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Eleven Years of Testing Spatial Visualization Skills

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Abstract. Over a period of 12 years, between 1999 and 2012, the spatial visualization skills of a total of 1939 new students of architecture at the Faculty of Architecture of the University of Ljubljana have been subject to careful analysis. For this work the Mental Rotating Test, known as "MRT", was used, which is one of the standard tests for the verification of these skills. The results of these tests have, on the one hand, confirmed some well-known facts about spatial visualization, but they have also demonstrated observable differences in the level of students' spatial visualization skills. Twelve years is a long enough period for the evaluation of both the applicability of the test itself, and the actual results. The testing process also gave rise to several questions about the validity of results obtained by using other well-known tests for the analysis of spatial visualization skills. This is the consequence of the narrowness of the field with which the individual tests deal, as well as the simultaneous complexity and inadequate knowledge about the actual phenomenon of spatial visualization, since this is a relatively young scientific field. One of the aims of the research was therefore to obtain new information in this field, including studies of the differences between the skills of left-handed and right-handed students, which were introduced in 2010.

Key Words: spatial visualization, mental rotation test (MRT), university education

MSC 2010: 97G80, 51N05

1. Introduction

Spatial visualization is a constituent part of man's spatial intelligence. Together with Man's linguistic, mathematical, locomotory, natural, musical and personal intelligence, it contributes to all human capabilities.

The study of spatial visualization is a relatively young scientific discipline. The first researcher in this field was Sir Francis Galten, who, in 1880, reported about his experimental

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findings in the field of mental visualization [13]. The idea that spatial visualization can exist separately from general intelligence was an important finding, which was confirmed by the results of psychometric studies. This was later followed by confirmation of the existence of a greater number of components of spatial visualization. However, due to the different analytical techniques used, confusion arose due to the different names used for its various constituent parts.

McGee [4] combined these elements into two important groups: spatial visualization and spatial orientation. He also classified the conceptualization of space into five components.

It has also been found that it is difficult to establish a clear boundary between the individual components of spatial visualization. For this reason, on the basis of the results of their studies, Linn and Peterson [12] developed the following definition of the concepts connected with spatial visualization:

1. Spatial visualization is a connecting concept, which in general refers to skills in the conceiving, transformation, creation and retrieval of symbolic, non-linguistic information. Spatial visualization involves mental rotation, spatial perception, and spatial visualization.
2. Mental rotation includes the ability to perform rapid and accurate rotations of a two- or three-dimensional picture or object.
3. Spatial perception is the ability of an individual to determine spatial relations with respect to his or her own orientation, (even) in the case of disturbing (external?) information.
4. Spatial visualization includes complicated manipulations of spatially presented information. In this case an analysis of the connections between the different spatial representations is needed.

According to J.P. Guilford [7], spatial visualization includes the following components:

1. Mental manipulations (orientation abilities, ability for "feel" three dimensions and ability to read two-dimensional drawings, ability to understand the complexity of spatial configurations, ability to remember proportions and shape, ability to sense the change in the shape of object, ability to determine the shape or position of the object after manipulation).
2. Manual manipulation (ability to draw a 2d image of spatial objects and/or to interpret relations between 3d objects, ability to determine the function or the composition of the whole when the parts are known).
3. Spatial creativity (ability to use sketching for finding 3d solutions, ability to work in 3d space, that is to create spatial constructions according to verbal requirements.
4. Speed of object's manipulation (speed of reaction, ability to rapidly develop images and interpret them correctly).

Apart from the above four concepts, a fifth concept exists, called "dynamic spatial ability", which includes an evaluation of relative speed and distance [10]. On the basis of various spatial visualization studies, Yilmaz [25] (2009) conceived a model which represents the following main components of spatial visualization skills:

1. Closure speed.
2. Spatial orientation.
3. Environmental ability.
4. Flexibility of closure.

5. Spatial relations.
6. Spatial visualizations.
7. Spatiotemporal ability.
8. Perceptual speed.

Thus the term “spatial orientation” represents a wider range, which is formed by the above-listed assembly of skills. As a result one obtains various names of concepts which combine together various combinations of the words “visual” and “spatial” with the words “representation”, “ability”, “orientation”, “perception” and similar, with the aim of defining more accurately each element of spatial visualization skills.

Unfortunately, spatial intelligence appears to have been underestimated with respect to other types of intelligence [19]. Perhaps this is the reason why the general public considers this skill to be inborn. Piaget and Inhelder [16] were concerned with this question. They developed several types of tests and proved that spatial visualization skills are developed in three stages of the growing-up of a child. Development during the growing-up period (from the age of 6 months onwards) was also confirmed by Huttenlocher and Newcombe [6]. Recent research, too, has confirmed that spatial visualization skills are developed throughout life, although this process is most active in youth [2, 4].

In the process of spatial visualization it is mainly the right side of the brain that is involved [22]. For many decades it has been well-known that, in the case of men, the right hemisphere is larger, and develops sooner than in the case of women [9]. Pakkenberg and Gundersen [15] maintain that men have approximately 16% more neurons of the neocortex than women, which can result in more extensive synaptic connections and cognitive differences. This is probably the reason that research has confirmed the differences between the sexes, since the right half of men’s brains is more developed. The superiority of the male sex is particularly apparent in the case of mental rotation tasks, less so in orientation tasks, and practically not at all in visualization tasks [5, 12]. Most experts agree that these differences do not become apparent until the end of puberty, and that the process of growing-up has an important effect on the development of this ability [14].

Many questions arise in connection with methods for developing spatial visualization skills, and the factors which have an effect on them. In recent years research has been mainly into the effect of modern technology, as well as into various methods of assessment and measurements, inspections and methods of improving spatial visualization skills.

There are various reasons why research should be performed into spatial visualization skills. It is generally known that good spatial visualization skills are a vital part of everyday life. It is particularly vital for certain professional fields such as architecture, building and civil engineering, mechanical engineering, the armed forces, certains types of sport, and work in traffic. The aim of this research is usually to find instruments for the effective evaluation of spatial visualization skills in individuals, while at the same time searching for effective methods to improve spatial visualization skills. It has been found, in the more developed countries, that the superior spatial visualization skills of employees results in more innovations and a more efficient working process, which in turn has a financial effect on the firm as a whole. For this reason courses are organized, frequently in fields connected with descriptive geometry, and modern audio-vizual techniques are used. It has been found [17] that descriptive geometry and engineering graphics can improve the spatial visualization skills of students, since these two fields are concerned with relationships in space and the projection of 3-dimensional space into a 2-dimensional medium. Courses for the improvement of spatial visualization skills are supported by tests which are performed at the start and beginning of the course, by means of which it is possible to record progress in this field.

The results of such testing methods usually indicate some progress. However, at the 2nd Croatian Conference on Geometry and Graphics, which was held in Šibenik in 2010, the question arose as to whether the improved results could have been due to the fact that participants had already performed the test once, so that solving it was easier for them. This effect could be seen in the results.

In parallel with research into spatial visualization skills, instruments for its measurement were developed. In 1971 Shepard and Metzler developed the so-called "Mental rotating test" (referred to in the text which follows as the MRT) [20]. Other similar tests also exist, e.g., MCT (the Mental Cutting Test, developed in 1939), DAT (the Differential Aptitude Test, developed in 1990), and TPS (Test Priestorovych Schopnosti — the Spatial Imagination Test, developed in 2003). Each of these tests is specialized for a particular segment of spatial visualization skills, although DAT and, particularly, TPS, aim to cover all the sub-fields of spatial visualization skills, whereas MRT is more specialized for the spatial perception of rotations and mirroring, and MCT for the relationship between a plane view and an actual object. The rapid development of computer techniques has much accelerated this process, particularly from the point of view of data processing, which has resulted in new knowledge. MRT was thus subjected to such development, since there was a need to improve it and remove all the external disturbing elements. Thus, Shiina and Suzuki [21] transformed and improved this method. As well as this, they unified the degree of difficulty for each studied case.

Leopold et al. [11] performed research into the spatial visualization skills of students at the universities of Kaiserslautern, Krakov and Houghton (Michigan), using the MRT, MCT, and DAT tests, and made comparisons of the results obtained. In the case of the majority of the tests, differences between the results obtained by male and female students were noted, as well as differences between the results obtained at the different universities. In all cases improvements were observed in the final test after one year of study. The similar results obtained in the different tests, and the high level of correlation between the achieved number of points for each of the three used tests, indicated that people with poorer spatial visualization skills have problems when attempting to solve tasks from different fields of spatial visualization skills.

In the case of the above-described research it should be mentioned that this was a one-off research project and not an on-going project over a longer period of time. There have been few long-term research projects in the field of spatial visualization skills. Takeyama el al. [23] performed research into the effectiveness of the teaching of orthogonal projection in 1995, but this research only lasted for two years. They used the MCT, as well as some other less frequently used test methods. The reason for the small number of such research projects probably lies in the fact that there are a lot of factors which have an effect on the development of the spatial perception of different generations of students. On the other hand, in order to be able to make realistic comparisons it is necessary to ensure uniform testing conditions, which means that various improvements in the testing method are open to question. At the Faculty of Architecture of the University of Ljubljana (referred to hereinafter as FA) a framework was established at the start of the testing process in 1999, which was then maintained throughout the whole investigated period, which made it possible to perform realistic comparisons of different generations of students. At FA it was decided that, due to the general lack of long-term information, each generation of new students should be tested.

The results of the tests performed at FA are also interesting because, in Slovenia, the greatest number of architects graduate from FA. Up until a few years ago FA was the only faculty of its kind in Slovenia. There is a lot of interest in enrolment at FA, so that, by means of entrance examinations, only the best candidates are accepted, i.e., those candidates with the best spatial visualization skills, which was shown by the results presented in [8]. On the basis of the results of the presently performed research it can be concluded that the students at FA probably represent the best part of their generation with respect to spatial visualization skills.

A long-term analysis is also important from the point of view that, according to the opinion of some psychologists and teachers, in the case of new students the level of knowledge of mathematics and technical subjects has fallen throughout Europe. Is it possible that, with such a fall, a fall has also occurred in the level of spatial visualization skills? The reasons which could confirm this hypothesis could probably be found in the environment in which we live. The new information technology has brought with it new behaviour patterns among young people. The traditional games that were played by children and teenagers, e.g., games with cubes or balls, whose rules and requisites were frequently made by the participants themselves, are on the wane. However, games where the perception of space and spatial relationships was very important were vital for the development of spatial visualization skills. Whether or not this effect can be seen in spatial orientation is another question, particularly because the available information technology makes the perception of space and spatial relationships easier. The purpose of the present research was thus to find answers to these questions, and, in particular, whether the level of spatial visualization skills of the population of students at FA is on the decrease, or not.

In 2010 a new item of data was introduced in the research: the determination of differences between results for right- and left-handed students. According to some theories [18] left-handed students should have better spatial visualization skills than right-handed students, so that, among architects, the percentage of left-handed students should be greater than the percentage in the general population.

2. Research method

The mental rotating test is one test for determining spatial visualization skills — in the field of mental rotation. At the Faculty of Architecture of the University of Ljubljana a version is used which was obtained from the National Center for University Entrance Examinations from Tokyo, Japan, together with keys for the solutions and assessments. The test is presented on paper of double A4 format. The aim of the first part of the test is to acquaint the student being examined with the appropriate method of solution. This is followed by test cases, with the correct solutions. This part takes about 10 minutes, so that the student has enough time to understand the actual procedure before he/she attempts to solve the test tasks.

The main part of the tests consists of the solving of 10 examples, twice. In every case two correct solutions are available. The time available for solving each of the sets of 10 examples is limited to 3 minutes.

The tasks are designed in such a way that in each case a basic object is given, which is represented by a series of 10 small cubes. The student has to choose two solutions which should represent the same object viewed at a different angle. The incorrect solutions represent a similar object which is usually a symmetrical mirror image of the actual given object (Fig. 1).

The test is performed at the start of the academic year. The test group consists of the

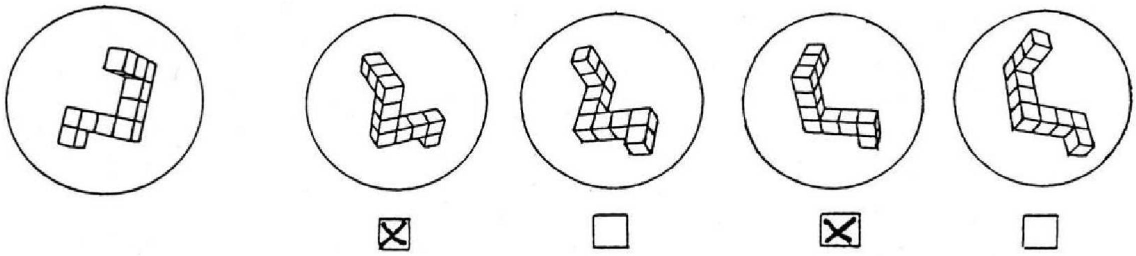


Figure 1: A test example with two correct solutions and two incorrect solutions

first year students. Starting in 1999, a total of 1939 students have been tested. Unfortunately it was not possible to perform the tests in 2000, due to objective reasons. A more detailed structure by academic years and sex is shown in Fig. 2.

Testing was also performed in some cases at the end of the academic year, and the results showed considerable progress. Since it is difficult to know to what extent the better results are due to the fact that the students had done the test once before, these results were not taken into account. In this way only the results of the first test are presented, where importance is attached to initial achievements in spatial visualization, and not its improvement. The most recent research included data about the left or right-handness of the students.

During the testing the whole sample was characterized by the beginning of the academic year, and by the sex of the students. In 2010 the apparent differences between left-handed and right-handed students were also evaluated. An overview of the resulting groups is presented in Table 1.

The individual designations of the groups have the following meanings:

- The first designation (e.g., 1999) means the year of testing (1999), or the period of

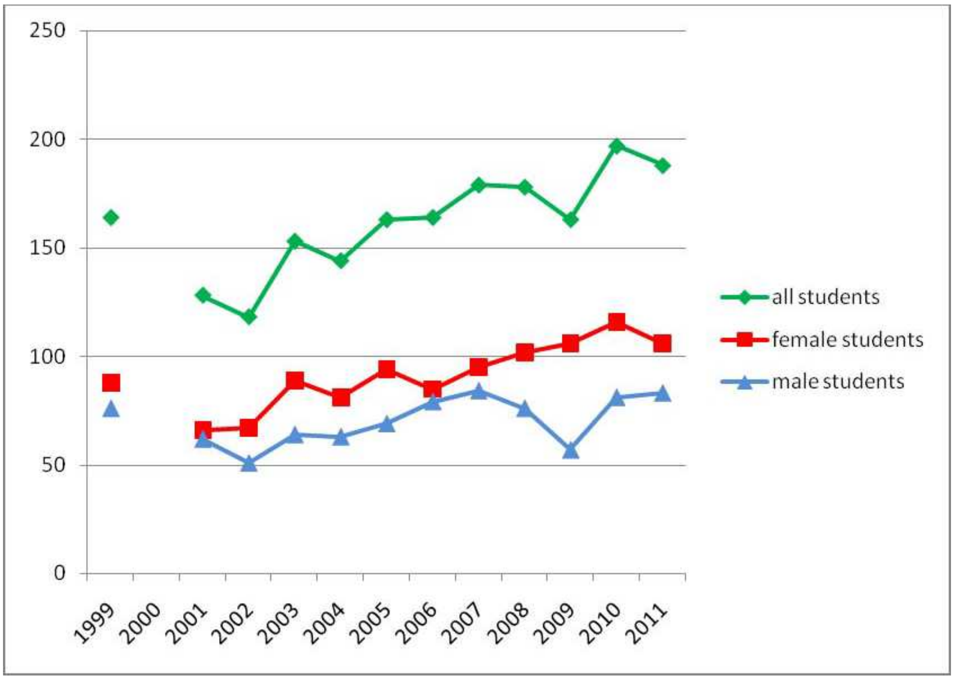


Figure 2: The structure and number of tested female and male students according to individual years

testing (e.g., 1999 – 2010)

- The second designation means:
  - all — the whole student generation
  - w — the female part of the student generation
  - m — the male part of the student generation
  - L — left-handed students
  - R — right-handed students

3. Results

A total of 1939 male and female students participated in the test (see Table 1). The number of those tested gradually increased, and reached its maximum in 2010 (197 participants). This difference is clearly visible, the number of participants in the previous academic year (163) being small in comparison with previous years. This trend follows the number of students studying the subject "Descriptive Geometry", which is even somewhat greater. This is because all those who had enrolled for this subject had either enrolled for the first time, or hadn't previously successfully completed it, whereas those doing the test were those who had enrolled in the subject for the first time. It is interesting to note that more female students performed the test than male students. There was a considerable difference in the period 2003 – 2005. In 2009 there was a quite a large drop in the number of male students, whereas there was a gradual increase in the number of female students over the period from 2006 to 2009, but a drop occurred in 2011. The greatest difference was observed in 2009. In that year 106 female students took the test, but only 57 male students. A very similar picture is obtained if the data about the number of students enrolled for the subject are studied.

The results presented in Table 1 and Fig. 3 show a relatively similar level of spatial visualization skills, with relatively small deviations in all the studied years. The values obtained vary from 20,0 points (50%) in 2006, to 21,6 points (54%) in 2004. The average number of points for the whole period is 20,78 points (51,8%). However, there are some oscillations in the level of spatial visualization skills according to sex. In the case of male students there were significant drops in the results for the years 2003 and 2009, whereas there was a significant drop in the case of female students in the year 2006. All these drops had an effect on the average number of points obtained in a particular year. The largest drop in the achieved levels of spatial visualization skills was observed in 2009, when the average number of points obtained dropped to only 18,9 (47,3%). After 2009, i.e., in the years 2010 and 2011, a rise occurred in all categories.

The results indicated the already known difference between the two sexes, which is characteristic for the whole of the studied period, and can be seen in Fig. 3. On average, this difference amounted to 7,4 points, or 18,6%. The average number of points achieved in the case of the female student population amounted to 17,5 (43,7%), and varied within the range from 15,5 points (38,8%) in 2006, to 18,9 (47,2%) in 2011. In the case of the male student population the average number of achieved points varied from 22,6 (56,5%) in 2009, to 26,3 (65,8%) in 2004. The average score was 24,9 points (62,3%).

A comparison of all the groups did, however, indicate a difference between the average for the period 1999 – 2011 and for those students who had enrolled in 2009, in all three groups. This difference is statistically significant only in the case of the male student population,

Table 1: The results obtained for individual groups of students

Group	*No. of participants N*	*No. of points*			*standard deviation*
		min.	*max.*	*average*	
1999 all	164	2	40	20,74	8,77
1999 w	88	2	38	17,39	7,55
1999 m	76	7	40	24,63	8,51
2001 all	128	0	38	21,08	9,24
2001 w	66	4	34	17,77	7,57
2001 m	62	0	38	24,6	9,74
2002 all	118	2	38	21,17	8,80
2002 w	67	2	37	17,43	7,42
2002 m	51	7	38	26,08	8,08
2003 all	153	0	40	20,2	9,00
2003 w	89	0	37	17,47	8,13
2003 m	64	0	40	23,92	8,76
2004 all	144	0	40	21,62	8,47
2004 w	81	5	32	17,91	6,11
2004 m	63	0	40	26,31	8,53
2005 all	163	4	40	21,21	7,95
2005 w	94	4	38	18,16	7,18
2005 m	69	8	40	25,27	7,33
2006 all	164	2	40	20,07	8,70
2006 w	85	2	33	15,51	6,27
2006 m	79	4	40	24,98	8,30
2007 all	179	3	40	21,25	8,64
2007 w	95	3	38	17,87	7,93
2007 m	84	6	40	25,07	7,80
2008 all	178	4	40	20,85	8,51
2008 w	102	4	35	17,27	7,25
2008 m	76	9	40	25,37	7,87
2009 all	162	4	40	18,94	7,31
2009 w	106	4	35	16,85	5,92
2009 m	56	8	40	22,89	8,07
2010 all	197	4	40	21,02	8,53
2010 w	116	4	35	17,64	7,52
2010 m	81	7	40	25,88	7,51
2011 all	188	4	40	21,38	8,43
2011 w	106	5	37	18,90	7,99
2011 m	83	4	40	24,53	7,95
1999-2010 all	1751	0	40	20,74	8,54
1999-2010 w	989	0	38	17,43	7,19
1999-2010 m	763	0	40	25,03	8,24
1999-2011 all	1939	0	40	20,78	8,53
1999-2011 w	1095	0	38	17,52	7,28
1999-2011 m	845	0	40	24,94	8,21
2010 L all	18	10	40	21,1	8,72
2010 L w	7	10	24	14,28	4,79
2010 L m	11	16	40	25,45	7,89
2010 R all	173	4	40	21,07	8,61
2010 R w	106	4	35	17,95	7,70
2010 R m	67	7	40	26,01	7,63
2011 L all	17	8	40	20,88	8,71
2011 L w	7	8	26	13.86	6,21
2011 L m	10	16	40	25,80	6,63
2011 R all	165	4	40	21,46	8,47
2011 R w	96	5	37	19,39	8,28
2011 R m	69	4	40	24,35	8,03

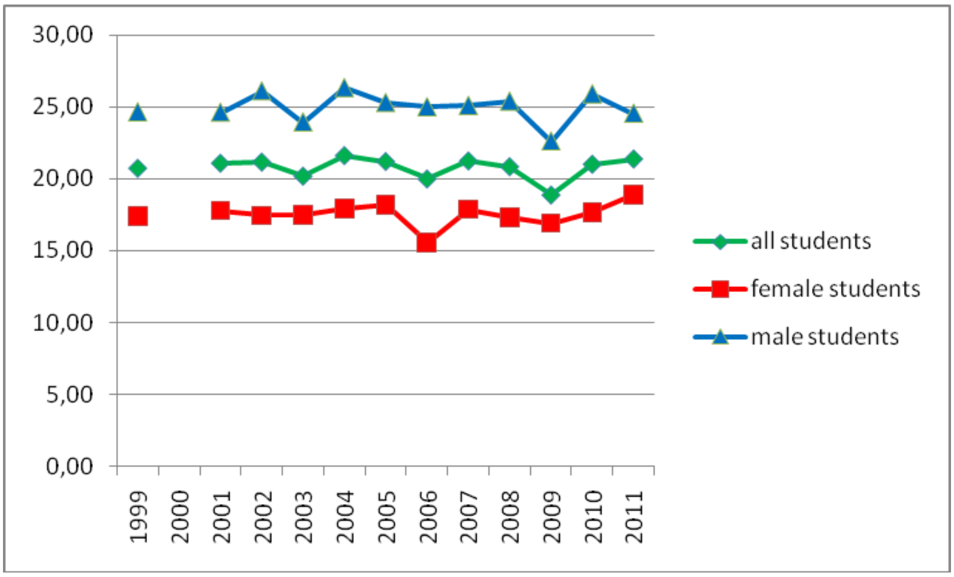


Figure 3: The average number of points achieved by students in the MRT tests, according to individual academic years

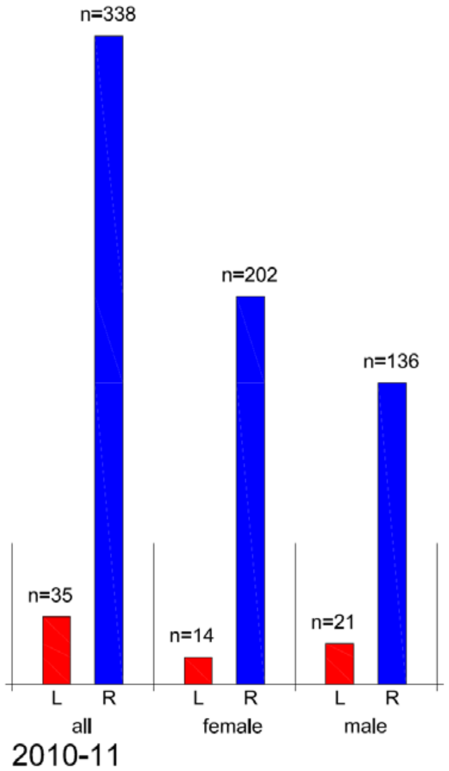
whereas in the case of the female student population, and the whole student population, this difference was not statistically significant.

The results of a comparison between right-handed and left-handed students showed that approximately 10% of the tested students were left-handed, less than 5% being ambidextrous. Also, less than 5 students did not state whether they were right-handed and left-handed. Thus the number of left-handed students was within the usual range for the proportion of left-handed people in the general population, which is considered to be between 5 and 30%. There is supposed to be a larger proportion of left-handers in the male population. This is also indicated by the results of this research (Fig. 4), since 15.44% of the studied male student population were left-handed, and only 6.9% of the female student population. The results of the Mental Rotating Test, shown in Fig. 5, showed very small differences in the whole student generation and in the male student population. In the case of the female student population and the whole population the results are better in the case of right-handers, whereas in the case of the male population they are better in the case of left-handers. There is a larger difference only in the case of the female student population: it amounts to 4.09 points (10.2%), but the sample is a very small one ($n = 14$). When we compare this result to Bölcskei [1], where the rate of improvement for left-handed architect males was 134%, we can find out that this results are probably the consequence of the small sample. The new research, we are planning in the future will give us the right answer.

4. Discussion

The results obtained in the MRT tests confirmed the differences between those obtained by students of either sex over the investigated period, which is comparable with the majority of research performed in other countries [11, 21, 24].

A significant fall in the level of spatial visualization skills was observed in 2009, which was statistically important in the case of the studied male student population. The reasons for the occurrence of a such a drop could be any of the following:



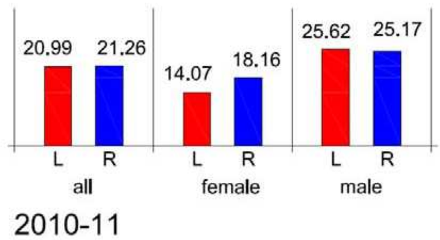


Figure 4 (left) and 5 (right): The average number of points achieved by students in the MRT tests, according to individual academic years

1. Only those future students who have above-average abilities (which are important for high school and particularly for matriculation) manage to break through the education system into FA.
2. The spatial visualization skills test is just one part of the entrance examination, whereas candidates learn to draw during their preparations for this exam. A certain number of points allocated in the entrance examination are the result of matriculation and success in various subjects in recent years at high-school, whereas additional points depend on the verbal examination.
3. In their youth boys no longer play so many (boyish) games, which are otherwise able to improve their spatial visualization skills (ball games, various other games and sports), and also, in their free time, they do not perform those activities which help to development spatial orientation (building blocks, modelling).

In spite of this, the results which were obtained in the years following 2009 have a more "normal" appearance, which means that in 2009 there was an oscillation similar to those which occurred, though on a smaller scale, in 2003 and 2006. It is presently not possible to know why such oscillations occur. For this reason it will be necessary to continue with such research in the future in order to find out whether there is a rational time interval for such deviations. The consequences of such oscillations could be observed in the case of the teaching of descriptive geometry, where it has been confirmed that populations with poorer spatial orientation skills have greater difficulties in following the study of this subject.

It was difficult to evaluate the differences between lefthanders and righthanders, since where such a difference was observed the sample was a very small one ($n = 14$). For this reason it will be necessary to continue such evaluations in future years.

Even though, at FA, the MRT test will continue to be used, due to its objectivity and the comparability of results, it is the intention of the author to cooperate with researchers from Hungary and the Slovak Republic in the assessment of the results of spatial visualization skills using other tests which can be useful in this field. Such a test is, for instance, the improved version of TPS. At the same time it would be desirable to compare the results obtained by the MRT and TPS tests, and thus determine more accurately the role which MRT has in the defining of an objective and integrated concept of spatial visualization.

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