknopf, 1990).

The further development of mental rotation skills from the age of 8 years onwards was the main concern of a study by Kail, Pellegrino, and Carter (1980). They used alphanumeric and abstract symbols and found a linear mental rotation function for children and adults: Rotation speed nearly doubled from the age of 8 years to adulthood and was faster for alphanumeric than for abstract symbols. The increase of rotation speed with increasing age seems to be a continuous process (Kail, 1988) and − like other speeded cognitive processes − could best be described using an exponential function.

While the results of studies which investigated the development of mental rotation are quite homogeneous the opposite is true for the results of studies examining gender differences in children. Linn and Petersen (1985) conducted a meta-analysis of gender differences in spatial abilities of children and adults. They found stable gender differences only in mental rotation tasks and reported that from the age of 13 years onwards boys showed a better mental rotation performance than their female peers. Some authors linked the emergence of gender differences with the beginning of the puberty (e.g., Newcombe, Bandura, & Taylor, 1983; Sanders & Soares, 1986; Waber, 1976). However, many other studies have reported gender differences favouring boys also in younger children (e.g., Levine, Huttenlocher, Taylor, & Langrock, 1999; Vederhus & Krekling, 1996; Voyer, 1995).

1.2. Mental training of mental rotation in adults and children

Training of mental rotation was the topic of many studies with adults. It could be shown that reaction time decreased with training either by extensive repetition of mental rotations (e.g., Kail & Park, 1990; Kaushall & Parsons, 1981) or by a brief training session without extensive repetition (Kass, Ahlers, & Dugger, 1998). However, there is evidence indicating that the mental rotation process itself is not improved by a mental rotation training (e.g., Heil, Rösler, Link, & Bajric, 1998; Tarr & Pinker, 1989). Heil et al. (1998) found that mental rotation training was highly object- and orientation-specific. Their participants showed a decrease of reaction times only for objects presented in the previous training and only if these objects were presented in exactly the same angular disparities as before. The results of Tarr and Pinker (1989) indicated that the slope of the mental rotation function declined and almost nearly disappeared due to extensive training. As in the study by Heil et al. training had no effect on the rotation speed of objects that were presented in different orientations than previously learned. Mental rotation seems to be replaced by the retrieval of stored memory representations.

In children, mental rotation training has been studied only rarely. In the study of Marmor (1977) half of the children received a short training prior to the experimental phase. The training consisted of seven trials with unaligned stimuli in front of a plywood backdrop which were manually rotated first by the experimenter and afterwards by the child. This training did not have any effect on the mental rotation ability. Extended practice of mental rotation with 11-year-olds and adults was studied by Kail and Park (1990). After working on more than 3000 trials of mental rotation of four alphanumeric symbols, the children's speed of mental rotation on those symbols was about six times higher than in the pretest. Similar results were found in another study by Kail (1986) in which even age differences in the speed of mental rotation were eliminated after extensive training. However, Kail and Park (1990) did not find a transfer effect on abstract symbols. The training effect was thus restricted to the alphanumeric symbols learned before and the mental rotation process itself did not seem to have improved. Therefore, they assumed that the reduction or elimination of age differences was based on solving the task by retrieving stored stimulus representations.

1.3. The involvement of motor processes in mental rotation

Manual rotation training could be an appropriate method to improve the process of mental rotation itself. Studies with adults have shown that mental and manual rotation are linked closely and share similar underlying processes (Wexler, Kosslyn, & Berthoz, 1998; Wohlschläger & Wohlschläger, 1998). In these studies, it was found that mental rotation was impaired by a simultaneous manual rotation that was incompatible in direction. A similar study was conducted with children (Frick, Daum, Walser, & Mast, 2005): 5-, 8-, and 11-year-olds and adults had to mentally rotate two-dimensional stimuli while executing a motor rotation by manipulating a wheel with a handle. The direction of the manual rotation had an effect on the reaction times of the mental rotation. By analysing the results separately for the different age groups, the authors found that only for the 5 and 8 years old children reaction times were longer for incongruent than for congruent directions. It was assumed that in younger children mental and motor processes are coupled more closely than in older children and adults.

Additional support for this assumption comes from a study by Funk, Brugger, and Wilkening (2005). Children of 5 and 6 years of age and adults had to mentally rotate pictures of hands in palm or back view. The participants had to press the corresponding response key with their hands either palm-down or palm-up. When the picture of the hand presented in the mental rotation task was in back view, the participants were faster in the palm-down condition. When the picture of the hand presented was in palm view, however, only the children profited from their own hand postures. Furthermore, all participants had longer reaction times when the hand on the picture was shown in a position which would be hard to imitate with the own hand (see also Petit & Harris, 2005; Sekiyama, 1982). In adults, the close relation between mental and manual rotation has also been shown with neuro-imaging methods. Motor and premotor areas which are involved in the execution of movements are also activated during mental rotation (e.g., Kosslyn, DiGirolamo, Thompson, & Alpert, 1998; Wraga, Thompson, Alpert, & Kosslyn, 2003).

2. Aims of the study and hypotheses

A slightly modified version of the manual training used here was evaluated in a study with adults (Wiedenbauer, Schmid, & Jansen-Osmann, 2007). The participants' task was to manually rotate a block figure into the orientation of a standard block figure. In comparison to a control group, the performance of the training group in a computer-based mental rotation test improved due to the manual training. However, training effects were associated with a faster processing of those stimuli learned in the training. Due to the close relation between mental and manual rotation especially in children (Frick et al., 2005; Funk et al., 2005) we expected that a potential effect of a manual training would not be object-specific in children.

To investigate the influence of a manual training on mental rotation abilities a computer-based manual rotation training for children was developed. Furthermore the mental rotation abilities before and after training were measured by a computer-based mental rotation test for children we developed, which records reaction times and errors. We assumed that the manual training would improve the rotation process itself, which should result in faster reaction times after training for both trained and untrained stimuli.

According to Cooper and Shepard (1973), the speed of the mental rotation process per se is reflected by the slope of the regression lines between reaction times and angular disparity, while the intercept should represent the stimulus encoding, comparison of the stimuli, and motor response. To analyse the potential training effect we used difference scores between the post- and the pretest for both reaction times and the parameters of the regression lines. We expected higher difference scores for the training group in comparison to the control group (Hypothesis 1). The difference scores of the reaction times were compared between stimuli learned in the previous training and untrained stimuli to demonstrate that the training effects were not object-specific (Hypothesis 2).

Finally, we investigated potential effects of gender in the mental and the manual rotation. Due to extant studies which found gender differences in children, we expected that boys should outperform girls in the mental rotation task (Hypothesis 3). However, it was not possible to predict the performance of boys and girls in the manual rotation task, as gender differences have never been investigated before in manual rotation.

Because the training effect has never been investigated in children before, we chose children aged 10 and 11 as previous studies have shown that children in this age group are able to use mental rotation without problems.

3. Method

3.1. Participants

The participants were 71 children. Seven children were dismissed due to an overall error rate in the mental rotation test of above 40%. The remaining 64 children, half of whom were girls, were 10 and 11 years old ($M = 10.67$, $SD = 0.71$). Children were recruited through advertisements in local newspapers calling for the participation in a computer-based spatial test. Prior to testing, all parents gave their informed written consent for their children to take part in the study. Children were paid for their participation.

3.2. Materials and design

The experiment was run on a PC with a 17″ monitor located approximately 50 cm in front of the subjects. The software 3D GameStudio A6 was used for creating virtual application. Input device was a two-button mouse and a Microsoft sidewinder precision joystick.

3.2.1. Mental rotation (MROT) pretest

In the MROT the children's task was to decide as quickly as possible whether two presented stimuli are identical or mirror images of each other while keeping errors to a minimum. The experimental stimuli consisted of coloured drawings of six different animals (the complete list of drawings is given in Appendix). The pictures were taken from the coloured set of the Snodgrass and Vanderwart pictures (Rossion & Pourtois, 2004; Snodgrass & Vanderwart, 1980) and were presented in front of a black background. On a given trial an animal was presented twice: An upright standing standard drawing was presented on the left side, a comparison drawing, which was rotated in the picture plane and either identical ('same' trials) or, in half of the trials, mirror reversed ('different' trials), was presented on the right side. Half of the standard drawings were presented facing to the left, the other half facing to the right. The angular disparity between the two figures was 22.5°, 67.5°, 112.5°, or 157.5° clockwise and counter-clockwise (i.e., 202.5°, 247.5°, 292.5°, or 337.5°). In each of the eight angular disparities, each pair of drawings was presented twice (once in a 'same' and once in a 'different' trial) which resulted in a total of 96 trials. Each trial started with a 500 ms presentation of a grey 5 mm fixation square followed by the two stimuli prompting the children to answer by pressing either the left mouse button marked in green ('same') or the right button marked in red ('different').

3.2.2. Mental rotation (MROT) posttest

A parallel version of the MROT was developed and used as posttest. The stimuli were presented in the same angular disparities as in the pretest. Stimuli were 12 drawings of animals which were different from those used in the MROT pretest (see Appendix). This resulted in a total of 192 trials (i.e., twice the number of the MROT pretest trials). Note that none of the drawings presented in the pretest was used in the posttest.

3.2.3. Manual rotation training

As in the MROT a standard drawing was presented on the left side and a comparison drawing on the right side. The children's task was to manually rotate the comparison drawing in the picture plane into the orientation of the standard drawing. The 12 coloured drawings of animals used in the training were taken from the same picture set as described above. To study object-specific training effects, six of these drawings were taken from the stimulus material of the MROT posttest (see Appendix). This resulted in six 'trained' and six 'untrained' figures in the MROT posttest. Standard and comparison figures were always identical and only differed in their angular disparity in the picture plane. The angular disparities between the two presented figures were the same as in the MROT. Each comparison drawing was presented in each of the eight angular disparities. Since each trial was presented twice (but never consecutively) the training consisted of 192 trials.

Input device for rotating the comparison drawing was a joystick embedded in a paperboard-box. This allowed for grasping the joystick as one would do when rotating a real object in the picture plane (see Fig. 1). The joystick was movable about one axis only. When the joystick was turned right/left, the drawing rotated in the corresponding direction.

Fig. 1. Stimuli and input device of the manual rotation training.

Within each condition (mental rotation pre- and posttest and manual rotation training) the trials were randomised.

3.2.4. Filler task for the non-training group

The junior edition of the computer quiz "Who wants to be a millionaire?" (German version) was used as a filler task for children in the non-training group. In this quiz, a virtual quizmaster asks the child questions whereupon the player has to choose the correct answer out of four possibilities. The degree of difficulty increases from one question to the next. This quiz was chosen because the task is non-spatial. Children were challenged to make an effort as they were told that the task was designed to test their general knowledge.

3.3. Procedure

The experimental sessions lasted for about 60 min and took place in a laboratory of the Heinrich-Heine-University of Düsseldorf. Two children were tested at the same time; randomly, one child of each pair was assigned to the experimental group and the other one to the control group, which resulted in a total of 32 children per group (half of whom were girls). The children were required to use headphones and were separated by movable walls to minimize distractions. They were familiarised with the MROT in 24 practice trials. Only in this familiarisation phase, a "correct/false" feedback for each trial was given. None of the drawings used here was presented in the following experimental phase of the MROT. After a 5 min break following the pretest, the experimental group had to complete the manual rotation training while the control group took the computer quiz for the same amount of time. The children of the experimental group were shown how to handle the joystick and were instructed to rotate the comparison drawing into the spatial orientation of the standard drawing and then to press the "fire button" of the joystick. It was possible to execute the required rotation in one fluent movement. If the spatial orientation of the standard and the comparison drawing differed by more than 15° to the right or to the left, the trial was registered as an error and the word "false" was presented in red letters. After the children had completed the manual training and the computer quiz, respectively, all children had a 5 min break and afterwards had to perform the MROT posttest.

3.4. Dependent variables and statistical analysis

Dependent variables were reaction time (RT) and number of errors. The four clockwise and counter-clockwise angular disparities were collapsed to augment the power of the results. This treatment is in line with many other previous studies (e.g., Heil et al., 1998). Within each angular disparity (22.5°, 67.5°, 112.5°, and 157.5°) the average RT in milliseconds for each child was computed only for correct answers in 'same' trials. Separately for each angular disparity and each child, RTs shorter than 500 ms and longer than two standard deviations above the mean were defined as outliers and therefore discarded. The number of errors (for both 'same' and 'different' trials) was computed overall as well as separately for each angular disparity.

3.4.1. Baseline mental rotation ability

The MROT pretest data were analysed to assess baseline mental rotation ability. An analysis of variance was computed; angular disparity (22.5°, 67.5°, 112.5°, and 157.5°) was defined as a within-subject factor; group (experimental vs. control group) and gender were the between-subject factors for RT and number of errors. Furthermore, regression lines (least squares lines) between angular disparities and RTs were computed separately for each child. The slopes and the intercepts were averaged across the children. An analysis of variance was computed to examine potential influences of group and gender on these parameters.

3.4.2. Training effects

Difference scores between pre- and posttest for each angular disparity were computed for RT and errors (to account for the different number of trials only half of the errors in the posttest were subtracted from the number of errors in the pretest). To study training effects these difference scores were compared between the experimental and the control group. To analyse object specificity trials with drawings that were trained in the manual rotation training ('trained') were compared to trials with untrained drawings ('untrained'). An analysis of variance was computed; angular disparity (22.5°, 67.5°, 112.5°, 157.5°) and drawing ('trained' vs. 'untrained') were defined as within-subject factors, group (experimental vs. control group) and gender were defined as between-subject factors.

To analyse training effects in more detail, regression lines (least square lines) between angular disparities and RTs for both MROT pre- and posttest were computed for each child. For slope and intercept, difference scores between pre- and posttest were computed. An analysis of variance was computed including these difference scores as dependent variables; group and gender were defined as between-subject factors.

3.4.3. Manual rotation behaviour

Rotation time and number of errors in the manual rotation training were recorded. Rotation time dependent on the angular disparity was only analysed for correct responses. Within each angular disparity and separately for each participant, rotation times longer than two standard deviations above the mean were defined as outliers and therefore discarded. The number of errors for each angular disparity and each child was computed. An analysis of variance was computed; angular disparity (22.5°, 67.5°, 112.5°, 157.5°) was defined as a within-subject factor for rotation times and the numbers of errors, gender was defined as a between-subject factor. Furthermore, regression lines (least square lines) between angular disparities and rotation times were computed separately for each participant. The slopes and the intercepts were averaged across the children and the effect of gender on these parameters was examined using an analysis of variance.

4. Results

In the analyses the statistical alpha level was set at 0.05. Moreover, significance levels of all ANOVA results were corrected according to Greenhouse–Geisser to compensate for the non-sphericity of the data.

4.1. Baseline mental rotation ability

There was a significant effect of angular disparity on RT in the MROT pretest, $F(3, 180) = 75.79$, $p < 0.001$, $\eta^2 = 0.55$. Repeated contrasts revealed significant differences between all four angular disparities with higher RTs for higher angular disparities. There was no difference between the experimental and the control group, $F(1, 60) = 2.79$, $p > 0.05$. Girls had higher RTs than boys (see Hypothesis 3), $F(1, 60) = 7.51$, $p < 0.05$, $\eta^2 = 0.1$, as illustrated in Fig. 2. No interactions were found. The slope of the regression line was 7.25 ms/degree (137.9°/s) and the axis intercept was 1092.04 ms. There was no effect of group concerning the slope, $F(1, 60) = 1.43$, $p > 0.05$, or the intercept, $F(1, 60) = 0.62$, $p > 0.05$. Gender had no effect on the slope (boys 6.66 ms/degree, girls 7.85 ms/degree),

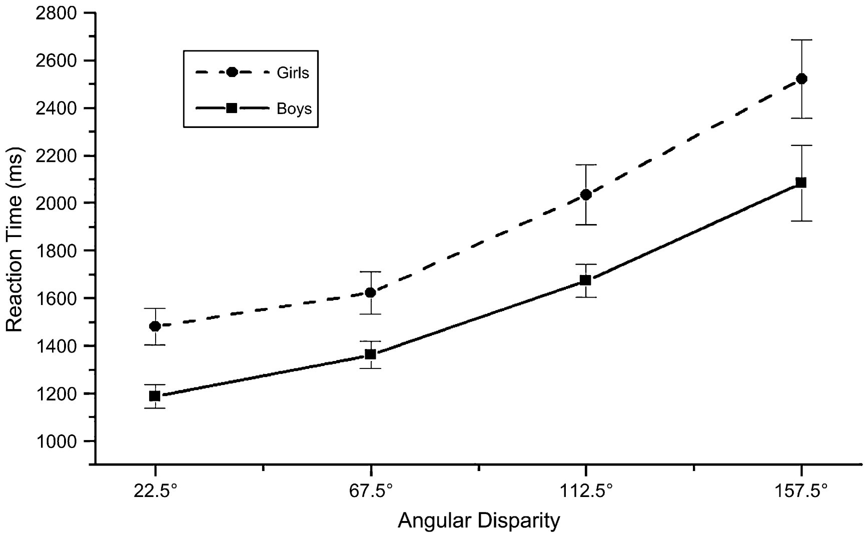

Fig. 2. Mean reaction times as a function of angular disparities in the mental rotation test (pretest) and gender. Error bars indicate standard errors.

$F(1, 60) = 0.86$, $p > 0.05$, but did affect the intercepts, namely boys 975.95 ms, girls 1208.12 ms, $F(1, 62) = 6.92$, $p < 0.05$, $\eta^2 = 0.10$. There were no significant interactions.

The overall error rate in the MROT was 6.39%. Angular disparity had a significant effect on the number of errors, $F(3, 180) = 15.86$, $p < 0.001$, $\eta^2 = 0.11$ (see Table 1). Repeated contrasts revealed significant differences between the last three angular disparities with increasing number of errors with increasing angular disparity. There was neither an effect of group, $F(1, 60) = 2.12$, $p > 0.05$, nor of gender, $F(1, 60) = 2.76$, $p > 0.05$, on the number of errors. Furthermore, no interactions between these factors were found.

4.2. Training effects

4.2.1. Reaction time

Group had a significant effect on the RT difference scores, $F(1, 60) = 4.82$, $p < 0.05$, $\eta^2 = 0.07$. As predicted (Hypothesis 1), the RT difference scores of the experimental group were much larger than those of the control group (see Fig. 3). Furthermore, angular disparity had a significant effect on the RT difference score, $F(3, 180) = 9.16$, $p < 0.001$, $\eta^2 = 0.12$. Repeated contrasts revealed that this significant effect was limited to the difference between the second and the third angular disparity. Gender had no effect on the RT difference scores, $F(1, 60) = 0.36$, $p > 0.05$. There was no difference between ‘untrained’ and ‘trained’ drawings in RT difference scores, $F(1, 60) = 0.01$, $p > 0.05$ (see Hypothesis 2). Furthermore, no significant interactions were found.

The difference scores of the parameters of the regression lines between the MROT pre- and posttest differed at least in tendency between the experimental and the control group concerning the slope, $F(1, 60) = 3.01$, $p = 0.09$, $\eta^2 = 0.05$, but not concerning the intercept, $F(1, 60) < 0.001$, $p > 0.05$. The difference score for the slope was higher in the experimental group (3.24 ms/degree) than in the control group (1.29 ms/degree). There was no effect of gender on the difference score of the slope, $F(1, 60) = 0.15$, $p > 0.05$, or of the intercept, $F(1, 60) = 1.07$, $p > 0.05$. Furthermore, there were no significant interactions.

Table 1
Mean number of errors (standard errors in parentheses) in the mental rotation test (pretest) as a function of angular disparities and gender

	22.5°	67.5°	112.5°	157.5°
Boys	1.09 (0.26)	0.78 (0.25)	1.47 (0.32)	1.63 (0.37)
Girls	1.19 (0.35)	1.56 (0.41)	1.78 (0.46)	2.78 (0.6)

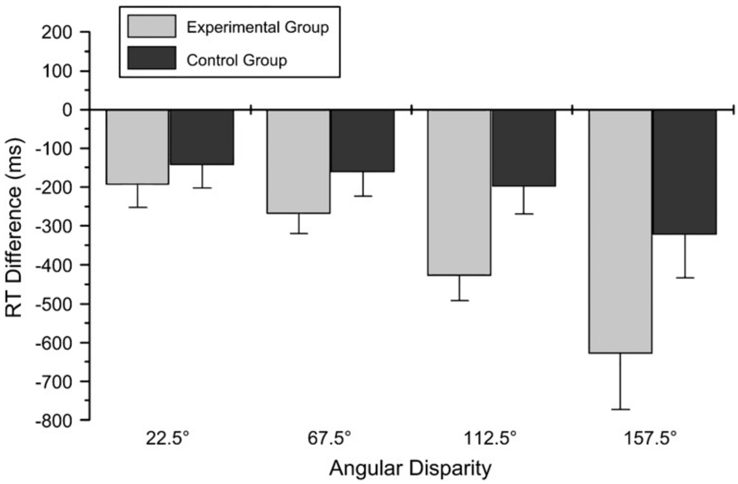

Fig. 3. Reaction time differences for the experimental and the control group as a function of angular disparity. Negativity indicates faster reaction times in the posttest. Errors bars indicate standard errors.

4.2.2. Number of errors

Difference scores for number of errors differed only marginally between the experimental and control group, $F(1, 60) = 3.6$, $p = 0.06$, $\eta^2 = 0.06$ (see Table 2). Descriptively, children in the experimental group had higher difference scores indicating fewer errors in the posttest than in the pretest. There were no other significant effects or interactions for error difference scores.

4.3. Manual rotation behaviour

Angular disparity had a significant effect on rotation time in the manual training, $F(3, 90) = 730.48$, $p < 0.001$, $\eta^2 = 0.96$. Repeated contrasts revealed significant differences between all consecutive angular disparities. Gender had no effect on rotation time, $F(1, 30) = 0.69$, $p > 0.05$. No interaction between these factors was found. Rotation time increased linearly with increasing angular disparity. The slope averaged across participants was 20.2 ms/degree (49.5°/s) and the axis intercept was 2225.96 ms. Gender had neither an effect on the slope, $F(1, 30) = 0.002$, $p > 0.05$, nor on the intercept, $F(1, 30) = 0.81$, $p > 0.05$.

The overall error rate in the manual rotation training was 2.9%. Angular disparity had a significant effect on the number of errors, $F(3, 90) = 4.38$, $p < 0.05$, $\eta^2 = 0.13$. Repeated contrasts revealed a significant difference between the first and the second angular disparity. Gender had no effect, $F(1, 30) = 0.16$, $p > 0.05$. No interaction between angular disparity and gender was found.

5. Discussion

As predicted in Hypothesis 1, the manual rotation training we constructed improved the mental rotation ability in children. Compared to the control group the children in the training group showed larger difference scores for reaction times indicating faster processing in the mental rotation posttest. The training effect was not limited to drawings which were presented in the training before. To analyse this training effect in more detail, regression lines between reaction

Table 2
Difference scores of mean number of errors (standard errors in parentheses) for the experimental and the control group as a function of angular disparities

	22.5°	67.5°	112.5°	157.5°
Experimental group	−0.57 (0.31)	−0.61 (0.39)	−0.83 (0.36)	−1.28 (0.5)
Control group	−0.44 (0.17)	−0.16 (0.21)	−0.31 (0.3)	−0.11 (0.6)

Note. Negativity indicates fewer errors in the posttest.

times and angular disparity were computed. It was shown that the improvement of the mental rotation speed in the experimental group was – at least in tendency – larger compared to the control group. This difference in the slope of the regression line between the pre- and posttest indicated that the mental rotation process per se was trained and not the other processing stages which are stimulus encoding, comparison of the stimuli, and motor response (see Cooper & Shepard, 1973) since we did not find an improvement in the intercept data.

The baseline performance of experimental and the control group did not differ in reaction times and mental rotation speed. Therefore, the conclusion that the training effect is due to the training per se seems to be valid, even if using difference scores in pre- and posttest designs might be problematic (compare Bonate, 2000). Furthermore, the manual rotation training seemed to reduce the number of errors which is in contrast with previous studies with adults (Leone, Taine, & Droulez, 1993; Wiedenbauer et al., 2007). Thus the training effect on reaction time cannot be due to a speed-accuracy trade-off.

5.1. What is trained by manual rotation training?

In the mental rotation posttest we differentiated between figures presented in the previous training and untrained ones. The effect of the training was not limited to learned figures which is in line with our initial assumption (Hypothesis 2) but in contrast to studies on extensive repetitions of mental rotations (e.g., Kail & Park, 1990) and to our own study on manual rotation with adults (Wiedenbauer et al., 2007). The manual training did not result in a simple retrieval of stored representations but seems to promote a faster performance of the rotation process itself. Evidence that children are indeed able to improve the mental rotation process itself stems from studies examining training effects of spatial computer games on mental rotation. In a study of McClurg and Chaillé (1987) children played two games which involved spatial operations and transformations. Compared to a control group without intervention, both games improved mental rotation abilities. Okagaki and Frensch (1994) investigated the effects of playing *Tetris*, a game involving the rotation of geometric objects, on the mental rotation abilities of undergraduates. Playing the game speeded up the reaction times in a later computer-based mental rotation test. But both studies have a great disadvantage, a training effect was only obtained after a high amount of training sessions over a long period. Training did take place on several days with long lasting training hours. Our results indicate that the kinetic representation of an object rotation can improve the performance in an imagery task even in a short training intervention. For children in particular it seems to be important to observe and act on how an object is rotated in space in order to understand the rotation process.

We assume that the mental rotation ability was improved by the manual rotation training because of the fact that the visual rotation process is coupled with a motor reaction. There is a congruent online update of movement and vision. The results of the present study support results of studies in visual-motor imagery research. Recently, it was shown that motor imagery and visual imagery are two complementary but neurally dissociable mental processes (Sirigu & Duhamel, 2001; Tomasino, Toraldo, & Rumiati, 2003; Tomasino, Vorano, Skrap, Gigli, & Rumiati, 2004). Thus, an imagined motor task – in this case the imagination of rotating the joystick – should not affect the mental rotation ability to the same amount than the real rotation of the joystick required in the present study. Further experiments seem to be necessary to investigate the difference of an imagined and real motor training on mental rotation. The fact that the control group showed slightly reduced reaction times in the posttest in comparison to the pretest (see Fig. 3) indicated that they profited by the mere repetition of a mental rotation task. This is in line with former studies concerning mental training of mental rotation in children (see Section 1). However, the larger training benefit of the experimental group demonstrates the effectiveness of a manual training.

5.2. Children's mental and manual rotation ability

Mental rotation ability before and after the training was assessed by using a computer-based mental rotation test. Like numerous other studies on mental rotation in children we used two-dimensional drawings (e.g., Estes, 1998; Marmor, 1975, 1977; Roberts & Bell, 2002). The results of the mental rotation test for children showed a linearly increasing function between reaction times and the angular disparity. This demonstrates that the 10 and 11 years old children used mental rotation to perform the task (see Shepard & Metzler, 1971). The mental rotation speed was 137.9°/s which is in agreement with other studies with children of about the same age: using only one kind of stimulus, Marmor (1975) found a mental rotation speed of 167°/s for 8-year-olds. In the study of Kail et al. (1980) 9 years old children showed a mental rotation speed of 141°/s for alphanumeric and 102°/s for abstract symbols. In the study presented here, the mean error rate in the mental rotation test was relatively low and the number of errors increased with increasing angular disparity. Obviously, the higher the degree of disparity was the more the difficulty performing the rotation children had, which is a common result in children and adults (e.g., Cooper, 1975; Estes, 1998; Kail et al., 1980; Marmor, 1975, 1977).

Similar results were found in the manual rotation training: increasing the angular disparity led to an increase in rotation time. This probably results from longer rotation distances that are associated with larger angular disparities. The number of errors was also higher for larger angular disparities. These similarities between mental and manual rotation emphasise the parallels between both kinds of rotation (see Wohlschläger & Wohlschläger, 1998).

5.3. The effect of gender in the mental rotation and the manual training

Concerning the mental rotation, we assumed that the boys would outperform the girls. The only gender difference we found was that boys produced faster reaction times in the pretest than girls. However, only the intercept data of the regression lines between reaction time and angular disparity differed between boys and girls. Thus we might conclude that boys and girls did not differ in the mental rotation process itself but in the other processes: girls took about 230 ms longer for at least one of these remaining processes, namely stimulus encoding, comparison of the stimuli, or motor response. This is in contrast to studies with adults which found gender differences only in the slope (Bryden, George, & Inch, 1990; Kail, Carter, & Pellegrino, 1979; Kail & Park, 1990).

In contrast to the mental rotation task in the pretest, there were no gender differences in the manual one. We suggest that the processes involved in manual rotation are similar to those involved in mental rotation. Stimuli are first encoded and then rotated. A comparison process stops the rotation as soon as the correct orientation is reached whereupon the motor response is given. There were, however, differences in the cognitive demands between the two tasks. As there were only ‘same’ trials in the manual task the two stimuli were compared with regard to their angular orientation and not whether they were identical or mirror reversed. Possibly this facilitates the task in comparison to the mental one which might explain why boys and girls perform at comparable level in this task. A study of Parsons et al. (2004) showed similar results: males outperformed females in a mental rotation test while the same participants showed no differences in their performance in a manual rotation task. In their task, participants had to rotate a three-dimensional block figure into the spatial position of another one and then to superimpose it. Their mental and the manual rotation tasks, however, differed in numerous ways. The mental rotation ability, for instance, was assessed using a paper and pencil test with two-dimensional stimuli, while the manual rotation in a virtual reality required the manipulation of three-dimensional stimuli. Parsons et al. assumed that the gender differences they found could be the result of these differences, an argument which could not hold true for the present study.

5.4. Educational implications of the study

The manual training we developed improves the mental rotation ability of children. The visualisation of the rotation process seems to help children to understand the basis of mental rotation. This could apply especially to children with impairments of spatial thinking. A study by Rizzo et al. (2001) indicated that participants with initially poor spatial skills in particular can benefit from computer-based rotation training. Therefore, the manual rotation training should be employed to improve the mental rotation ability of children with visual-spatial deficits, such as children with spina bifida.

Mental rotation abilities seem to be positively correlated with mathematical competencies (Burnett, Lane, & Dratt, 1979; Casey et al., 1997). Furthermore, it could be demonstrated that children with dyslexia show impaired performance in a mental rotation task (Rüsseler, Scholz, Jordan, & Quaiser-Pohl, 2005). The poor performance of the dyslexic children was not limited to the mental rotation of letters, but also appeared when three-dimensional block stimuli or drawings were used as stimuli. It could be assumed that children with poor mathematical skills or with dyslexia would benefit from mental rotation training. Hypothetically, they could improve not only their spatial abilities but also their mathematical skills and reading/spelling skills, respectively.

5.5. Conclusion, limitations, and further research

The study presented here indicates that a manual rotation training can improve the mental rotation performance of 10 and 11 years old children. In contrast to previous studies the training effect was not limited to stimuli learned in the training. In further studies the effect of a manual training should be investigated systematically with regard to different age groups and long-term learning. The study did not involve a follow-up session. We do not know anything about the stability of the training effects. Because our results show that rather the strategic behaviour was learned and memory based processes were not involved we might assume that the training is still effective if a follow-up test occurred. This is, however, speculative and has to be investigated in more detail. Furthermore, the different components of the training could be investigated in more detail. There is evidence that the visual perception of stimuli in rotation is related to mental rotation. Podzebenko, Egan, and Watson (2005) revealed similar activation of the same cortical areas in the parietal lobe in tasks where participants conducted mental rotation of letters or looked at the rotation on the monitor. To analyse the different components, a training study could be executed which compares different training groups like a mental rotation, a visualisation, and a motor training group.

Acknowledgments

This study was supported by grant JA 889/3-1 of the Deutsche Forschungsgemeinschaft (German Research Foundation) to Petra Jansen-Osmann. We would like to thank Jan Dombrowski, Martin Heil, Kristina Küper, Léonie Lange, Monika Renvert, Juliane Schmid, and Corinna Vorstius for their help. Furthermore, we thank three anonymous reviewers for their helpful comments on an earlier draft of this paper.

Appendix. Names of the drawings used in the MROT pre- and posttest and the manual training

A. MROT pretest: elephant; fox; alligator; cow; leopard; horse.
B. Manual rotation training: bear; donkey; dog; pig; tiger; goat; monkey; bunny; cat; mouse; turtle; sea lion.
C. MROT posttest: bear; donkey; dog; pig; tiger; goat; camel; lion; rhinoceros; deer; sheep; racoon.

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