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FUNCTIONING OF SPACIAL ABILITIES AMONG ARCHITECTURE STUDENTS

FUNKCJONOWANIE WYOBRAŹNI PRZESTRZENNEJ WŚRÓD STUDENTÓW ARCHITEKTURY

Abstract

It seems to be a popular judgement in public opinion that an architect is an outstanding person in terms of spatial thinking skills. But is this belief fully justified, or is it just a myth, a social heuristic idea?

The purpose of this paper is to expose this theorem to falsification through an experiment. In order to achieve meaningful results, the Mental Rotation Test (MRT) tool was used. The survey was conducted on a group of 185 students. The influence of the process of educating architects on the level of the task was also examined. The experimental group was divided into three groups: those beginning their studies in architecture, architecture students completing their education process, and students from other majors. Statistical analysis of the results showed no significant differences between the examined groups.

Keywords: architectural psychology, architecture students, mental rotation test, sex differences, spatial abilities

Streszczenie

W opinii publicznej popularny jest osąd, zgodnie z którym architekt stanowi osobę wybitną pod kątem zdolności myślenia przestrzennego. Jednak czy przekonanie to jest w pełni uzasadnione, czy stanowi jedynie pewien mit, społeczną ideę heurystyczną?

Celem niniejszego artykułu jest narażenie owego twierdzenia na falsyfikację poprzez eksperyment. W roli zadania dostarczającego miarodajnych wyników wykorzystane zostało narzędzie *Mental Rotation Test* (MRT). Badanie przeprowadzone zostało na grupie 185 studentów. Zbadany został także wpływ procesu kształcenia architektów na poziom wykonanego zadania. Grupa eksperymentalna podzielona została na trzy: studentów rozpoczynających studia na kierunku architektura, studentów architektury kończących proces edukacji oraz studentów innych kierunków. Analiza statystyczna wyników nie wykazała istotnych różnic między badanymi grupami.

Słowa kluczowe: psychologia architektury, różnice płciowe, studenci architektury, test rotacji mentalnej, wyobraźnia przestrzenna

1. INTRODUCTION

While reviewing the literature, it is common to encounter a variety of terminology and constructs aimed at describing what in English is referred to as “spatial ability.” In an attempt to describe this construct, researchers use phrases such as: “spatial skills,” “spatial perception,” “spatial reasoning,” “spatial visualization” or “visual-spatial ability.”¹ Achieving a scientific consensus is difficult, not only due to the differences in the way of defining, but also in the very scope of the defined feature. Different perspectives also concern the amount and types of spatial abilities, the names of their individual components, or the methods of measuring subcomponents.

One of the first approaches to the construct of spatial imagination was Thurstone’s distinction of seven basic mental skills.² Research on the topic of spatial mental abilities was continued during the World War II by the US Air Force. Experiments on groups of pilots indicated that the spatial ability consists of many components. Elements that Guilford describes as “spatial orientation” and “the ability to rotate mentally” were distinguished.³ The first one was based on the ability to recognize objects in different positions, as well as to perceive spatial patterns. The second one was based on the mental manipulation of three-dimensional objects.

In later research, McGee divided spatial abilities into two components, the first of which was “spatial visualization,” understood as the ability to rotate two- and three-dimensional objects in the mind. The second was “spatial orientation,” which involved manipulating the mental image from the perspective of one’s own body.⁴

Among the diversity of voices in the discussion as the most frequently quoted, Lynn and Petersen’s perspective deserves special attention. Researchers defined spatial abilities as symbolic and non-verbal information used as the ability to describe, transform, shape, and remember spatial information.⁵ Their work focused on measuring spatial abilities in three different categories: “spatial visualization,” as the ability to compose various spatial details when necessary to obtain a correct solution; “spatial perception” as the ability to define spatial relationships despite vague and complex perceptual data, and “mental rotation.” That is, the ability to quickly and correctly rotate 2D and 3D objects in the mind. Spatial abilities understood in this way are a key feature in many areas of human activity and culture. This *a priori* character seems to be an evolutionarily significant element, giving a great cognitive advantage over other species, opening the way, for example, to creating artifacts or transforming the environment. At the same time, it is controversial to what extent this skill is a personal feature and to what extent it can be trained and changed over time.

Among the domains based on spatial abilities the following can be mentioned: art, engineering, and mathematics – in particular geometry. Architecture is a kind of unification of the human activity. When analyzing the literature on the theory of architecture, it is easy to see how often spatial imagination is emphasized as the essence of creativity and ingenuity. This was already

¹ F. Kalelioglu, *The Effects of Using Web-Based 3D Design Environment on Spatial Visualisation and Mental Rotation Abilities of Secondary School Students*, Informatics in Education, 2020, no. 19(3), pp. 399–424.

² L.L. Thurstone, *Primary mental abilities*, University of Chicago Press, Chicago 1938.

³ J.P. Guilford, *The nature of human intelligence*, McGraw-Hill, New York 1967.

⁴ M.G. McGee, *Human spatial abilities: Psychometric studies of environmental, genetic, hormonal, and neurological influences*, Psychological Bulletin, 1979, no. 86(5), pp. 889–918.

⁵ M.C. Linn, A.C. Petersen, *Emergence and characterization of sex differences in spatial ability: A meta-analysis*, Child Development, 1985, no. 56(6), pp. 1479–1498.

noticed by Adolf Loos, formulating concepts such as *Raumplan*, created in a way in opposition to the creation of space only on the basis of a two-dimensional plan.⁶ Contemporary theories include Valerio Olgiati's analyses, presenting spatial creative activity in an extremely *a priori* light.⁷ According to the Swiss architect, the idea and form of the building should be closed before the artist makes the first sketch.⁸ Therefore, the relationship between the creator and his environment becomes crucial in the process of creating architecture, in which the idea of transforming space has the character of a mental operation, it must appear before taking any action.⁹

2. THE STATE OF RESEARCH ON SPATIAL IMAGINATION

Among the studies conducted so far in the topic of spatial ability, the most common pattern encountered is to test the effect of specific training on tasks requiring competencies consistent with the construct defined by Linn and Petersen. Erkoç, Erkoç and Gecu investigated the effectiveness of using *Google SketchUp* software in improving eighth grade students' mental rotation skills.¹⁰ Significant differences were found between pretest and posttest scores in a mental rotation task performed six weeks apart. During this period, the experimental group underwent training using *SketchUp* software. Significant differences were also found between the results of students who were trained in spatial skills using only the traditional method, i.e., hand drawing.

The effect of training on performance on mental rotation tests has also been shown in studies by Ogunkola and Knight.¹¹ For ten weeks, the experimental group participated in technical drawing classes taught by specialized teachers. The Vandenberg and Kuse Mental Rotation Test was used to measure spatial ability.¹² The results of the study indicated that students who participated in the training achieved higher scores on the mental rotation test than students who did not participate in the course.

The purpose of Kalelioglu's study was to determine the effects of applications based on a three-dimensional computer aided design (CAD) environment on sixth graders' spatial visualization and mental rotation abilities.¹³ Training using these applications has been shown to significantly increase students' spatial visualization skills and ability to visualize cross-sections of objects. In addition, study participants scored higher on the mental rotation test after eleven weeks of the course (pretest-posttest of the experimental group).

Furthermore, to the direct effect of training, the research also sought to answer the question of whether performance on spatial ability tasks is influenced by the type of study

⁶ A. Loos, *Ornament i zbrodnia. Eseje wybrane*, Centrum Architektury, Warszawa 2013.

⁷ O. Valerio, M. Breitschmid, *Non-Referential Architecture*, Park Books, Zurich 2019.

⁸ M. Breitschmid, *Die Bedeutung der Idee in der Architektur von Valerio Olgiati = The significance of the idea in the architecture of Valerio Olgiati*, Niggli, Sulgen 2009.

⁹ J. Stempin, *Remarks on Shaping Resilient Dwelling Space* [in:] Kozłowski T. (ed.), *Defining the architectural space. The truth and lie of architecture = Definiowanie przestrzeni architektonicznej. Prawda i kłamstwo architektury*, vol. 9, Oficyna Wydawnicza Atut, Wrocław 2020.

¹⁰ M. Erkoç, Z. Gecu, C. Erkoç, *The Effects of Using Google SketchUp on the Mental Rotation Skills of Eighth Grade Students*, Kuram ve Uygulamada Eğitim Bilimleri, 2013, no. 13(2), pp. 1285–1294.

¹¹ B. Ogunkola, C. Knight, *Technical drawing course, video games, gender, and type of school on spatial ability*, The Journal of Educational Research, 2019, no. 112(5), pp. 575–589.

¹² S. Vandenberg, A. Kuse, *Mental Rotation, a Group Test of Three-Dimensional Spatial Visualization, Perceptual and Motor Skills*, 1978, no. 47(2), pp. 599–604.

¹³ F. Kalelioglu, *op. cit.*

undertaken (architecture students vs. students in other disciplines). Campos-Juanatey and his colleagues' research involved students from two university courses, Architecture and Business Management.¹⁴ The participants' task was to compare the degree of sameness of two maps rotated relative to each other. It was shown that architecture students made fewer errors in the test than business students.

A separate and frequently addressed research issue was gender differences in spatial ability.¹⁵ Tucker and Torus combined the themes of sex differences and spatial ability training in their examinations.¹⁶ They showed no significant differences between men and women in their ability to mentally rotate before training. However, these differences emerged at a statistically significant level after the first semester of learning theory, sketching, and technical drawing. There were also significant differences between men and women in terms of mental rotation ability after the second semester of the course, during which students learned to use 2D and 3D software. In both cases, men scored higher on the Mental Rotation Test than women. The researchers concluded that men derive more benefits from training.

3. RESEARCH METHOD AND HYPOTHESES

As the aim of this paper, it was determined to check the differences between the groups of students permanently educated in spatial abilities and the group of students of other majors. In the nature of the first of the above, a group of architecture students was defined. It was further subdivided into two subgroups. The first one consisted of first-year engineering students (first year of education), while the second one consisted of second-year master's students (fifth year of education). The following questions were formulated:

- Is the group of people just starting their studies in architecture (first year) characterized by significantly higher spatial abilities than students of other majors?
- Do students after the five-year education process in architecture (5th year) have a significantly higher level of spatial abilities than students of other majors?
- Do students after a five-year education in architecture (5th year) have a significantly higher level of spatial abilities than students just beginning the education process (1st year)?
- Do students majoring in architecture have significantly higher spatial abilities than students in other majors?
- Among architecture students, do women differ significantly from men in spatial ability?
- Are female students significantly different from male students in terms of spatial ability?

It was assumed that people studying at the faculty of Architecture will constitute a group distinguished from the rest of the population in terms of spatial abilities, and that the education process at the faculty of Architecture will have a significant influence on these abilities. Guided by the above premises, the following research hypotheses were formulated:

Hypothesis 1: The group of first-year Architecture students differs significantly from students of other majors in terms of spatial abilities.

¹⁴ D. Campos-Juanatey et al., *Habilidad de los estudiantes de arquitectura para la rotación de mapas urbanos*, Revista de Estudios e Investigación en Psicología y Educación, 2017, no. 4, pp. 106–111.

¹⁵ M.C. Linn, A.C. Petersen, *op. cit.*

¹⁶ C. Tucker, B. Torus, *Sex differences in mental rotation ability in basic architectural education*, 3rd International Conference “Archi-Cultural Interactions through the Silkroad”. Selected papers, 2015.

Hypothesis 2: The group of 5th year Architecture students differs significantly from students of other majors in terms of spatial abilities.

Hypothesis 3: The group of 5th year Architecture students differs significantly in spatial abilities from the 1st year students.

Hypothesis 4: Architecture students differ significantly in their spatial abilities from students in other majors.

Hypothesis 5: Female architecture students are significantly different from male architecture students in terms of spatial ability.

Hypothesis 6: Female students are significantly different from male students in terms of spatial ability.

4. DATA COLLECTION PROCEDURE AND INSTRUMENT

The Vandenberg Mental Rotation Test (MRT) was used to measure spatial ability.¹⁷ The test was developed by Peters and his colleagues in 1995. It consists of 24 multiple choice questions. Each question presents an object formed from 6-unit cubes. Four figures are placed to the right of the object. The subject's task is to indicate two figures identical to the object on the left. The examinee receives 1 point for each question, provided they indicate both correct answers. If he selects only one of the two correct answers, he receives 0 points. The maximum number of points in the test was 24. The experiment was on a time limit of 10 minutes. Figure 1 presents a sample test question.

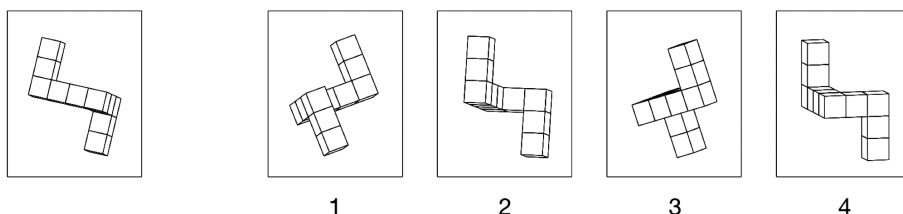


Fig. 1. Sample question for Mental Rotation Test.

The study was conducted remotely using software available at www.testportal.pl. It is a paid web application that allows you to create tests and accurately measure the time taken to solve them. Before the beginning of the study, participants received the study manual in Polish, translated by the authors of this article. The respondents were also asked to complete a metric containing basic information: gender, age, year, and field of study. Each participant was informed that by taking the test he or she agrees to participate in the study and that the study is anonymous. Subjects were given information about their ability to withdraw from participation at any time during the study.

After the participant clicked the “begin test” button, test questions were displayed on subsequent browser pages. Participants were not given the opportunity to go back to previous questions and to correct their answers. The questions in the test were arranged in a fixed

¹⁷ M. Peters et al., *A redrawn Vandenberg and Kuse Mental Rotations Test: Different versions and factors that affect performance*, *Brain and Cognition*, 1995, no 28(1), pp. 39–58.

order according to the original test sheet. The clock, located on the right side of the screen, was counting down the time left to solve the test. If the user did not manage to answer all the questions, the test closed after 10 minutes, and the results obtained by the user were recorded. Conducting the survey remotely was associated with some anomalies. If the participant intentionally closed the Web browser before completing all test items, then the Web site recorded completion of the test at 10 minutes. These types of responses from the subjects may presumably affect the results of the significance of differences test for the variable “response time.” Due to the inability to identify the results of individuals who have completed the test by closing their web browser, these responses will not be removed from the study.

5. PARTICIPANTS

There were 228 participants in the study. There were 43 scores of 0 points. These results were removed from the study. The sample size was $N = 185$. The study involved 131 students of architecture and related fields (114 females and 17 males) and 54 students of other fields (43 females and 11 males). Among the students of majors related to architecture, there were students of urban planning, architecture and urban design, interior architecture, landscape architecture, and interior and exterior architecture design. The group of architecture students included 35 first-year students and 27 fifth-year students. The remaining 69 students were second, third- and fourth-year architecture students. The mean age of the study participants was 22 years.

6. STATISTICAL ANALYSIS

Statistical analyses were performed using IBM SPSS Statistics version 27. In this paper, results were considered statistically significant when the significance level was $p < 0.05$. Values of tests considered statistically significant are indicated in bold. The independent variables in the study were field of study and gender. The dependent variables were mental rotation ability and response time. These variables were expressed on a quantitative scale. Table 1 presents the basic descriptive statistics of the variables “mental rotation ability” and “response time” for all subjects. The response time was expressed in seconds.

Variable	M	SD	Mdn	Min	Max	Skewness	SES	Kurtosis	SEK
Mental rotation ability	14.67	6.116	16.00	1	24	−0.541	0.179	−0.633	0.355
Response time	551.70	76.335	598.00	283	600	−1.888	0.179	2.925	0.355

Legend: M – mean, SD – standard deviation, Mdn – median, Min – minimum value, Max – maximum value, SES – standard error of skewness, SEK – standard error of kurtosis

Table 1. Basic descriptive statistics of quantitative variables.

The average score on the test is 14.67. The median value is 16. This means that half of the results obtained in the study have a value of 16 or less and the other half of the results have a value of 16 or more. The minimum score is 1 point and the maximum score achieved is 24 points. The absolute value of the skewness is 0.541 and is larger than the doubled standard error of kurtosis (SES). The distribution of the variable “mental rotation ability” is therefore left skewed (negative skewness). The absolute value of kurtosis is 0.633 and is less than twice the standard error of kurtosis (SEK). The distribution of the variable “mental rotation ability” is mesokurtic. Figure 2 shows the distribution of this variable.

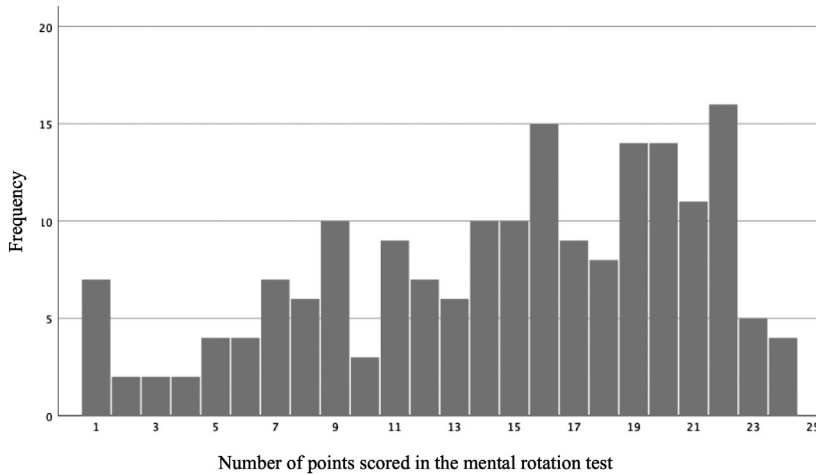


Fig. 2. Distribution of the variable “mental rotation ability”.

Table 2 presents the basic descriptive statistics of the variables “mental rotation ability” and “response time” distinguishing between architecture students and students of other majors. The response time was expressed in seconds.

	Variable	M	SD	Mdn	Min	Max
Mental rotation ability	Architecture and related fields	15.15	5.728	16.00	1	24
	Other disciplines	13.50	6.887	14.00	1	24
Response time	Architecture and related fields	556.00	73.116	599.00	283	600
	Other disciplines	541.28	83.430	585.00	304	600

Legend: M – mean, SD – standard deviation, Mdn – median,
Min – minimum value, Max – maximum value

Table 2. Basic descriptive statistics of quantitative variables, differentiating the field of study.

The average number of points obtained in MRT among architecture students is higher than among students of other majors and amounts to 15.15 points. The median score among architects is also higher at 16. In the group of students from other majors, the median value is 14 points. The minimum value in both groups is 1 point, the maximum value in both groups is 24 points.

For further analysis, the Kolmogorov-Smirnov test was conducted for the dependent variables. This test allows to compare the empirical distribution (of a sample variable) with the theoretical distribution (normal distribution). The significance level of the Kolmogorov-Smirnov test for the variable “mental rotation ability” is less than 0.001. The level of significance in the Kolmogorov-Smirnov test for the variable “response time” is less than 0.001. This means that the empirical distributions of the mentioned variables do not follow a normal distribution. Due to this property, the following analysis will use a non-parametric test: the Mann-Whitney test (for independent measurements).

Mann-Whitney tests were conducted to verify the six hypotheses formulated above. Table 3 presents the results of each test of significance of differences. The significance level obtained ($p = 0.993$) does not allow us to accept Hypothesis 1. The study found no significant differences in mental rotation ability between first-year architecture students and students in other majors. The significance level obtained ($p = 0.825$) does not allow us to accept Hypothesis 2. The study found no significant differences in mental rotation ability between 5th year architecture students and students in other majors. First and fifth year architecture students scored higher on the MRT test than students in other degree programs. These differences, however, are not statistically significant. The significance level obtained ($p = 0.820$) does not allow us to accept Hypothesis 3. The study found no significant differences in mental rotation ability between first-year and fifth-year architecture students. Fifth year architecture students scored higher on the MRT test than first year architecture students. However, the differences in these results are not statistically significant. The significance level obtained ($p = 0.187$) does not allow us to accept Hypothesis 4. The study found no significant differences between architecture students and students in other majors in terms of mental rotation ability. In the MRT test, architecture students scored higher than students in other majors. These differences, however, are not statistically significant (Table 3).

		1 st year architecture students versus students of other disciplines	5 th year architecture students versus students of other disciplines	1 st year architecture students versus 5 th year architecture students	Architecture students versus students of other disciplines	Architecture students: women versus men	Students: women versus men
Mental rotation ability	Z	- 0.008	- 0.221	- 0.228	- 1.320	- 2.546	- 3.087
	significance	$p = 0.993$	$p = 0.825$	$p = 0.820$	$p = 0.187$	$p = 0.011$	$p = 0.002$
Response time	Z	- 0.065	- 2.427	- 2.349	- 1.220	- 0.650	- 1.157
	significance	$p = 0.948$	$p = 0.015$	$p = 0.019$	$p = 0.223$	$p = 0.516$	$p = 0.247$

Table 3. Mann-Whitney test results for all tested hypotheses.

The obtained significance level ($p = 0.011$) allows us to accept Hypothesis 5. Significant differences were found between female and male architecture students in terms of mental rotation ability. Among architecture students, males (mean rank: 86.47) scored higher on the MRT test than females (mean rank: 61.74). The obtained significance level ($p = 0.002$) allows us to accept Hypothesis 6. Significant differences were found between male and female students in terms of mental rotation ability. Among students, males (mean rank: 121.73) scored higher on the MRT test than females (mean rank: 87.88).

Nonparametric tests of significance of differences were also conducted for the dependent variable: “response time”. The study found statistically significant differences in response times between 5th year architecture students and students in other majors ($p = 0.015$) and between 1st year architecture students and 5th year architecture students ($p = 0.019$). Fifth year architecture students (mean rank: 49.37) took longer to solve the MRT test than students in other majors (mean rank: 36.81). Fifth year architecture students (mean rank: 37.15) took longer to solve the MRT test than first year architecture students (mean rank: 27.14).

7. CONCLUSION

The results of the study did not allow us to reject the null hypothesis that students of architecture majors do not differ significantly from students of other majors. The authors point to the following possible scenarios as potential causes of this phenomenon.

Hypothesis 1: Architects have specific spatial abilities; however, the MRT test is not an accurate testing tool for these abilities. They do not overlap with the features examined by the MRT test.

It may seem intuitive that the group studying architecture should differ from the population in spatial ability. These students are subjected to many years of training, during which they are regularly exposed to both three-dimensional models, on which imaginative operations are performed, and various types of two-dimensional drawings, which are a form of presentation of designed spaces. It is conjectured that the MRT test used is not an accurate tool in terms of testing architect-specific abilities. These suppositions may also be supported by the argument indicating the lack of statistically significant differences between students starting and finishing their education. Previous studies have often shown the effect of even short training sessions using 3D software on the MRT test score. Thus, the authors conjecture that, overall, the process of architectural education, while undeniably influencing students, has no effect on the specific trait of mental rotation ability.

Hypothesis 2: The MRT test is an accurate tool for spatial ability with respect to skills specific to architects, but due to the factors listed below, architecture students and students in other majors do not differ in these abilities.

The specificity of the recruitment process of candidates for architecture majors should be pointed out. The dominant form of the entrance examination is freehand drawing. It could be argued for the thesis that drawing is a form of testing candidates’ artistic ability, but it is not an accurate tool for measuring their spatial ability. As the statistical description showed both in the group of architects and students of other majors there were maximum and minimum results for the sample. The medians were 16 and 14 for the above groups, respectively. Thus, as one possible interpretation, the authors point to the lack of differentiation at the level of candidate selection and the heuristic of equating artistic and drawing skills with spatial abilities.

Hypothesis 3: The element that differentiates architecture students is not the correctness but the time to complete the task.

The analysis showed a statistically significant difference in response time between the fifth-year group and the first-year student group. However, this result is not conclusive. It can be assumed that due to the specificity of the Internet survey method, the maximum time (10 minutes) will be reached by both those who completed the test with commitment, who did not have enough time, and those who closed the browser before the end of the time, obtaining a low score. In addition, the short time spent on the test is no indication that the test is easier to administer. Potentially, in the adopted form of the survey, it was possible to review all questions while answering only one or two questions. Such records would be characterized by low point scores and very short task times.

In order to further test this hypothesis, it would be advisable to conduct a separate study in which both groups (architecture students and students from other majors) would be given unlimited time to complete the tasks and the goal would be to obtain the highest possible percentage of maximum responses. A comparison of task completion times among error-free test takers would allow us to explore the hypothesis posed above.

The difference in the level of task completed between the genders of the participants was indicated as a statistically significant difference. This result coincides with numerous previous publications. In reviewing the literature, it appears that the effect of gender differences relates to specific properties of the MRT test. Whether gender differences will also reveal themselves using other spatial ability research tools remains an open question. The significant statistical difference indicated may not be representative due to the disparity in the size of each group.

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