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Development of mental rotation ability at primary school level

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ABSTRACT

Although mental rotation ability has been researched broadly in cognitive psychology and neural studies, development of mental rotation and the effective method of training are rarely considered as an area of study in the education field. We aimed to study the development of mental rotation through the training program by three-dimensional twisty puzzle in two groups of school students (8-9-years, n=13 and 11-12-years, n=17). This quasi-experimental study with the pre-test post-test design was conducted at the Tehran international school girls. The students' mental rotation ability was evaluated using the well established testing methods (VMRT; Vandenberg & Kuse, 1978). After the initial test and training program (twelve 60-minute sessions), the results of the within-subject ANOVA indicated that 8-9-years school children were incompetent after post-test through follow-up session, whereas the 11-12-years school students did make gain in post-test and three months after training program. The study findings suggest that development of MR ability by three-dimensional puzzles can be wielded throughout extra school training program among primary school students.

*Keywords***:** Mental rotation, primary school students, age difference, three-dimensional puzzle

1. INTRODUCTION

Spatial ability or visuo-spatial ability is the capacity to understand and remember the spatial relations among objects or space which can be viewed as a unique type of intelligence. It may be defined as the ability to generate, retain, retrieve, and transform well-structured visual images [1].

It is important to recognize that mental rotation (MR) is a cognitive process studied by cognitive scientists and neuroscientists. Particularly, it is a specific and distinct from the other spatial ability because it involves areas associated with motor simulation in the brain [2]. It is also involves the process of imagining how a two-dimensional or three-dimensional (3D) object would look if rotated away from its original upright position [3]. Similarly, it is a rigid transformation where the object stays geometrically similar after rotation [4].

There are a handful of studies that have dealt with developmental changes in MR performance [5-7], which mostly focus on the gender difference [8-11]. On the other hand, development of MR and the effective method of training are rarely considered as an area of study in the education field. Although there are somewhat conflicting results in the literature regarding whether spatial ability can be improved, numerous studies [12, 13] have indicated that it can be improved through training if appropriate materials are provided. Furthermore, a number of recent studies have found that 3D MR is too challenging for elementary school children [14, 15].

It is well known that age is a factor that influences someone's spatial skills. According to Piaget, spatial skills take place through three different stages [16]. The first stage involves learning topological visualization which enables children to comprehend topological relationships among object. Topological skills are primarily 2D and are acquired by most children by the age of 3 to 5. This is followed by the second stage where they acquire projective representation ability. This stage involves visualizing 3D objects and perceiving what they will look like from different viewpoints or what they would look like if they were rotated or transformed in space. Most individuals have this ability in their teenage years. Finally, in the third stage they learn to combine their projective representation ability with their concepts of measurement. The projective representation ability appears during adolescence and continues to mature till adulthood is reached.

Recent studies have provided evidence that development of spatial skill has been associated with engagement with spatial play activities such as puzzles, blocks, and shapes among children under the age of 7 [17-19]. There is also strong evidence that engagement in spatial activities may develop spatial ability [20-22]. This association holds even after controlling for other variables, such as parental education, that might influence this relationship. Moreover, socio-economic status (SES) and cognitive development reciprocally influence each other over the lifespan, and interact not only with parental SES during childhood, but also with several other variables in the surrounding environment [23].

Although MR training could be an appropriate method to improve the process of MR itself, it has been studied rarely in children. Existing researches revealed that MR ability is sensitive to training in children [24, 25]. On the other hand, if playgrounds provide an ideal opportunity for children to master physical and social skills, 3-D puzzle is a playground for the mind where students explore possibilities, problems and solutions at their own pace. So, solving 3D puzzle improves ability to analyze and understand a 3D body that involves 3D MR, stimulates brain, enhances thinking and analytical power, helps improve concentration

and boosts speed-hand-eye and brain coordination. Therefore, we aimed to study the effect of 3D twisty puzzle on development of MR ability in two groups of school students at the Tehran international and adaptive school girls (TI&ASG).

2. OBJECTIVES

The interest of the study is the investigation of the gains obtained by students after training with 3D twisty puzzle. We supposed that it helps to improve students' MR ability and their performance and if this will be the case, 3D twisty puzzle training program may be considered as a useful instrument for primary school students with respect to MR ability.

3. MATERIALS AND METHODS

3. 1. Study design and population

The present research was a quasi-experimental intervention study using the pre-test post-test method. The statistical population included female primary school students, in the first semester 2017-2018 academic year at TI&ASG.


Figure 1. Left (upper) to right (bottom): introduction, training tutorial, speeding method and end of program

A total of 30 students who met the inclusion criteria were selected in two different age groups including 13 students aged 8-9-years and 17 students aged 11-12-years as the samples. In order to enhance the MR ability, the researchers design a Rubik's cube training program. The idea behind this program is to help to understand a 3D body that involves 3D MR. The Rubik's cube is one of the most famous and popular 3D combination mechanical twisty puzzles in history that was invented by Erno Rubik in 1974, who had created this object to help instruct his students on how to think about spatial relationships [26]. The cube composed of 26 exposed sub-cubes, each containing one of six possible colored stickers on the exposed faces, requires a series of movement sequences, or algorithms, in order to be solved. Therefore, the learners practice to manipulate in their mind the complex spatial information that involves configuration of cubes and such ability is scholarly defined as visuo-spatial abilities.

The training was performed in twelve 60-minutes sessions on even days of the week for one month. The sessions included familiarizing participants with the features of a classic Rubik's cube and then solving it with layer-by-layer method as previously described [27]. Finally, the speeding method was practiced, which is mainly focuses on solving the cube in the fastest and most easiest way (Figure 1). The training was run by three experts known as speed cube solver. All the students were given a demographic data form to complete in case they decided to participate in the study. The students received a Rubik's cube, award and certificate for their participation.

3. 2. Measuring tool

The MR ability was assessed using the well established test by Vandenberg and Kuse MR test (VMRT), 1978 [28]. The test includes 24 items (two sets of 12 items) of 3D objects. Each item is made of one reference figure on the left and four target figures on the right. Participants were given 3-minutes for each set of 12 items, and sets were separated by a 2-minutes break. A point is awarded only if both correct stimuli are identified, which discourages guessing. Maximum score that can be obtained is 24. A sample test item is illustrated in Figure 2. Reliability for this test is generally high and has been reported between .83 and .91 for subjects from ages 12 to adulthood [28-32].
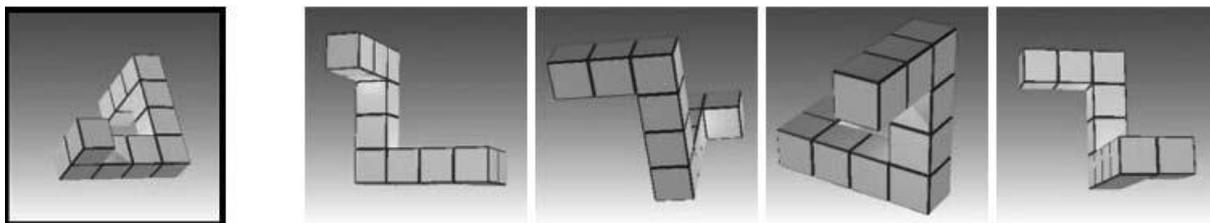
Figure 2. Example of VMRT-3D sample items. Note: The participants were asked to detect the two correct alternatives identical to the left target figure.

In order to compare and determine the effectiveness of the training program, the subjects were asked to retake the VMRT at the end of the training program and three months later, using English language instructions. The test was completed during the first morning session and the order of administration was counterbalanced among participants. All

participants were assured their data would remain anonymous and confidential. The collected data were kept on the investigators' computers and reviewed only by the investigators.

3. 3. Inclusion criteria

The inclusion criteria were: being 8-9 or 11-12 years right-handed students at the Tehran international school girls with ability to read, write, understand and speak English fluently. Having normal or corrected-to-normal vision, certified by a specialist physician.

3. 4. Exclusion criteria

The exclusion criteria were: having serious physical or psychological disease. Having any specific experience in MR and participating in similar programs in duration of the study.

3. 5. Ethical consideration

Ethics approval was granted and provided before seeing participants. The process of sampling and examination began after explaining the project to the students and their parents/guardians. Written informed consent and verbal consent were obtained. Participants could withdraw from the study at any time without having to justify their decision.

3. 6. Analysis of data

Indexes of mean, standard deviation (SD) and frequency were used to describe purposes. For the assumption of normality, the Shapiro–Wilk test was examined on all data sets. The test-retest method was used to determine the reliability of the VMRT using Pearson product-moment correlation coefficient. To determine the changes in VMRT scores, repeated measures (within-subject) ANOVA was used. We also applied η^2 after repeated measures.

Finally a Wilcoxon signed-rank test was further performed for skewed score. The data were statistically analyzed by IBM SPSS V23.0 at a significance level of 0.05.
In reference to effect size, since different benchmarks have been used to interpret η^2, we used $\eta^2 = .01 - .09$ for a small effect, $\eta^2 = .10 - .24$ for medium effects, and $\eta^2 \geq .25$ for large effects [33].

4. RESULTS

In this study, 30 foreign national students from different countries who were studying in primary school at Tehran international school girls in the academic year 2017-18 were selected in two age groups (8-9-years-old, 3rd grade and 11-12-years-old, 6th grade) as the samples. The means age were 8.6 ± 0.48 and 11.7 ± 0.46 years ($p < 0.0001$). All the students coming from relatively high SES, and belonged to the urban community. Furthermore, all the parents of students had a high academic degree. The income of 55% and 70% of parents of the students in the 8-9-years and 11-12-years groups was more than 3.5 thousand dollars per month, respectively (P=0.514). This basic information was confirmed by the demographic questionnaire (Table 1).

In this research, the test-retest method was used to determine the reliability of both groups' VMRT. As a result of the pre-test and the post-test conducted four weeks later apart

on 8-9 and 11-12-years school students, Pearson's product-moment correlation coefficient was found to be .80 good and .90 excellent reliability respectively.

Table 1. Demographic characteristics of the participants and their parents in both groups

Variable	8-9-years, n =13	11-12-years, n = 17	P value
Female	Percentage: 100%	Percentage: 100%	
Age	8.63 ± 0.48	11.75 ± 0.46	0.0001
Level of education	3rd grade	6th grade	
The amount of parents' income:			
Code 1: income ≥ 3.5 (thousand dollars)	Code 1: 55%	Code 1: 70%	0.514
Code 2: income ≤ 3.5 (3.5 thousand dollars)	Code 2: 45%	Code 2: 30%	
Father's education degree:			
Code 1 & 2: (education based on degree)	Code 1: 40%	Code 1: 45%	
Code 1: bachelor degree	Code 2: 60%	Code 2: 55%	1.00
Code 2: master degree or higher			
Mother's education degree:			
Code 1 & 2: (education based on degree)	Code 1: 40%	Code 1: 45%	1.00
Code 1: bachelor degree	Code 2: 60%	Code 2: 55%	
Code 2: master degree or higher			

Our findings revealed that the training program effect was in favour of 11-12-years school children when comparing pre-test, post-test and follow-up mean and standard deviation (*SD*) scores 5.59 (2.83), 8.35 (2.94) and 8.59 (2.87), while 8-9-years school children had a mean (*SD*) scores of 3.23 (1.23), 4.46 (1.56) and 3.61 (1.04) respectively. All VMRT mean scores are summarized in Table 2.

Table 2. Results of pre-test, post-test and follow-up from the VMRT in both groups

Age groups	n	Pre-test		Post-test		Follow-up	
		Mean	*SD*	Mean	*SD*	Mean	*SD*
8-9-years	13	3.23	1.23	4.46	1.56	3.61	1.04
11-12-years	17	5.59	2.83	8.35	2.94	8.59	2.87

n: number of students. *SD*: standard deviation.

The ANOVA revealed that the effect of 3D twisty puzzle Rubik's cube on the 8-9-years school children in three stages was significant, $F(2, 24) = 12.76$, two-tailed $p < 0.001$ and $\eta^2 = 0.14$. A similar effect in favor of 11- 12-years school children was observed when comparing VMRT, $F(2, 32) = 33.37$, two-tailed $p < 0.001$ and $\eta^2 = 0.19$. These results showed that 11-12-years school children have slightly greater impact on MR ability than 8-9-years school children, though both have medium effect sizes.

The findings related to changes on VMRT in 11-12-years school children during the study also showed that this training program increased the mean scores of VMRT in post-test and in follow-up session three months later, as shown in Figure 3. It is noteworthy that in 8-9-years school children the mean scores of VMRT in post-test increased substantially, whears reduced three months after, as it can be seen in the Figure 3. This simply indicates that this group of children were incompetent after post-test through follow-up session. In addition, it appears that the follow-up data of VMRT in this group of children were skewed. For this purpose, the overall pre-test, post-test and follow-up results of VMRT in both groups of participants are shown in Figure 3 below.
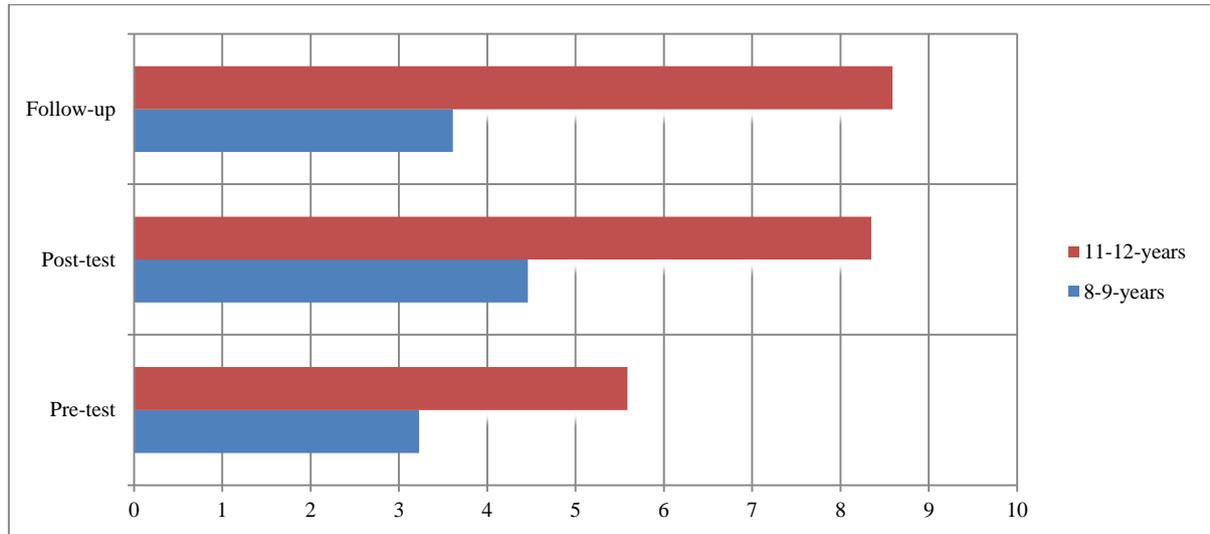
Figure 3. The overall MR performances of 8-9 and 11-12-years school children

Finally, in order to make sure whether the difference between the mean scores of pre-test and follow-up in 8-9-years school children was significant or not, researchers used a Wilcoxon signed-rank test and the result ($Z = 1.633$, $p = 0.102$) characterized as statistically not significant.

5. DISCUSSION

This study was designed to investigate the effect of Rubik's cube on MR performance among participants. First, and in accordance with previous studies [14, 34], the 11-12-years school students were found to score higher than 8–9-year school students. As expected, and in agreement with previous studies, we attribute this to an increase in general processing speed

[35], rotation rate with age [6], and it also might be partly due to students' maturity, life experience, and school programs including mathematic courses, particularly geometry, which may substantially contribute to improve their visuo-spatial ability [36].

Although 11–12-years being surely more exposed to MR tasks than 8–9-year school students, the training program improved MR performance in both groups during post-test. We noticed that the 8–9-year school students encountered difficulties performing VMRT. The possible reason makes the test used in our study difficult to be figured out by them was the time constraint. We presume that such tests need more time to be clarified by this age group, which needs further experimental study. This is probably one of the reasons why the VMRT is not frequently used with children younger than 13 years old [37, 38]. However, the current results showed that the training program (twelve 60-minute sessions) may be enough to show short-term improvement in MR ability among 8–9-year school students.

Another notable finding of the present study was the continuation of training program benefit in the three months follow-up stage. The results show that the training program used in this study can be considered an effective way for increasing MR ability among 11-12 years-old students in a long term. In general, training studies involve formal instruction of a skill, whereas practice studies involve the repeated use of the skill. Several training studies showed that spatial ability of an individual can be improved with the help of some applications like giving a treatment, using concrete materials, manipulative, various toys and computer programs [24, 25, 39-41]. From the body of work described in this paper, it appears that MR ability can indeed be developed through practice, but the type of program and the duration of program are important aspects to consider.

Our experiment confirms the reports from previous studies that the Rubik's cube is an activity that involves higher level of MR and can be practiced to improve spatial abilities over time [19, 42]. Thus, regardless of whether Rubik's cube is classified as a game or toy, and/or a teacher tool [43], it tests a person's ingenuity and knowledge. This study suggests that development of MR ability with 3D twisty puzzle can be wielded throughout extra school training program among primary school students.

On the other hand, the effect of SES on children's cognitive development is well established [44]. In fact, the SES identified as an important factor in influencing spatial cognition and the development of visuo-spatial memory, specially in performance on measures of and MR ability [45]. In our study all the participants were studied in a unique educational environment with relatively high SES.

It's also worth mentioning that due to ethical issues, it's not possible to conduct a control group in this study. Lack of a control group in order to assess and compare the effectiveness of Rubik's cube training program was one of the constraints of this study. In addition, since the number of students in this study was small and from a limited age range, it's uncertain whether the same findings will hold for the broader population of students.

6. CONCLUSIONS

The development of MR ability have been neglected or inadequately implemented in the educational environment. The findings of this research demonstrate that Rubik's cube is not for entertainment only, but serves also as a functional way of education.

Thus, practice with the Rubik's cube, a 3D twisty puzzle, seemed particularly beneficial for primary school students VMRT scores perhaps because the Rubik's cube and the VMRT display 3D images.

The contribution of this research lies in extending the current understanding of both the use and application of Rubik's cube training program as an important and useful tool in primary schools. By implementing a training program aimed at developing the MR ability of primary students, it appears to have a positive impact on female students' success.

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