Training mental rotation skills to improve spatial ability

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Prior research indicates that spatial skills, such as Mental Rotation Skills (MRS), are a strong predictor for mathematics achievement. Other studies have shown that MRS can be instilled through training and that they are a good predictor of another spatial skill: route learning and wayfinding skills. This paper explores these assumptions and reports an experiment with 43 undergraduate psychology students from a university in the south of England. Participants were randomly assigned to two conditions. Both groups were given pre- and post-tests on wayfinding in a maze. The intervention group trained with a MRS tool, based on a standardised MRS task. The control group did filler tasks by completing crossword puzzles. Collectively, the 43 students made 43×48=2064 assessment items for MRS, and 2×43=86 mazes. Although the intervention group showed a decrease in time needed to do the maze task, while the control group saw an increase, these changes were not significant.

Keywords: mental rotation skills, spatial tasks.

Introduction

With a new mathematics curriculum since 2014 (Department for Education, 2013) and continuing worries about mathematics achievement in England from an international perspective (e.g. PISA and TIMSS) policy-makers are constantly looking for ways to improve mathematics achievement. This paper describes one such way, through training in Mental Rotation Skills (MRS) and a focus on spatial orientation. As MRS are suggested to be strong predictors of achievement in science, technology, engineering and maths (STEM) subjects (Casey, Pezaris, & Nuttall, 1992), the expectation is that maths achievement will improve. The study has three aims:

1. The study aims to design a digital online version of a MRS measurement, so these could be assessed and trained. The environment that is chosen has the flexibility to easily modify the conditions of the measurement, for example whether the configurations can be manipulated or not. We want to make sure the online version is comparable with the original standardised measures.
2. To see if the measurement tool can serve as a means to train MRS.
3. To see if training MRS with the intervention has a notable impact on spatial orientation in a maze task.

Literature background

The starting point of this study makes several assumptions that are underpinned by previous research. Firstly, there is an assumption that MRS can be instilled by training. Perceptual tasks in animals lead to enhanced performance after hundreds of trials, with changes in synaptic connectivity (Recanzone Jenkins, Hradek, & Merzenich, 1992), based only on repetition, feedback and often gradual adjustment. In a meta-analysis of training studies for spatial skills, Uttal et al. (2013) found that mental rotation training can lead to stable gains in MRS. A longitudinal study by

Sorby (2009) suggested training benefited undergraduate students who initially exhibited poor spatial skills. These students achieved higher grades in engineering, mathematics, and science courses and were more likely to progress in their studies, compared with those who had not participated in the training (Sorby, 2009). A second premise is that mental rotation skills are a strong predictor for maths achievement. Having good spatial skills strongly predicts achievement and attainment in science, technology, engineering, and mathematics fields (e.g., Uttal et al., 2013). Lauer and Lourenco (2016) even brought this back to children in their first year of life and asserted that spatial aspects not only act as precursors to later spatial intelligence but also predict math achievement during childhood. Other evidence also suggests that spatial tasks are related to arithmetical and mathematical performance (Dumontheil & Klingberg, 2011). Cheng and Mix (2014) found evidence that mental rotation training improved maths performance in 6 to 8-year olds. However, Cheng and Mix (2014) conjecture that it might be possible that certain spatial tasks are more similar to certain maths tasks than they are similar to other spatial tasks if the same processes are engaged. For example, mental rotations skills have been shown to be good predictors of other large scale spatial abilities such as orientation, route learning and wayfinding skills (Nori, Grandicelli & Guisberti, 2006), especially in children (Fenner, Heathcote, & Jerams-Smith, 2000; Merrill, Yang, Roskos & Steele, 2016). Taken together, we combine these assumptions by designing an online MRS tool which we use with undergraduate students. By combining the study with a maze task we want to look at transfer to spatial orientation.

Methodology

This study used a 2x2 factorial design with two conditions:

- An intervention group. This group used a combined assessment and training tool based on a standardised MRS instrument.
- A control group. Students in the control condition completed crossword puzzles similar to those used as filler tasks in previous research on MRS (e.g. Cherney, 2008).

Both groups were asked to perform a maze task before and after the MRS and filler tasks. As we were also interested in the specific comparability of the Spatial Task with previous research we also recorded precise usage data. The participants were 43 undergraduate psychology students from a Russell Group university in the south of England. Two instruments were used: a Maze Task and Mental Rotation Skills Task.

Maze task

This study used a standard virtual 3D maze task (e.g. Meneghetti et al, 2016) where participants had to learn a route through the maze. The time taken to navigate the maze was recorded. During training, participants were given directions, for example "Turn Right at the next junction". There were local cues on the walls at each junction and four distal cues visible beyond the maze, one in each cardinal direction. On the test trial only the local and distal cues were available.

Mental rotation skills task

The MRS task was based on Ganis and Kievit's (2015) redesign of an existing standardised MRS (Shepard & Metzler, 1971). Stimuli are composed of a pair of three-dimensional objects: the baseline object has to be compared to a target object. Participants are asked to mentally rotate the target object to determine whether it can be brought into alignment with the baseline object. There are two types of stimuli:

‘same’ stimuli, where the two objects can be brought into alignment via rotation, and ‘different’ stimuli, where this is not possible. The stimuli use four angles: 0, 50, 100 and 150 degrees. Different to Ganis and Kievit (2015), this study uses one block of 48 trials. The four orientations occur equally often. On half of the trials, the objects in a pair were the same. The order of the trials was kept the same as the original validation study that randomized them, with no more than three same or different trials occurring consecutively. It is expected that response times increase with angle of rotation, and that different trials are slower than same trials.

Technical implementation

The technical implementation of the intervention is based on tried and tested applets for Building Blocks and Views (Boon, 2009). In this study, rather than interactive 3D elements, we used static 3D pictures in accordance with the standardised MRS task. The applets normally also have a scoring and feedback system that motivates pupils to find optimal solutions for the given tasks. The intervention can be run within a dedicated learning environment for maths, tracking student answers and providing log files. In this study, participants do not see if they have answered correctly or not, they only see their ‘progress’. Figure 1 shows a screenshot of one of the 48 MRS tasks.

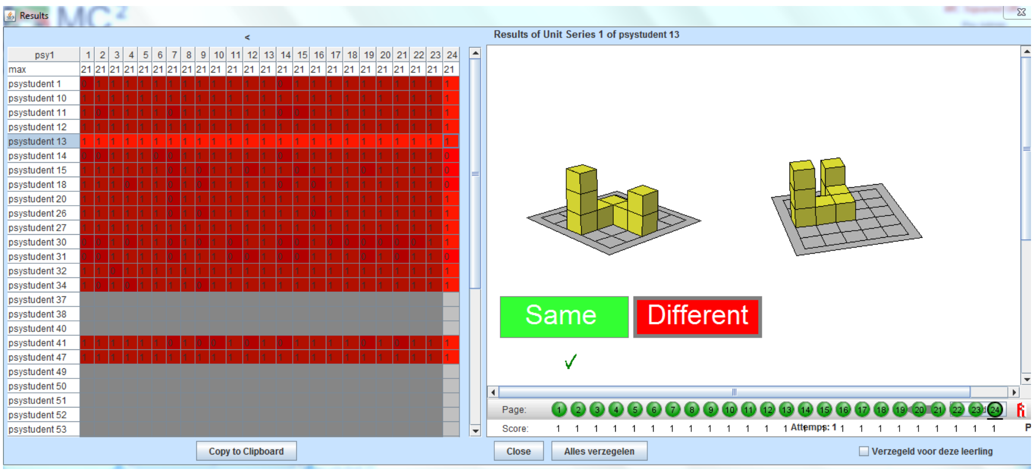

Figure 1 Administration panel for the MRS part of the study, task to the right.

Data analysis

We conducted multivariate analyses of covariance to determine effects. After collecting data we removed the data for the first MRS trial needed to get acquainted with the environment, leaving 47 trails. In addition, there were two trials where students took several minutes; as these data points were several SDs removed from the mean, we chose to remove them. Response times were measured in seconds. As we have three aims we use three corresponding data analysis approaches:

1. To compare our online version we conduct ANOVAs to check if, like the original study, response time and error percentage are linearly related to the angle of rotation, also while accounting for ‘same’ or ‘different’ tasks.
2. To see if the measurement tool can serve as a means to train MRS, we compare the ‘split-half’ scores with ANOVAs: does the second half yield lower error rates and lower response times than the first half. This is possible because the design of the MRS measurement has a balanced number of ‘rotation angles’.
3. To see if training MRS with the intervention has a notable impact on spatial orientation in a maze task, we check if the gain for the intervention condition is higher than the control group.

Analyses were performed with JASP 0.8 beta.

Results

Collectively, the 43 students made 43×48=2064 assessment items for MRS, and 2×43=86 mazes. Data for the first assessment item was discarded. In addition, two student results, both over 400 seconds were classified as outliers and discarded. The rest of the data was included in the subsequent analysis, with each analysis pertaining to one of the initial questions.

Analysis 1: validating the online MRS tool

Table 1 shows the average response times (RT) and error rates for the four angles of rotation. The table does not distinguish between 'same figure' or 'different figure' trials. The graph has an additional best-fit regression line.

Angle	RT		Errors	
	M	SE	% error	SE
0	8.04 (*)	4.63	6.3	8.4
50	10.33	3.26	14.0	9.4
100	11.63	2.32	15.5	9.7
150	14.51	12.97	20.5	10.9

Table 1 response time and error rate for different MRS angles. (*) The first item yielded several results that were more than two standard deviations removed from the mean. This could have been caused by the absence of a training question. The original duration was 19.10 seconds.

Comparing this with the original validation study the linear relationship of RT and error rate is in line with those findings: RT is higher for larger angles, and the error rate also increases. Different trials were made slower (M=13.47) than same trials (M=9.01) and with a much higher error rate (21.2% versus 7.56%).

	Angle			
Configurations…	0	50	100	150
Different	12.07	11.47	12.19	17.90
Same	4.67	9.19	11.06	11.11

Table 2 Differences in response time for 'same' and 'different' tasks.

Indeed the effect of solution speed varies by the angle of rotation, as seen in Table 2. However, there are differences in that the 0, 50 and 100 degrees are done at roughly the same speed for different configurations but not for same. The speed for 100 and 150 degrees is not different for similar configurations but it is for different ones. We hypothesise there might be a 'sweet spot' where an increased angle only lengthens the evaluation time for different configurations.

Analysis 2: does student performance improve during the MRS tool?

As Figure 2 demonstrates, we cannot conclude that response times improved during the intervention.

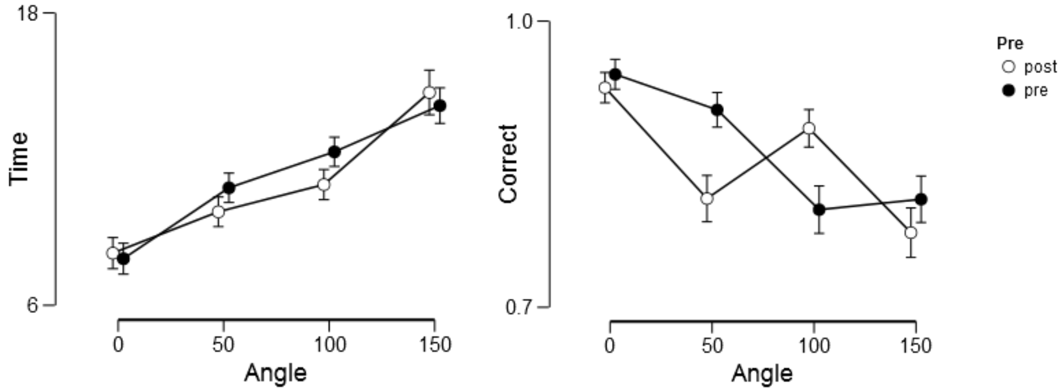

Figure 2 MRS response times and correctness did not improve during training.

Correctness did not change for 0 and 150 degrees in the course of the MRS task sequence. However, for 50 degrees performance deteriorated, and for 100 degrees performance increased.

Analysis 3: relation MRS and maze tasks

Assumptions for an ANCOVA were met: there was no statistical difference between groups on the pre-test, and there was homoscedasticity. Looking at the gain from maze pre-test to post-test in seconds, group 1, the intervention group showed a reduction in duration (of magnitude -12.55 s), while group 2 saw an increase in time (+17.24 s). However, an ANCOVA, with duration spent in the MRS task and precision, as well as their interaction were added to the regression formula. When controlling for pre-test maze score, MRS duration and MRS precision, as well as the interaction between MRS duration and precision there was no statistically significant difference between control and intervention group on the post-test maze score.

Conclusion

We can draw several conclusions. Firstly, that the online tool ‘behaves’ roughly similar to the standardised MRS measurement. The key finding is that response times and error rates increase linearly with the angular disparity between the two objects, suggesting that people transform internal representations of these objects incrementally, similarly to what takes place with rotations in physical space. Now we know this, we could build on this tool and make changes in modalities. For instance, the environment allows different modes of configuration with regard to what students can manipulate and change. By fixing one element and changing one other, it is easier to conduct more rigorous trials, while maintaining an ‘ease of use’. Secondly, that the speed of the participants does not improve following the use of the MRS tool. For performance there is a more mixed picture but it is hard to draw conclusions here. The length and intensity of the module might not be enough to show this. Finally, although the intervention group, with MRS tool utilised between maze pre- and post-test, showed a decrease in duration, these changes were not significant. We hypothesise that this might be because of the limited duration of the intervention; we suggest that in future trials the duration of the intervention could be extended.

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