The influence of juggling on mental rotation performance in children with spina bifida

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ABSTRACT

This study examined the influence of juggling training on mental rotation ability in children with spina bifida. Children between the ages of 8 and 12 solved a chronometric mental rotation test. Half of the children received juggling training (EG) over an 8 week time period; the other half did not receive training (CG). Afterwards, all participants completed the mental rotation test again. Children of the EG showed a significant decrease in reaction time and an increase in mental rotation speed compared to the control group. This indicates that juggling improves the rotation in the mental rotation process in children with spina bifida.

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1. Introduction

Spina bifida (SB) is a congenital defect in which the neural tube fails to close in early embryogenesis. The reported prevalence in Europe is one per 1000 births (Masuhr & Neumann, 2005). This malformation can occur at any point along the spine. According to the severity and location of the defect, difficulties can occur with ambulation, bladder and bowel control, and fine motor functions. In 80% of these cases the patients develop hydrocephalus associated with an Arnold-Chiari malformation of the cerebellum and the hindbrain, which blocks the cerebrospinal fluid flow. Girls are more often affected than boys.

The cognitive abilities of children with spina bifida have been a matter of research and it has been shown that these children tend to have a higher risk of cognitive deficits. Children with spina bifida often have a lower than average IQ, which ranges between normal and that of a slight learning disability. Additionally, in nearly all studies it was shown that the performance IQ of these children is lower than the verbal IQ (Jacobs, Northam, & Anderson, 2001; Lindquist, Carlsson, Persson, & Uvebrant, 2005; Wills, Holmbeck, Dillon, & McLone, 2003). However, Jacobs et al. (2001) failed to find this significant discrepancy between verbal and performance IQ in spina bifida children. Due to the impaired abilities concerning the performance IQ, it is assumed that spina bifida children show impairments in spatial abilities. Mammarella, Cornoldi, and Donadello (2003) investigated the visuospatial working memory in children with spina bifida and showed that these children have difficulties in visual discrimination and visual processing. Furthermore, Dennis, Fletcher, Rogers, Hetherington, and Francis (2002) documented that these deficits are more apparent in action-based visual perception tasks than in object-based visual perception tasks. Based on this, they suggest that object based visual perception is a process in which features are detected with regard to an allocentric frame, whereas action based visual perception is a process which uses a more egocentric reference system which allows action that is visually guided and goal directed. Furthermore, this process requires representations of multiple stable states and is therefore coupled to movement. In tasks where only visual perception is required (e.g. face recognition), children with spina bifida performed as well as age-matched controls (Dennis et al., 2002). Additionally, children with spina bifida solved tasks requiring ventral stream visual processing better than those which required dorsal stream visual processing. The intact ventral visual processing stream is also found by Swain, Joy, Bakker, Shores, and West (2009), who compared children with spina bifida to healthy controls and found no significant differences between the two groups. Since the ventral processing stream is intact and the performance of the dorsal processing stream seems to be impaired in children with spina bifida, one can make the assumption that processes that rely on the dorsal processing stream might be impaired in these children.

Most of the studies mentioned above concentrate on one aspect of the visuospatial abilities and, as far as we know, only one study has tried to investigate all aspect of spatial cognition in children with spina bifida. According to Linn and Petersen (1985) the classical visuospatial abilities are comprised of the spatial perception, spatial visualization, and mental rotation. Jansen-Osmann, Wiedenbauer, and Heil (2008) examined the classical visuospatial...
abilities, spatial working memory, spatial behavior, and spatial knowledge in children with spina bifida. They investigated these abilities in connection to the motor abilities with regard to the spina bifida children's impaired ability to walk compared to sex-, age-, and verbal IQ-matched healthy controls. Jansen-Osmann et al. (2008) showed that children with spina bifida performed worse in all measured spatial tasks than controls. Furthermore, they found correlations between the age of walking and the Children's Embedded Figures Test, visuospatial memory, and performance in a maze for children with spina bifida. These results indicate that the different motor development in early childhood do have an effect on the performance in the above mentioned tasks. This relationship between motor development and spatial abilities has already been shown in studies with physically disabled children and orientation (Foreman, Stanton, Wilson, & Duffy, 2003) and in children with spina bifida in containment (Simms, 1987). More evidence for the relationship between motor development and spatial abilities is given by studies with children who have developmental coordination disorder (DCD). Wilson et al. (2004) investigated 16 children with DCD (mean age: 10.4 years) and a healthy control group of 18 children (mean age: 10 years). They showed, using a mental rotation task with pictures of hands as stimuli, that children with DCD solve this task with an atypical reaction-time pattern compared to healthy children. These results suggest that DCD children do not enlist motor imagery processes into their judgment of mental rotation tasks. Loh, Piek, and Barrett (2011) investigated children with DCD, Attention Deficit/Hyperactivity Disorder (ADHD), and children with both DCD and ADHD regarding their cognitive functions. They found significant poorer perceptual reasoning abilities in the groups of children with DCD suggesting that a deficit in visuospatial abilities might be caused by the DCD, which means by the impaired motor performance, and not the ADHD.

Since Jansen-Osmann et al. (2008) found an impairment of the classic visuospatial abilities, which include mental rotation, research on this specific aspect has particularly been done because during the process of mental rotation the dorsal processing stream is activated (e.g. Podzelenko, Egan, & Watson, 2002). According to Dennis et al. (2002) children with spina bifida show decreased abilities in tasks requiring the dorsal stream. Based on this, one can assume that the mental rotation ability in these children is impaired.

Wiedenbauer's and Jansen-Osmann's (2007) study concerning mental rotation ability showed that manual rotation training could improve this ability. Therefore, 19 children with spina bifida and 19 matched controls were assessed with a chronometric mental rotation test before and after manual rotation training. The entire testing procedure, comprised of the pre- and post-test and the training, was conducted in 60 min for each participant. Children with spina bifida showed impaired mental rotation abilities compared to controls demonstrated by slower reaction times in the pretest. Both groups improved their mental rotation abilities after the manual training, although children with spina bifida benefited more than controls. The reduction of reaction times was twice as high for the children with spina bifida, indicating that children with poor mental rotation abilities benefit more from rotation training than children with normal mental rotation abilities (Rizzo et al., 2001). Due to the kind of manual training used, the question of suitability for daily use comes up and the need for a more appropriate training for these children, one that could be carried out at home, is apparent. Preliminary considerations for choosing the training were the practicability at home, the suitability for different disability levels, and the effectiveness for training the spatial abilities. So far there are only few studies that have investigated the influence of motor or coordination training on spatial abilities in children with spina bifida (Wiedenbauer & Jansen-Osmann, 2008). To choose a suitable training we assessed the research of motor training and its effect on spatial abilities in healthy children. Since juggling training has already been found to improve mental rotation performance (Jansen, Lange, & Heil, 2011; Jansen, Titze, & Heil, 2009), it also is considered to be suitable for children with spina bifida. The suitability of this task was judged based on the versatility of items that can be juggled and the number of items that can be used to juggle. Because of these aspects juggling can be adapted to the individual skills of the children.

Jansen, Titze et al. (2009) showed that juggling improved the mental rotation performance in students. In this study, two groups (23 per group) solved a chronometric mental rotation task at the beginning and at the end of a 3 month time period. In between the tests the experimental group received one and a half hour of juggling training once a week according to a specifically developed program. Although a test effect for the second test was found in the control group, the results of the study clearly indicate that the experimental group's improvement in reaction time was above the repetition effect. Jansen, Titze et al. (2009) found this effect only for the angular disparity 90° and 180°, but not for 0°. But since 0° does not need any rotation, this might explain the missing effect for this condition. However, juggling showed no effect on error rate. These results were expanded by the study of Jansen, Lange et al. (2011), who showed that this effect is also found in school-aged children and that the training effect is specific for juggling.

Taken together, on one hand the studies mentioned above show that children with different motor impairments, e.g. children with DCD and also children with spina bifida, show an impaired mental rotation performance. On the other side, neuroscientific studies suggest that juggling leads to an increasing plasticity (Draganski et al., 2004) in one area which is also involved in mental rotation (Jordan, Heinez, Lutz, Kanowski, & Jäncke, 2001). On a behavioral level it has been demonstrated that juggling enhances mental rotation performance (Jansen, Lange et al., 2011; Jansen, Titze et al., 2009). Due to the fact that children with spina bifida benefit from mental rotation training and due to the positive “juggling” studies, the main goal of this paper is to investigate the influence of juggling training on the mental rotation ability in children with spina bifida.

2. Method

2.1. Participants

Nineteen children with spina bifida (15 girls and four boys) aged between 8 and 12 (M = 9.74, SD = 1.45) years old took part in the study. Children were recruited by means of advertisement in local newspapers and in the journal of the German Society of Spina bifida and Hydrocephalus and with the cooperation of social pediatric centers in Bavaria, Baden-Württemberg, and North Rhine-Westphalia. Prior to testing, all parents gave their written consent for their children's participation. The ethical review committee was informed.

In addition to general information, the medical condition and infantile motor development were assessed by a questionnaire. All children had myelomeningoe and, apart from one child, all suffered from a shunted hydrocephalus. The localization of the lesion was lumbar in 15 children, thoracic and sacral in two children respectively. None of the children suffered from epilepsy, uncontrolled seizure disorder, perception disorder, or behavioral occurrences. Thirteen of the children learned to walk with or without assistance (6 in the intervention group, 7 in the control group). The other six children are not able to walk and sit in a wheelchair (4 in the intervention group, 2 in the control group). All children had normal or corrected to normal vision.
The children were divided into two parallelized groups according to their age, gender, and their cognitive processing speed, measured with the Connecting Number Test (Oswald, & Roth, 1987), which could be transferred into IQ-values. Consequently, the two groups, experimental group (EG) and control group (CG), did not differ in their age (EG, \( M = 9.8 \), SE = 1.6; CG, \( M = 9.7 \), SE = 1.4; \( F (1,18) = .038 \), n.s.), or in their IQ (EG, \( M = 78.9 \), SE = 11.1; CG, \( M = 78.3 \), SE = 8.0; \( F (1,18) = .016 \), n.s.). Gender was balanced between the groups. None of the children were able to juggle before participating in this study. All children received monetary compensation and juggling scarves and balls as gifts for their participation.

2.2. Material

2.2.1. ZVT

The Connection Number Test (ZVT; Oswald & Roth, 1987) measures cognitive speed. The numbers 1–90 are presented on four sheets with an irregular sequence in a matrix of nine rows and 10 columns. The participants are advised to connect the numbers in the ascending order as fast as possible with a pen. For each participant the time that was needed to connect all 90 numbers was measured. The time of all four sheets is then added and divided by four. The results can be converted into IQ estimations. The correlation between the ZVT and the standard IQ test is about \( r = .60 – .80 \) (Vernon, 1993). Internal consistency and 6-month test–retest reliability is about 0.90–0.95. The test was assessed once for each participant at the beginning of the time period.

2.2.2. Chronometric mental rotation test

All participants were assessed with a chronometric mental rotation test at the beginning and the end of an eight-week-time period. Each child was tested individually in familiar surroundings in a pre- and post-test at the beginning and the end of an eight-week-time period. Two stimuli were presented at the same time on the monitor. The experimental stimuli consisted of 18 perspective line drawings of three dimensional cube figures similar to the ones used by Shepard and Metzler (1971) and Jansen-Osmann and Heil (2007) (compare Fig. 1).

The maximum size of each stimulus on the display was 7 cm \( \times \) 7 cm and the distance between the stimuli was 14 cm. The children were allowed to choose their most comfortable viewing distance. Two stimuli were presented at the same time on the screen. The right stimulus was either identical to the left one or mirror-reversed. The angular disparity between the two stimuli was 0°, 90°, or 180° in a clockwise or counter-clockwise direction. The children had to decide as quickly and accurately as possible whether the two stimuli were the same or mirror-reversed. To respond they had to press either the left button of the mouse (for the same) or the right button (for mirror-reversed). The two response buttons were marked with a green (left) and a red (right) point to clarify the options. Each trial began with a 500 ms blank background then the pair of stimuli appeared and remained on the screen until the participant responded. Based on the studies of Jansen, Titze et al. (2009) and Jansen, Lange et al. (2011) all participants received feedback in form of a “+” for a correct answer and a “−” for an incorrect answer. The feedback was presented for 500 ms on the screen. The next trial began after 1500 ms. Every combination of objects (18 cube figures), type of response (same/mirror-reversed), and angular disparity (0°, 90°, and 180°) was presented three times, resulting in a total number of 324 trials. To familiarize the children with the respective task a block of 54 unrepeated practice trials was performed at the beginning of the tasks. Afterwards, the block of 324 trials followed with breaks after every 27th trial. The reaction time and the error rates were measured and the same tasks and stimuli were used in the pre- and post-test. Both tests were separated by an interval of 8 weeks.

2.2.3. Mental rotation speed

According to Shepard and Cooper (1982) and Heil and Rolke (2002) several processing stages occur during mental rotation: perceptual processing, identification and discrimination of stimuli and identification of its orientation, mental rotation, judgment of parity, response selection, and execution. To investigate the influence of training on mental rotation itself, the mental rotation process needs to be excluded from the other processes. This can be done by analyzing the data with the help of regression lines between angular disparities and reaction times. The speed of the mental rotation process itself is indicated by the slope of the regression line. Therefore this analysis was conducted with the data of the participants.

2.2.4. Juggling training

During the 8 week period the children of the experimental group received juggling training once a week for 1 h. The training was comprised of the juggling of scarves, because they are slower and more convenient for children with myelomeningocele, rather than the juggling of balls. Every child was taught according to his or her individual abilities. This included that every child graduated to the next level of difficulty (more scarves or balls) only when they could juggle consecutively for at least 30 throws. At every session the numbers of successful throws were recorded. A throw was only counted as successful when the current juggling material was thrown and caught without interruption. A cascade with three scarves, in which each scarf is thrown and caught once, is counted as three throws. The data recorded included the throwing of one, two, or three juggling scarves from one hand to the other hand in the early training sessions and in the later training sessions the throwing of one or two juggling balls.

Children of the control group received no training and were requested to not learn juggling during the 8 week time period. After the study the juggling program was made available to all children of the control group.

3. Statistical analysis

For the analysis of the data the system SPSS 18.0 was used. Only correct answers were considered and the analysis was restricted to “same” responses because angular disparity is not unequivocally defined for “different” responses (Jolicoeur, Regehr, Smith, & Smith, 1985). Before the analyses the reaction times (RTs) were trimmed for outliers. The RTs more than two standard deviations above or below the mean per condition and per participant were excluded. For the experimental group this resulted in an exclusion of 2.3% of the pretest data and 2.5% of the posttest data; for the control group 2.2% of the pretest data and 2.2% of the posttest data was excluded. To investigate whether feedback has an influence on mental rotation performance we compared the error rates in the 12 different experimental blocks. Since the error rate did not differ between the several blocks in the pretest \( (F (11,198) = 1.52, \text{n.s.}) \) \( \eta^2 = .078 \) \( (F was averaged for the children in the intervention and control group), it was assumed that feedback did not have an influence on mental rotation performance.  

Fig. 1. Example of the cube figures used in the chronometric mental rotation test.
One analysis of variance for the dependent variable difference-score in reaction time was calculated with the between-subject factor “group” (EG, CG) and the within-subject factor “angular disparity” (0°, 90°, and 180°). Difference score was considered to be effective since Souvignier (2000) and Rogosa, Brandt, and Zimowski (1982) have considered this as valid measurement for the detection of changes in a pre-post-design. Despite previous assumptions that this is an invalid measurement they found that this is not true when considering the actual changes in individuals. Another analysis of variance for the dependent variable “error rate” was calculated with the between-subject factor “group” (EG, CG) and the within-subject factor “angular disparity” (0°, 90°, and 180°). Furthermore, the data was analyzed with respect to the motor abilities of the children independent of group: a univariate variance analysis with “difference score” as the dependent variable “mental rotation speed”, the between-subject factor “motor abilities” (walking vs. wheelchair), and the within factor “angular disparity” (0°, 90°, and 180°) was conducted.

One analysis of variance was calculated with the dependent variable “mental rotation speed”, the between-subject factor “group” (EG, CG), and the within-subject factor “angular disparity” (0°, 90°, and 180°) (compare Wiedenbauer, Schmid, & Jansen-Osmann, 2007). Mental rotation speed was calculated – separately for each participant – as the inverse of the slope of the regression line, relating RT and angular disparity, expressed as degree per second. Furthermore, the juggling performance was registered. All sets of data were tested for normal distribution.

4. Results

4.1. Improvement of juggling

All children in the experimental group showed an improvement in their juggling performance as a result of training. Table 1 shows the number of successful throws for each participant in the experimental group at the beginning and the end of the juggling training. More than 30 consecutive throws were considered as confident juggling (compare Table 1). Although individual performance varied at the end of the training, all children of the experimental group except one were able to juggle reliably with at least two scarves.

4.2. Reaction time

There was no main effect for the factor “angular disparity”, \( F (2,34) = 1.475, n.s., \eta^2 = .080 \), but a significant main effect for the factor “group” \( F (1,17) = 6.102, p < .05, \eta^2 = .264 \), and a significant interaction between “angular disparity” and “group”, \( F (2,34) = 4.751, p < .05, \eta^2 = .218 \). Children in the experimental group showed a decreased reaction time at all angular disparities (“0°”: \( M = -687.51 \) ms, \( SE = 208.47 \) ms; “90°”: \( M = -2014.75 \) ms,

\( SE = 828.17 \) ms; “180°”: \( M = -1750.37 \) ms, \( SE = 584.46 \) ms). In contrast, the control group showed no such decrease in the reaction time (“0°”: \( M = -176.98 \) ms, \( SE = 114.41 \) ms; “90°”: \( M = 84.07 \) ms, \( SE = 640.29 \) ms; “180°”: \( M = 892.07 \) ms, \( SE = 707.88 \) ms). The before mentioned interaction is due to the fact that the difference between EG and CG is highest for 180° (\( d = 1.32 \)) condition compared to the 0° (\( d = 1.08 \)) and 90° (\( d = 0.91 \)) condition (compare Fig. 2).

Concerning the effect of motor ability, there was no main effect for the factors “angular disparity”, \( F (2,34) = 1.04, n.s., \eta^2 = .058 \), or “motor ability”, \( F (1,17) = .68, n.s., \eta^2 = .004 \), and no significant interaction between “angular disparity” and “motor ability”, \( F (2,34) = .51, n.s., \eta^2 = .003 \).

Interestingly, reaction time did not differ between 90° and 180° averaged over both groups of children (pretest: \( F (1,18) = 3.830, n.s., \eta^2 = .175 \); posttest: \( F (1,18) = 1.492, n.s., \eta^2 = .077 \)).

4.3. Error rate

The repeated-measures ANOVA assessing the error rate discovered a significant main effect for the factor “group”, \( F (1,17) = 6.085, p < .05, \eta^2 = .264 \). Children in the experimental group reduced their errors (\( M = 6.06, SE = 1.80 \)), whereas the children of the control group increased their errors (\( M = -1.26, SE = 2.40 \)). There was neither a significant effect of “angular disparity”, \( F (2,34) = .233, n.s., \eta^2 = .014 \), nor for the interaction between both factors, \( F (2,34) = 1.168, n.s., \eta^2 = .064 \).

Table 1

<table>
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<th>Participant</th>
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Fig. 2. Difference between the reaction times in the chronometrical mental rotation tasks from post- to pre-test. A more negative score indicates a larger reaction time gain. The results are presented separately for each group and angular disparity. Error bars indicate standard errors.
4.4. Mental rotation speed

The analysis of mental rotation speed revealed a significant interaction between “time” and “group”, \( F (1,17) = 8.62, p < .05, \eta^2 = .336 \). Children from the experimental group increased their mental rotation speed (pre: \( M = 64.41 \text{s} \), SE = 10.45; post: \( M = 91.28 \text{s} \), SE = 12.41). The control group showed a decrease in mental rotation speed (pre: \( M = 103.47 \text{s} \), SE = 18.80; post: \( M = 63.90 \text{s} \), SE = 8.37). (See Fig. 3).

4.5. Additional results for the experimental group

Based on our results we chose to investigate whether the cognitive improvement was a lasting effect in our EG. Due to the missing progress for the control group in the mental rotation ability and the amount of time needed for assessing all children in the different parts of Germany, a 6-month follow up was only performed for the experimental group. Six months after the post-test every participant solved the chronometric mental rotation test again. We conducted a univariate analysis of variance with the dependent variable "reaction time", the within subject factor “angular disparity” (0°, 90°, and 180°), and the between subject factor “time” (pre-test, follow up). The pre-test and follow up were chosen because pre-test and post-test data were already considered in the first analysis. The factor “angular disparity” and “time” were explored with an analysis of variance. A significant main effect for “angular disparity”, \( F (2,18) = 66.15, p < .01, \eta^2 = .880 \), and “time”, \( F (1,9) = 13.45, p < .01, \eta^2 = .599 \), was found. Additionally, an interaction between both factors, \( F (2,18) = 4.584, p < .05, \eta^2 = .337 \), was shown. For the 0° condition the reaction time was lower in the follow up test (\( M = 1815.40, SE = 308.25 \)) compared to the pre-test (\( M = 2671.96, SE = 489.49 \)). \( F (1,9) = 12.52, p < .05, \eta^2 = .582 \), this was also found for the 90° condition, \( F (1,9) = 8.769, p < .05, \eta^2 = .494 \) (follow up: \( M = 3696.85, SE = 316.71 \); pretest: \( M = 6244.32, SE = 1003.45 \)), and the 180° condition, \( F (1,9) = 16.72, p < .01, \eta^2 = .650 \) (follow up: \( M = 4112.75, SE = 604.62 \); pretest: \( M = 6007.49, SE = 769.90 \)). Interestingly, in all three conditions (pre-test, post-test, and follow up) the experimental group’s reaction times did not differ between 90° and 180° (pre-test: \( F (1,9) = .602, n.s., \eta^2 = .063 \); post-test: \( F (1,9) = .025, n.s., \eta^2 = .003 \); follow up: \( F (1,9) = 1.221, n.s., \eta^2 = .119 \)).

In Fig. 4 we present the data from the pre-test, post-test and follow up test for the EG. Reaction time decreased from pre-test to post-test and to the follow up test; decrease for 0° (pre-posttest: \( d = 0.51 \); pretest-follow up: \( d = 0.66 \); 90° (pre-posttest: \( d = 0.85 \); pretest-follow up: \( d = 1.14 \)), and 180° (pre-posttest: \( d = 0.94 \); pretest-follow up: \( d = 0.87 \)) (compare Fig. 4).

5. Discussion

Due to the fact that the reaction time in the chronometric mental rotation test was influenced by the training, resulting in faster reaction time for the experimental group, it was shown that a beneficial influence of juggling on mental rotation performance also exists for children with spina bifida. This was proven for all angular disparities, although it is thought that in the 0° condition no mental rotation is needed. This study adds to the data of earlier reports about the influence of juggling on mental rotation performance in adults and school-aged children (Jansen, Lange et al., 2011; Jansen, Titze et al., 2009). Furthermore, the difference score gains in the conditions “90°” and “180°” produced in this study are similar to the results found in the juggling studies with adults and children mentioned above. In both conditions the reaction time gain was similar. The linear increase in reaction time in relation to increasing angular disparity (Shepard & Metzler, 1971) is a typical function observed in mental rotation tasks, but not in studies which describe the reaction time gain from pre- to post-test. Astonishingly, our data revealed no significant increase in the reaction times between 90° and 180°. This is in line with previous findings of Jansen-Osmann and Heil (2007), who also did not find the linear increase in reaction time between 90° and 180° for cube figures.

Additionally, the non-linear increase between these two angular disparities has also been found in visuomotor mental rotation (Neely & Heath, 2009, 2010), who explained this differences with the use of an vector inversion strategy in the 180° condition which is cognitive less demanding and results in faster reaction times. This phenomenon might be explained by the specific design used in each experiment. We used only three orthogonally angular disparities (0°, 90°, and 180°) which might have led to these findings. Beyond this explanation one could assume that in 180° condition a different solution strategy (flipping the object) was used compared to the 90° condition (mental rotation). The use of different strategies might account for the non-linear increase between these angular disparities.

Wiedenbauer and Jansen-Osmann (2007) have already presented the positive effect of manual rotation training on mental rotation ability in children with spina bifida. The present study confirms and enlarges these findings. While Wiedenbauer and Jansen-Osmann (2007) used two-dimensional drawings as stimuli for their study, this study confirmed the mental rotation improvement in
children with spina bifida when using three-dimensional drawings. In comparison to the study of Wiedenbauer and Jansen-Osmann, an additional change was made regarding the intensity of training that was offered to the participants. Whereas the children in Wiedenbauer's and Jansen-Osmann's study had a one training session of 24 min, the training conducted in this study lasted 1 h per week for an 8-week-time period. Furthermore, the juggling training offered in this study is a more familiar, respectively more everyday-life based training, than the manual training and therefore more suitable to be integrated in the daily living of the children.

It has already been shown that children with spina bifida demonstrate decreased mental rotation ability and spatial abilities compared to healthy children (Wiedenbauer & Jansen-Osmann, 2006). This study shows that these children benefit from training with regard to these abilities. Our results are in line with other studies that highlight the benefit of training for spatial abilities, especially for those participants that initially show poorer mental rotation abilities (Rizzo et al., 2001). We found no differences between children who learned to walk and children who were restricted to a wheelchair regarding their mental rotation ability. This could mean that either children with spina bifida benefit from juggling training regardless of their motor abilities or that other motor abilities besides locomotion (walking vs. wheelchair) are important for the performance in spatial tasks. Since this research question was not part of this investigation, this aspect should be looked into in more detail in future studies. Additionally, it was shown that the improvement of the mental rotation ability outlasted the time in which training was offered and lasts at least as long as 6 months after the training. However, one has to consider that some of the benefit might result from learning.

Because we could show that the participating children indeed performed a mental rotation, which is proven by the increasing reaction times with increasing angular disparity (i.e. Shepard & Metzler, 1971), we also analyzed the reaction times further with regard to the mental rotation speed. The children in the experimental group showed an improvement in their speed from pre-(64.41°/s) to post-test (91.28°/s), children of the control group showed a decrease in the speed from pre- (105.47°/s) to post-test (63.90°/s). This indicates that children with spina bifida improve their mental rotation speed due to juggling training. When considering the different stages of mental rotation mentioned by Shepard and Cooper (1982), the findings of this study indicate that juggling has a direct effect on the stage in the mental rotation process which requires the rotation. Since it was shown that the slope of the regression differed between the two groups from pre- to post-test, the difference can be attributed to the “rotation of the objects” stage. This is in line with the results of Wiedenbauer and Jansen-Osmann (2007), who also found an improvement in mental rotation itself after training. Because the gain in mental rotation speed after the juggling training was also visible in the 0° condition, juggling seems not only to improve the rotation itself but also the stages in the rotation process where encoding is required.

Changes in neurophysiologic processes due to juggling were already shown by Draganski et al. (2004) and Scholz, Klein, Behrens, and Johansen-Berg (2009). Draganski et al. (2004) revealed that a 3 month juggling training induces an increase in brain plasticity in exactly that area, namely the intraparietal sulcus, which is involved in mental rotation (Jordan et al., 2001). Draganski et al. (2004) found that the experimental group had a significant gain in gray matter in the mid-temporal area and the intraparietal sulcus. Therefore, they concluded that juggling, which involves the perception and the spatial anticipation of objects, has an impact on the structural plasticity in the visual areas. These neuroscientific findings were expanded by the findings of Scholz et al. (2009) who also found changes in gray matter after juggling training, but could additionally show that these changes also occur in white matter. With diffusion tensor imaging they found significant increases in the white matter in the posterior intraparietal sulcus of the experimental group. These findings were independent from the training progress. These neurophysiological findings can further be supported by the study from Eisenegger, Herwig, and Jäncke (2007). They found an activation of the primary motor cortex corresponding to the hands while performing a mental rotation task, suggesting that this brain area is generally involved in the processes of a mental rotation task. Since juggling is a motor behavior using the hands, it is assumed that the primary motor cortex is activated during this task (Scholz et al., 2009). According to Eisenegger et al. (2007) the primary motor cortex is involved in mental rotation and thus juggling seems to have a direct influence on mental rotation.

Based on the changes in neurophysiologic processes, one might also assume that the improvement in mental rotation might be due to improvement in the action-based visual perception of children with spina bifida. Dennis et al. (2002) showed that children with spina bifida have an impaired performance in action-based tasks, which includes mental rotation. According to Dennis et al. (2002), action-based tasks require representations of multiple stable states and therefore are coupled to movement. This relationship might be the basis on which the improvement in mental rotation through motor training is explained. Because of the practice and the improvement in juggling, the coordination of multiple stable states might be trained with this task and through that result in a better performance in the mental rotation test at the end of the training. This can be explained from a more behavioral point of view by the idea that these two abilities (juggling and mental rotation) are connected through their underlying features. Both abilities require cyclic activities and temporal and spatial constraints (Jansen, Titze et al., 2009). During throwing and catching in juggling, the hands move along trajectories that are more or less elliptical (Post, Daffertshofer, & Beek, 2000); during mental rotation cyclic trajectory movements around three axes are needed to bring one object into the position of the standard object. Whereas mental rotation is thought of as a covert manual rotation (Wohlschläger & Wohlschläger, 1998), juggling is considered to be similar to a spatial clock (Post et al., 2000).

5.1. Limitations

Given that the improvement in mental rotation performance was already proven to be specific to juggling training, no training was used in the control group. Former studies have shown a beneficial effect of juggling training compared to non-training (Jansen, Titze et al., 2009) and compared to stretching training (Jansen, Lange et al., 2011). Because the “juggling effect” did not differ due to the control group (no training vs. other motor training), it was decided to use a control group without training due to the high economic effort and difficulties to conduct this study. However, future studies should include a training control group to rule out that the improvement is due to the additional attention and enrollment of activity that the experimental group received. Additionally, one might argue about the stimuli used were inappropriate because of their three-dimensionality, but since the children showed the linear increase in reaction time with increasing angular disparity, it can be assumed that the children were able to solve this task using mental rotation. These stimuli were selected in order to compare this study to earlier studies regarding the influence of juggling on mental rotation performance (Jansen, Lange et al., 2011; Jansen, Titze et al., 2009). Furthermore, the follow-up did offer an interesting result, but the limitation created by the missing control group must be considered carefully. In future studies the influence of
training on different stimulus material might be an interesting topic as well as the use of other objects in the posttest to investigate transfer effects in more detail.

6. Conclusion

Children with spina bifida benefit from juggling training regarding their mental rotation ability. They demonstrated a decrease in reaction time due to the training compared to a control group. This effect was still observable in the follow-up test. Therefore, this study shows that the improvement of the mental rotation ability through juggling is not only present for healthy children and adults, but for children with spina bifida as well. Furthermore, the study suggests a possible therapy that could be considered for children with spina bifida. Future research must investigate whether the results are also found for different age groups of children with spina bifida and if further cognitive abilities are influenced by motor training in these children. Additionally, it should be investigated whether people with other neurological disorders also benefit from training with regard to their mental rotation ability.

References


