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The influence of juggling on mental rotation performance in children

Petra Jansen [1], Léonie F. Lange [2], Martin Heil [3]

[1] Institute of Sport Science, University of Regensburg; [2] Department of Anaesthesiology, Charité University of Medicine, Berlin; [3] Institute of Experimental Psychology, University of Düsseldorf, Germany

Summary

Study aim: To assess the influence of juggling training on mental rotation performance in children.
Material and methods: Two groups of girls aged 6 – 14 years were studied: experimental (EG; n = 26) and control (CG; n = 24). All girls solved a mental rotation task with 3-D block figures on computer screen (pre-test). After the initial test, EG girls participated in juggling training for 3 months; the CG girls participated in light strength training with theraband stretch bands. After 3 months, all girls solved the mental rotation task again (post-test). The post-pre differences in the mental rotation performance were recorded.
Results: Children who learned juggling performed the mental rotation task significantly ($p<0.05 – 0.01$) faster, in terms of reaction time, at non-zero angular disparity than their mates who were strength-trained.
Conclusions: Since mental rotation skills enhance spatial imagination, problem solving and mathematical skills, it may be assumed that juggling training enhances also other cognitive domains and is worth implementing in the education process.

Key words: Motor behaviour – Spatial performance – Juggling – Mental rotation – Children

Introduction

Research in the developmental, as well as in cognitive science, is focused on the relations between motor abilities and cognitive performance. Since Piaget's work [19], it has been assumed that the sensorimotor system is important for mental representation. Evidence supporting this assumption came recently from modality theories which emphasise the importance not only of a central control executive function, but also of modal functions [7]. It was shown that a dysfunction in motor development is often associated with a dysfunction in cognitive development and *vice versa* [8]. This relates to the specific assumption [3] that motor development and movement experience are relevant factors for cognitive performance, especially for spatial abilities [1]. Spatial abilities are cognitive processes that involve visualisation, orientation, and mental rotation [17]. Thereby, mental rotation is the ability to imagine how an object would look if rotated away from the orientation in which it is actually presented [21].

The influence of motor processes on solving a mental rotation task in adults was already demonstrated [22]. Mental rotation tests result in faster times and fewer errors when manual and mental rotations were compatible. In another study with adults [24], it could be shown that mental rotation could be trained with the help of a manual rotation programme, where mental rotation was trained *via* motor rotation consisting of moving a joystick.

The effects of motor processes on solving a mental rotation task were also investigated in children. A sample of 5, 8, and 11-year old children and of adults performed a mental rotation task while simultaneously rotating their hand, guided with a handle, in the direction compatible/ incompatible with the mental rotation task. The 5 and 8-year old children solved the mental rotation task, compatible with the motor task, easier than the 11-year old or adults, showing association between motor and mental rotations in younger children [6]. In contrast to that, a motor effect during mental transformations of body parts was only found in one of two experiments (performed with children aged 5 - 6 years, 7 years, and adults) and this effect was less pronounced in younger children [16].

An experimental study of body-oriented motor training, without using a handle or a joystick, on visual spatial tasks in children is missing until now. In a study on adults it was shown that juggling training over a period

Author's address Prof. Petra Jansen, Institute of Sport Science, Universitätsstr. 31, 93053 Regensburg, Germany
petra.jansen@psk.uni-regensburg.de

of 3 months improved mental rotation performance compared with a control, untrained group [12]. That result is valid from a neurological point of view because increase in brain plasticity was shown after juggling training [4] in exactly that brain area (intraparietal sulcus) which is involved in mental rotation [15].

It is not yet known if motor and imagery processes in children and adults are alike [6,16]. The main goal of this study was to find out if coordinative motor training (here: juggling training) would lead to an enhancement of mental rotation performance in children as shown earlier for adults [12]. Beyond that, the present study expands on that former study. Because a purely motor benefit could also explain the reported differences in the reaction velocity in juggling subjects compared to the control ones [12], the control group in this study was subjected to another conditional form of motor training, namely strength training with theraband stretch-bands. The study included only girls for the well-known gender differences in mental rotation performance, even in children [18], were not our objective.

Material and Methods

Participants: A group of 57 girls aged 6 – 14 years participated in this study; 29 of them were randomly assigned to the juggling group and 28 to the strength training group. Seven girls did not participate in the post-test, thus the experimental group (EG) counted 26, and the control group (CG) 24 subjects. The girls were trained in gymnastics, in Wesel, Germany, during their regular gym classes. The girls from each group were trained by two instructors at different corners of the gym. The parents of children gave their informed consent for children's participation and data utilisation after having been made familiar with the objective and protocol of the study which was approved by the local Committee of Ethics. In addition, the club committee and the gymnastics instructors agreed to carry out the experiments during the lessons. The children received juggling balls or the theraband stretch bands as gifts and the entire gymnastics group received €300 for their participation. The girls had normal or appropriately corrected visual acuity. None of the children were able to juggle before participating in this study.

Procedure: All participants were subjected to timed pre- and post-study mental rotation tasks which took place in a quiet locker room or in a first-aid room, in two different gyms in Wesel, in groups of three children. Each girl worked with her own laptop (15-inch monitor at about 50-cm distance) not seeing her mates and had her personal test leader. The experimental stimuli consisted of 18 perspective line drawings of three-dimensional forms (each one composed of 10 cubes) [13,21] and were 3D-rotated around the horizontal or vertical axis. Each form had a maximum size of 7 × 7 cm on the screen spaced by 14 cm. In each trial, two drawings of the same form were presented together. The stimulus presented on the right side of the monitor was either identical to the left side or mirror-reversed. The angular disparity between the two stimuli was 0, 90 or 180° (see Fig. 1 as an example). The subjects responded "same" by pressing the left touchpad button with index finger and "different" by pressing the right touchpad button with the middle finger.

Individual sessions lasted about 50 min each; every trial started with a grey-background screen and after 500 ms the pair of stimuli appeared and the subject had to decide whether the two stimuli were "same" or "different" (mirror-reversed). The stimuli remained on the screen until the subject responded by pressing a touchpad-button. The participants were instructed to react as quickly and as accurately as possible. The "+" or "–" sign was displayed for 500 ms in the centre of the screen to indicate the correctness of given response. The trials were spaced by 1500-ms grey-background screen intervals. After a block of 27 trials, the participants could choose to take a short break. They were asked to start the new block by pressing the space key. Each combination of objects (18 different drawings), normal or mirror-reversed, and angular disparity (0, 90 or 180°) was presented 4 times during the test, which resulted in a total number of 432 trials. In order to make the participants familiar with the test sequence, 54 unrecorded test trials were performed at the beginning of the experiment. The stimulus items were the same in the pre- and post-study mental rotation tests separated by a 3-month interval. In that time period, the children of the experimental group (EG, juggling) were subjected to juggling training twice weekly, 15 min at the beginning and 15 min at the end of regular gymnastics classes. The training was based on the Rehoruli's method and designed by a German juggler, Stephan Ehlers [5]. The children practiced various throw-and-catch tasks, their difficulty increasing every week. The children were instructed to train at home for about 10 min daily. At every session, the exercise time and the numbers of successful throws were recorded – how often a ball was successfully thrown from one hand to the other during the juggle performance.

Control children subjected to strength training (CG) were underwent a light strength training with theraband stretch bands. The following exercises were applied: "Biceps curls"– the girl stood with one foot on the theraband, its ends being grasped with one hand each and wrapped up until tight, then both arms were bent alternately, and

"Knee bend" – the girl stood on both feet on the theraband, shoulder length apart, then bent down and wrapped the ends of the theraband round her hands; after that, she sat up and stretched up her arms simultaneously. Control girls were also asked to train at home for 10 min a day and the numbers of repetitions of the "Knee bend" exercise they were able to perform were recorded during the training sessions.

The motor training effect in the juggling group (EG) was expressed as the difference between the first and the last training sessions in the numbers of successful throws. That effect in the strength-training group (CG) was expressed as the difference in the numbers of "knee band" exercise.

Data analysis: Only trials with correct response were used for reaction time (RT) analysis which was further restricted to "same" responses only, for angular disparity could not be unequivocally defined for "different" responses [14]. Moreover, all RT values outside the mean ± 2SD interval were eliminated prior to the analysis. Nevertheless, the analysis of all data combined revealed identical results.

The percent differences in the error rate scores (difference score error) and the post-pre RT differences (difference score RT) were dependent variables [24]. The data were subjected to one-way ANOVA for each group separately, the significance levels being corrected according to Huynh and Feldt [11] in order to compensate for non-sphericity of the data. Pearson's coefficients of correlation were computed for age, mental rotation performance and motor behaviour (difference score between the first and last training session for juggling or strength performance). The level of $p \leq 0.05$ was considered significant.

Results

No significant between-group difference in the reaction time (mental rotation task) was found at baseline. In the experimental group, juggling performance significantly ($p<0.01$) increased following the 3-month training compared with the pre-training status (baseline). The same was true for the control group performing "knee bend" exercises (Table 1). An example of the items of the mental rotation task is presented in Fig. 1.

The results of the training-induced differences in the reaction time are presented in Fig. 2. Significantly ($p<0.01$) better results were attained by girls from the experimental group (EG) than from the control one (CG) at angular disparities equal to 90 or 180°. Moreover, mean RT improvement in EG was significantly ($p<0.01$) highest at 90°. No significant angle-related differences were noted in CG. Regarding the error rate scores, no significant differences either between groups or between angular disparities were found.

Table 1. Mean values (±SD) of age, reaction time pre-training and of training effects

Variable / Group	Juggling n = 26	Strength n = 24
Age (years)	10.4 ± 2.2	10.5 ± 2.4
Reaction time (ms) pre	3704 ± 1055	3297 ± 1061
Motor training effect	16.8 ± 30.8**	2.33 ± 1.76**
Range	0 – 117	0 – 6

** p<0.01

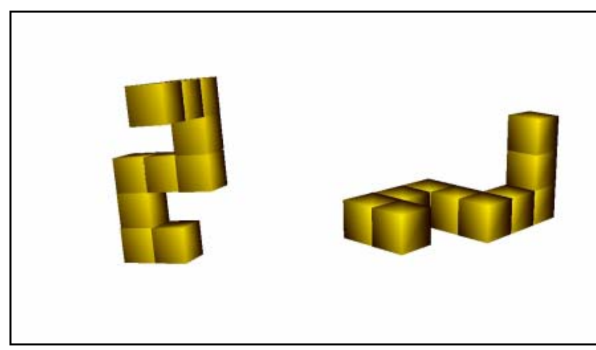

Fig. 1. An example of the items of the mental rotation task

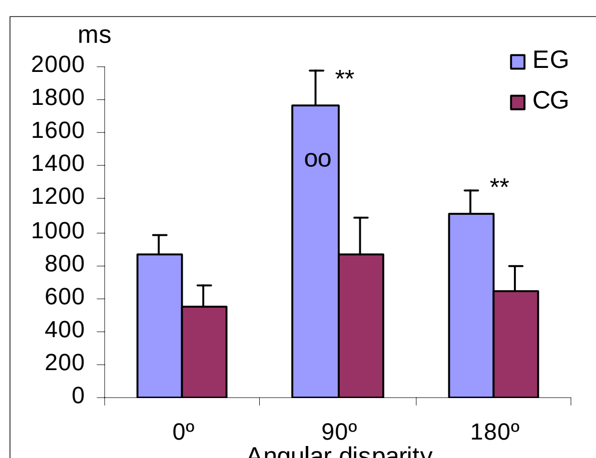

Fig. 2. Post-pre differences in reaction time in the mental rotation task (Means ±SE)

** Significant ($p<0.01$) difference between groups; °° Significantly ($p<0.01$) different from mans at 0 and 180°

Training effects were significantly ($p<0.05$) correlated with age in both groups but no significant correlations were noted with either difference scores in RT or with error rates (Table 2). Multiple regression calculus applied to data in the experimental group showed that a significant contribution to the mental rotation task had only age ($p<0.05$), that of motor performance remaining non-significant.

Table 2. Coefficients of correlation of training effects with age or difference scores in the mental rotation task

Group Correlated variable	Juggling n = 26	Strength n = 24
Age	0.466*	0.443*
Difference score (RT)	-0.012	0.160
Difference score (Error)	-0.142	0.216

* $p<0.05$

Discussion

This study was a continuation of our earlier report on juggling [12] and showed the relations between juggling and the mental rotation performance in schoolchildren. The results indicated that the training effect was specific for juggling and not for a general motor effect. The juggling training affected the reaction time (RT) in trials, in which the angular disparity was 90 or 180°, that at 0° remaining unchanged. Of course, no mental rotation is required to compare the two stimuli at 0° disparity, that condition serving thus as a kind of reference for the other two. In contrast to RT, there was no effect of juggling training on error rates. This finding is in accordance with many other studies showing that reaction time is the substantially more sensitive measurement for mental rotation effects than error rates [10].

This study confirmed the results of an earlier study [23] that manual rotation training can improve the mental rotation performance of school-aged children but the results depended on age [6]. It was demonstrated that only those aged 5 or 8 years but not the 11 years old had shorter RT in mental rotation tasks when the spinning of a hand crank matched the assumed path of mental rotation, rather than the other way round. When mental rotation of pictures showing body parts were studied, motor effects in mental rotation were not stable [16] and it was concluded that imagery and motor planning shared common resources. This is in accordance with the view that mental representations such as mental rotation are controlled by different modal functions connected to sensory and action systems [16,19]. When interpreting the results of mental rotation processes in terms of embodiment [25] and modal functions, the experimental design has to be very precise. It might be speculated why juggling and not a strength task is effective in mental rotation. Both motor tasks imply a performance feedback; girls from both groups received feedback from their training improvement, although the feedback in the juggling group was coordinative and that in the strength group was a strength one; it could be assumed that juggling and mental rotation shared common features, since both juggling and mental rotation required a cyclic activity and had temporal and spatial constraints [12]. In juggling, the hands move along more or less elliptical trajectories while throwing and catching balls move in a regular fashion [20]. In mental rotation, one object is brought along a cyclic trajectory around the three axes to bring it in the position of the standard object. While juggling may be thought of as a “spatial clock” [20], mental rotation seems to be a covert manual rotation [26]. The latter authors showed that rotational hand movements interfered with mental rotation and *vice versa*. Furthermore, juggling requires mirrored movements of hands while mental rotation requires the decision of whether two rotated objects are superimposable or mirrored. Further studies are needed to compare the effects of mental rotation and of other motor tasks involving cyclic arms or body activity, e.g. swimming or discus throwing.

The here presented data suggest that the age, not motor development, is the key factor in the improvement. This assumption has to be investigated in further studies with cognitive development monitoring in order to more precisely assess the effects of the cognitive and motor processes on mental rotation performance. That latter is not influenced automatically by the motor system but since it shares common features with higher motor processes, such as juggling, it might be influenced by a specific motor task. Another issue to be investigated into are the known gender-related differences (cf. [13]); a stronger activation of motor cortex was noted in women than in men when observing hand vs. dot movement, in men the situation being reversed [2].

Furthermore, the role of hormones ought to be discussed in more detail. The girls in this study were 6 – 14 years old and differed in their hormonal status. Because at least the effect of testosterone level on mental rotation performance has been shown [9], the varying hormonal status before and during puberty has to be regarded in further studies.

Summing up, a relation between juggling and mental rotation performance and, in a broader sense, between motor and cognitive performance was demonstrated. Further studies are needed to evaluate, in detail, the effects of age, gender and training duration on how cognitive the motor tasks need to be to have a positive influence on other higher-level cognitive tasks such as problem-solving, as well the stability of such effects.

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