 Anthropologist, 20(1,2): 128-139 (2015)

# Test Development Study on the Mental Rotation Ability

**Nazan Sezen Yüksel[1] and Ali Bülbül[2]**

***[1]Hacettepe University, Faculty of Education, Department of Mathematics Education Ankara, Turkey***
***[2]Hacettepe University, Faculty of Education, Department of Mathematics Education, Ankara, Turkey***
***E-mail: <[1]nsezen@hacettepe.edu.tr>,[2]<bulbul@hacettepe.edu.tr>***

**KEYWORDS** Spatial Ability. Confirmatory Factor Analysis. Goodness of Fit. Validity. Reliability

**ABSTRACT** The mental rotation ability is one of the important components of spatial ability. The purpose of this paper is to develop a test that includes mathematical context regarding the ability of mental rotation measured by various tests in the literature. To this end, a 32-item test was established by departing from questions found in field test in the literature and by adding new questions containing mathematical content. As a result of validity-reliability tests performed following the pilot application, 3 items were removed from the test and mental rotation test took its final form by 29 items. Cronbach's alpha internal consistency of this test with its final form was acquired as .81. According to confirmatory factor analysis, goodness of fit indices was found to be $\chi^2$ /SD = 1.42, GFI = 0.92, CFI= 0.93, NNFI= 0.91, RMR= 0.012 and RMSEA= 0.037.

## INTRODUCTION

High-level cognitive skills are those that individuals use at many points in their lives and that include non-routine situations. Having several different components, it is undoubtedly evident that spatial ability is one of the most important among these components. In addition to various definitions related to spatial ability, certain classifications on this ability have been applied. Gorska et al. (1998) discussed the spatial ability with its five components. These are "spatial perception, spatial visualization, mental rotation, spatial relations and spatial orientation" components. Jušèáková (2002 cited in Gergelitsová 2007) indicated that sub-factors of spatial ability were "Passive spatial orientation, visual memory, visual diagnostics, active spatial orientation, mental manipulation, manipulation made by hand and technical creativity in spatial imagination". Kimura (1999) defined six dimensions of spatial ability that claim to emerge with experimental measurements clearly. The first of these is "spatial orientation" which is the ability to predict exactly changes in orientation of an object; secondly, "spatial location memory" which is the ability of remembering the location of a series of objects. "Targeting ability" defined as the ability to project a bullet at a certain target is the third dimension discussed. However, classifying this ability is difficult since it is associated with motor skills. The fourth dimension, "spatial visualization", is defined as the ability to determine and quantify orientation changes in an image. Although this ability seems similar to mental rotation, this ability does not require mental rotation of objects; however, it requires visibility of locations associated with a steady object. "Separation from the background, revealing (disembedding)" defined as the fifth dimension is the ability to find a simple object hidden inside many complicated shapes. "Spatial perception" as the final dimension represents individual ability to detect which of horizontal and vertical orientations is dominant where distracting patterns are found.

Another ability emphasized in most of these classifications is the ability of mental rotation. The mental rotation is the ability to rotate visual projection of two- and three-dimensional objects (Addepalli 2005). This ability emerges in the process of deciding how mirror images will be or two objects in different directions are the same (Wohlschläger and Wohlschläger 1998). While Linn and Petersen (1985) defined mental rotation as the ability to rotate 2-dimensional and 3-dimensional objects accurately and quickly, Okagaki and Frensch (1994) defined this as "the ability to mentally visualize visual stimulants".

*Adresses for correspondence*:
Dr. Nazan Sezen Yüksel
Hacettepe University, Faculty of Education,Ankara Turkey
*Telephone*:+90 (312) 2978601
*Fax*: +90 (312) 2978600
*E-mail:* nsezen@hacettepe.edu.tr

Kosslyn and colleagues (1995) defined mental rotation as the ability to visualize rotation of object in space. Researchers stated that an individual can manipulate moving pictures by focusing his/her visual systems just like viewing physical manipulations of a subject. Mental rotation ability is important for many occupations for example engineering, medical professions and other jobs which use creativity (Hegarty and Waller 2005) and linked to the mathematicalabilities (Heil and Jansen-Osmann 2008; Thompson et al. 2013).

Just as spatial skills, ability of mental rotation plays a crucial role in mathematical success. Gender differences observed in mathematical success are actually based on certain cognitive variables. One of the most important cognitive variables is specified as mental rotation (McGuinness 1993, cited in Delgado and Prieto 2004). Another example of effect of mental rotation to success in mathematics is problem solving strategies. That is because many problems can be solved with the help of visualization as in analytical strategies. This raises two kinds of strategies. An individual conducts an automatic problem-solving application by memorizing the algorithm or makes use of visuo-spatial practices of problems (Delgado and Prieto 2004). On the other hand, it is another result concluded from applied studies that applications conducted in descriptive geometry courses contribute positively to score achieved in mental rotation test (Bölcskei et al. 2013).

Analyzing studies in the literature, determination of mental rotation ability is compared with different mental rotations tests developed in such sense. The most important among studies related to mental rotation was conducted by Shepard and Metzler (1971). The test developed within the scope of this paper served as reference to several studies. Shepard and Metzler analyzed mental rotation of visual stimuli by using visual cues. Within the scope of the test, subjects were shown two different visual stimuli and they were asked to decide whether they are the same or not. Figures were rotated both on a plane and by adding a third dimension (in-depth). As a result of the study, they concluded that increase in angle of rotation increased duration to find the correct figure. In the question, by providing various rotated states of different shapes in a plane or in depth, it was asked to determine forms with the same shape.

Battista et al. (1982) employed "Purdue Spatial Visualization Test: Rotations" test. This test was developed by Guay in 1977. The test consists of 30 items, and these items were designed to measure the ability to rotate three-dimensional objects mentally.

In the question, in accordance with rotation process specified in the question, finding the rotated state of given shape is asked.

As another example of mental rotation test can be tests by Peters et al. (1995) adapted from "Vandenberg and Kuse Mental Rotations" test. The test consists of 24 questions in total. The nature of each problem is the same. Questions included in the test are based on finding the new state of a shape constituted from unit cubes when it is rotated in distinct directions and angles. In the question, it was asked to mark two of options that belonged to the same shape.

The Picture Rotation Test, developed by Hinze and Quaiser-Pohl in 2003, aims at measuring mental rotation ability levels of children in early childhood period (4-6 years) (Quaiser-Pohl 2003). The Test consists of a total of 12 questions, 6 human pictures and 6 animal pictures. In preparation stage of image rotation test, Piaget's assumptions were taken into consideration. According to Piaget, children in pre-processing stage (1.5 to 7 years) can remember only the start and final positions of a moving object and insufficient in determining positions during movement. Therefore, it is possible to identify mental rotation abilities of children of this age range only through fixed representations of spatial objects (Quaiser-Pohl 2003).

In researches conducted on mental rotation ability, it is a significant result that this ability varies based on gender. Goldstein et al. (1990), in their research, suggested that mental rotation ability differed based on gender and limited time was a factor in the emergence of this difference. As for the reason for such situation, they demonstrated the fact that boys tent to fulfill their assignments and yet girls tents to behave slowly and carefully. According to hypotheses of Goldstein and his colleagues, it was claimed that this difference could be eliminated by removing time limit in Mental Rotation test applications.

Voyer et al. (1995), in their study, stated that mental rotation performances of boys compared to other spatial ability performances were higher than those of girls. Moé (2009) brought some clarification to this situation. According to Moé, reasons for mental rotation performance observed higher in boys are: “biological reasons, strategic reasons and spatial experiences”. Biological reasons mentioned here is the fact that mental rotation ability is connected with hormonal factors or hemispheric specialization and brain structures. Strategic reasons; as noted by Goldstein et al. (1990) are described as time constraints. However, Peters (2005) concluded in his study that increasing the standard duration did not lead to any reduction in meaningful difference by gender as found earlier. The last of reasons put forward by Moé regarding mental rotation difference by gender, spatial experiences are described as the fact that role of previous spatial assignments (computer, video games and certain sports) has important effects on this ability.

In certain applied studies, hormonal features are considered as the reason for meaningful difference in spatial ability on behalf of boys. Several researchers stated that this difference was related to a hormone indigenous to males and it could arise from the fact that spatial ability as a component of mental rotation was a feature recessive on X chromosome (Bock et al.1973; Stafford 1961; Newcombe et al. 1983). The conclusion obtained by Linn and Petersen (1985) in their meta-analysis study on researches applied during 1974-1982, also supports these studies regarding the fact that boys compared to girl tend to perform better in mental rotation tests.

A demand for determining how much a test including questions related to mathematics field along with questions of mental rotation tests in the literature measures this ability, created the need for developing the test subjected to this paper.

### The Aim of the Paper

The question of how this ability may find area of use in various disciplines aries depending on the fact that tests towards determination of mental rotation ability are limited in numbers, and current tests are applied among various groups regardless of differences such as age and educational background. The purpose of this paperis to develop a test which includes mathematical context different from mental rotation tests in the literature.

### Research Problem and Sub-Problems

What are the psychometric properties of the mental rotation test developed like?

- What level are item discrimination and item difficulty values of Mental Rotation test?
- What is the level of reliability of the Mental Rotation test?
- What is the level of validity of the Mental Rotation test?

## METHODOLOGY

### Research Design

This paper is a test development work. A plan was made related to the path to be pursued based on test development studies in the literature (Çaliºkan and Kaptan 2009; Feyzioðlu et al.2012), and within the scope of this plan:

- Forming an opinion about question types by analyzing the literature;
- Preparation of test questions and answer choices;
- Submitting the prepared draft test to field experts and students convenient to target group;
- Implementation of pilot application; conducting item analysis, validity and reliability analyses in accordance with acquired data;
- In accordance with obtained analysis results, test taking its final form;

These stages were foreseen by the researchers.

### Research Sample/Working Group

The pilot implementation of the test was carried out with a total of 307 students attending mathematics and mathematics education programs in two state universities in Ankara. At that stage of test development, as distinct from the other tests in the literature, the demand for including mathematical context resulted in selecting students among those attending programs related to mathematics. Students’ grade levels and academic achievement status were not taken into account.

### Data Collection Instrument and Procedure

The following states were passed in the development process:

*1. Stage:* Firstly, mental rotation tests found in the literature were analyzed. As a result of these analyses, elementary manners aimed at measuring were determined. Accordingly, from a student found qualified according to “Mental Rotation Test”;

- Ability to determine new states of three-dimensional objects according to defined rotation process.
- Ability to recognize new state of the same object after different processes.
- Ability to detect different appearances from different points of view according to rotation process in coordinate axes is expected.

*2. Stage:* Writing process began for questions that would be included in the test as a result of related literature scanning and determination of objected behaviors with the test. Questions were prepared in three groups according to the intended behavior. The first of them was free rotation questions in which any axis or angle of the expression was not involved, second one was controlled free rotation questions towards rotating shapes in specified rules or specified angles and third one was questions for mathematical context of shapes. The following questions (Figs. 1, 2, 3) can be given as samples belonging to for each group.

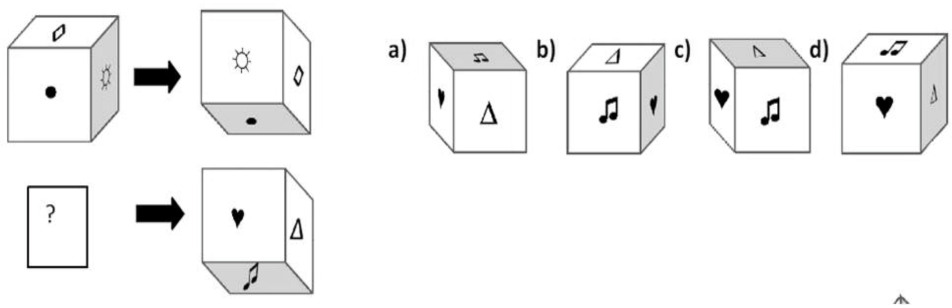
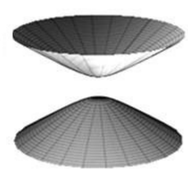



**Fig. 1. An example of free rotation questions**

**Which shape is obtained from after rotation on the plane in positive direction $70^0$ of next shape?**



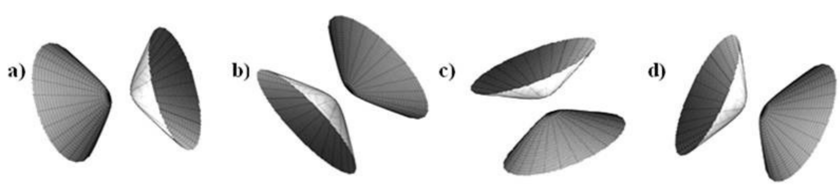
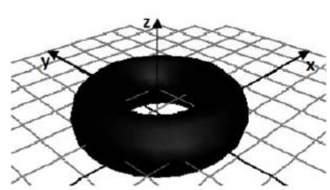



**Fig. 2. An example of controlled rotation questions**

**Which is not the one of the shapes on the xyz-coordinate system that obtained from the rotation around the x-axxis of tours on next shape?**



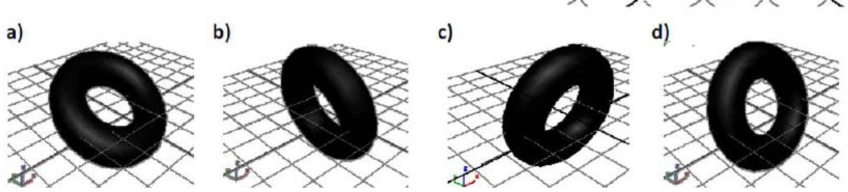




**Fig. 3. An example of contextual rotation questions**

*3. Stage:* After writing down the test items, prepared draft was submitted for the review of mathematics and mathematics education experts. At this stage, competence of question included in the test in terms of both visual and mathematical language was discussed and necessary corrections were conducted at this stage. After the arrangements were applied, the test was presented to two teacher candidates attending Mathematics Education programs and they were asked to specify any points they have difficulty in understanding. When teacher candidates stated that they had difficulty in seeing axes in three-dimensional coordinate system rotation questions in general, axis designations in questions for this part were prepared in a more pronounced way.

*4. Stage:* At this stage, after making necessary arrangements, the test with completed draft was formally edited to be implemented as a pilot application. At the stage of formal arrangement of the test, any example was included before proceeding to the test. This example is included with a view to create a perception regarding how a pattern will be established on rotation in questions of the test (Fig. 4).

**Fig. 4. Example figure given for rotation rule**

In this section, appearances of the shape given in Figure 4 as a result of rotating by 90 degrees around the axes x, y, z respectively are given (Figs. 5, 6, 7). By rotating the shape given above by 90 around x-axis.

Based on the rotation rule given in Figures5, 6, 7, it is aimed that a student can establish a pattern about how rotation will be by rotating around x, y, z-axes and can conduct mental rotation process based on this rule.

**Data Analysis**

To analyse the data, many of statistical software are used. At first, to make item analysis to obtained data is used Iteman 5.0; for reliability analysis is used SPSS 17.0 and for confirmatory factor analysis is used Lisrel 8.5 statistical software and other necessary statistics

.

## FINDINGS

Findings related to item analysis, reliability and validity analyses of the Mental Rotation test developed within the scope of the paper are as follows:

**Findings towards Item Analysis**

This test, developed by the researchers, was administered to 307 students. Item difficulty belonging to test items is calculated as 0.31 at the lowest and 0.68 at the highest level. Considering the selectivity index values, the lowest value is obtained as 0.30 and the highest value as 0.56. Other results related to this analysis are as given in Table 1.

**Table 1: Item analysis results for Mental Rotation Test**

| | |
|---|---|
| Number of items | 32 |
| Number of subjects | 307 |
| Average | 21.67 |
| Standard deviation | 5,178 |
| Kurtosis | -0,549 |
| Skewness | -0,320 |
| Average item difficulty | 0.67 |
| Average items selectivity | 0.47 |

**Findings Related to Reliability Analysis of Mental Rotation Test**

Items belonging to the prepared test was scored dichotomously in the form of 1 (true) - 0 (false) based on given answers. In the literature it is emphasized that in cases where item points are not continuous, (available-not available, yes-no, true-false) KR-20 should be used and in cases item points are constant, Cronbach's α coefficient should be calculated (Gözüm and Aksayan 2003). However, in the literature for the use of binary scoring, although necessity to use KR-20 technique is emphasized, in case where all items are scored in 1-0, Cronbach's α coefficients are known to give the same result (Cronbach 1951). Therefore, as for reliability study of the devel-

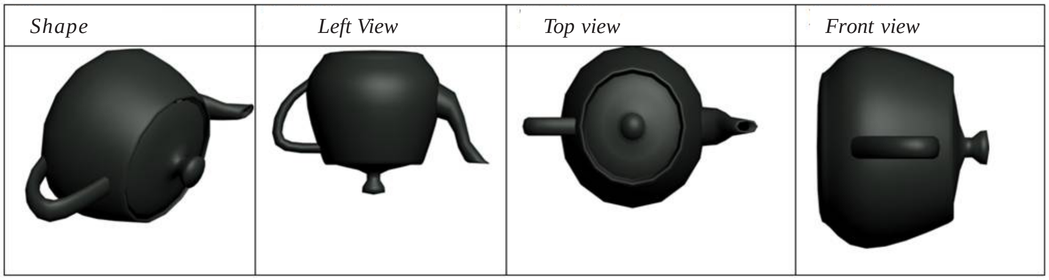



**Fig. 5. State of the sample shape after rotating by 90⁰ around x-axis**

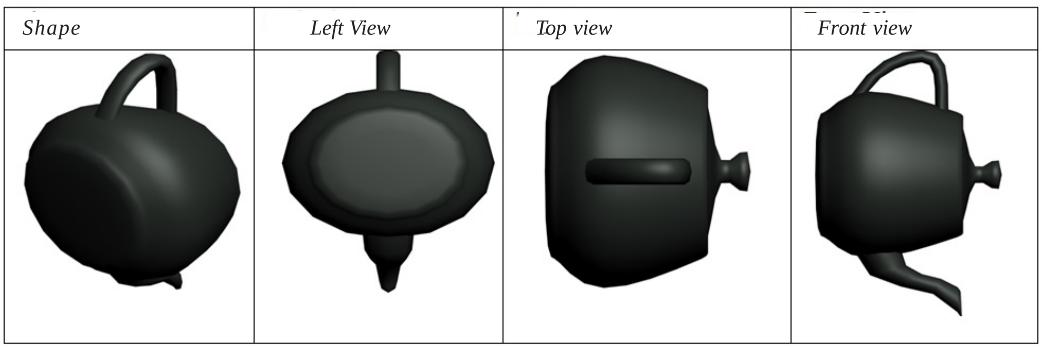



**Fig. 6. State of the sample shape after rotating by 90⁰ aroud y-axis**

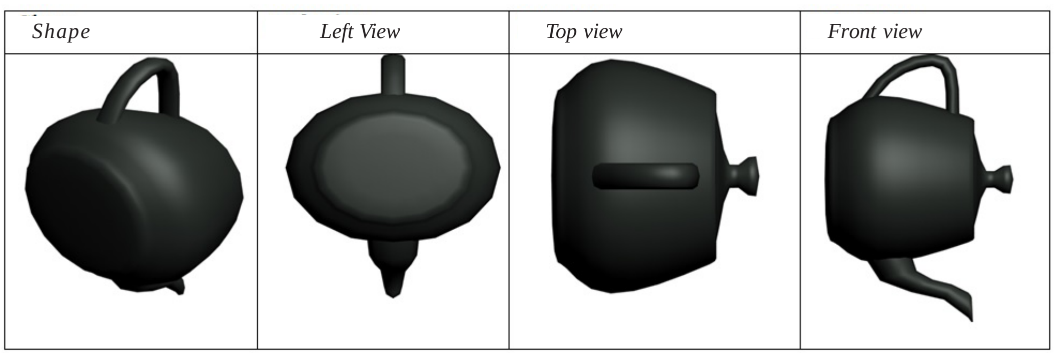



**Fig. 7. State of the sample shape after rotating by 90⁰ around z-axis**

oped test, Cronbach α coefficient of internal consistency were considered.

Cronbach's α coefficients belonging to mental rotation test developed within the scope of the paper was found as .81.

### Findings Related to Validity Analysis of Mental Rotation Test

In this section, studies conducted with a view to provide evidence for the validity of mental rotation are included. For determination of structural validity of Mental Rotation test, another mental rotation test from the literature was taken into consideration. This test was put forward by Peters et al. in 1995 as a revised version of the test developed Vandenberg and Kuse (1978) with the name of "A Redrawn Vandenberg and Kuse Mental Rotations Test: Different Versions and Factors That Affect Performance" (Peters et al. 1995). Authorization to use the test was granted by Michael Peters on June 14, 2011 on condition that test items are not published and they are used for the purpose of validity study within the research. When these two tests, developed by researcher (ZD), and found in the literature (MR), were administered to the same group, correlation coefficient among obtained data was calculated as 0.81 (Table 2).

**Table 2. Correlation analysis between developed and literature-based mental rotation tests**

| | | *ZD* | *MR* |
|---|---|---|---|
| *ZD* | Pearson's Correlation | 1 | .812** |
| | Sig. (bidirectional) | | .000 |
| | N | 128 | 128 |
| *MR* | Pearson's Correlation | .812** | 1 |
| | Sig. (bidirectional) | .000 | |
| | N | 128 | 128 |

**. Correlation is meaningful at the level of 0.01 (bidirectional

In the other part of validation studies, the question of whether results from the literature regarding groups where this test is applied are also valid for this developed test. Vandenberg and Kuse (1978) and Hamilton (1995, cited Alias et al. 2002) in their research, stated that boys compared to girls have higher levels of mental rotation ability. Linn and Petersen (1985) in a similar manner suggested that level of mental rotation abilities were higher in male students.

Obtained data was applied with t-test with a view to determine whether the test developed within the scope of this study showed any differences according to gender differences, and if there were any differences, of which group they were in favor. Accordingly, the analysis results obtained are as Table 3.

## Findings towards Confirmatory Factor Analysis

The final procedure applied in order to provide evidence for the validity of tests is Confirmatory Factor Analysis (CFA). In the application of Confirmatory Factor Analysis, the Maximum Likelihood Factor Analysis among factorization techniques was used. However, maximum likelihood factor analysis requires multivariate normal distribution assumption for variables and if the data set does not meet this premise, it can yield to unreliable result (Table 4) (Brown 2006, cited in Çokluk et al. 2010).

**Table 4: Analysis of mental rotation testaccording to normality assumptions**

| | | *Mental rotation* |
|---|---|---|
| | | *T* |
| *N* | | 307 |
| *Normal Parameters* | Average | 17.14 |
| | Std. deviation | 5.567 |
| *End Differences* | Absolute | .073 |
| | Positive | .057 |
| | Negative | -.073 |
| *Kolmogorov-Smirnov Z* | 1.286 | |
| *Sig. (2-tailed)* | .073 | |

Analyzing the Single Kolmogorov-Smirnov analysis results, p-value obtained for the developed test seems to be >0.05.

Following the provision of normality assumption, confirmatory factor analysis was applied to the data. According to this; $X^2$/ sd= 2.29, GFI= 0.82, CFI= 0.65, NNFI= 0.63, RMR= 0.015 ve RMSEA= 0.065 fit indices were obtained. Considering modification suggestions, three items which were observed as necessary to connect with various items and in accordance with these suggestions whose effect on $\chi^2$ seemed very great (4th, 10th, and 32nd items) were removed from the test.

Based on removal of these items, and again in line with modifications recommendations, goodness of fit statistics achieved by connect-

**Table 3: Analysis of mental rotation test according to gender**

| | *Levene'stest for equality of variances* | | *t-test for equality of means* | | | | |
|---|---|---|---|---|---|---|---|
| | *F* | *Sig.* | *t* | *Df* | *Sig. (2-tailed)* | *Mean difference* | *Difference std. error* |
| *When Variances Are Considered Equal* | 6.747 | .010 | -6.971 | 229 | .000 | -4.12308 | .59150 |
| *When Variances Are Considered Equal* | | | -6.861 | 201.61 | .000 | -4.12308 | .60091 |

ing 14th and 26th, 21st and 23rd items were given in Table 5.

**Table 5: Confirmatory factor analysis for Mental Rotation Test**

| | *Goodness of fit statistics* |
|---|---|
| $X^2$/sd | 1.42 |
| Comparative Fit Index (CFI) | 0.93 |
| Root Mean Square Residual (RMR) | 0,012 |
| Goodness of Fit Index (GFI) | 0.92 |
| Non-Normed Fit Index (NNF is) | 0.91 |
| Root Mean Square Error of Approximation (RMSEA) | 0.037 |

Accordingly, analyzing the fit indices; GFI = 0.92, CFI=0.93 and NNFI=0.91 show goodness of fit; $X^2$/ sd=1.42, RMR=0.012 and RMSEA=0.037 indices indicates the perfect fit. Accordingly, the Mental Rotation Test took its final form with 29 items.

In accordance with First level Confirmatory Factor Analysis, path diagram acquired for mental rotation test is as Figure 8.

## DISCUSSION

The purpose of this paper is to approach the ability of mental rotating by different attitude and for this aim to develop a test. The main difference of this paper that separates from other studies in literature is to approach the mental rotation ability as a discipline. This discipline is mathematics. It is overemphasized on the relationship between spatial ability and mathematical performance (Tosto et al. 2014; Cheng and Mix 2014; Oostermeijer et al. 2014).

At the above, there is a detailed information is given about test developing stages. In every developing test stage, within the context of this paper; a certain definition of mental rotating test ability is defined and by this definition target behaviors which are wanted to measure by tests are composed.

In the initial phase of test development process, tests found in the literature and other test developed towards other components of spatial ability such as spatial visualization, mental cutting were analyzed. The purpose of analyzing those tests related to other abilities is to create a perception of what can be the thing that distinguishes this ability from other types of capabilities and to prepare items to be included in the test in this context. As a result of examination of the relevant literature, behaviors to be measured with the mental rotation test being developed are specified.

Accordingly a student, found qualified according to this test, is expected to have “ability to determine new states of three-dimensional objects according to defined rotation process”, “ability to recognize new state of the same object after different processes”, and “ability to detect different appearances from different points of view according to rotation process in coordinate axes”.

Considering the target behaviors, test items were prepared and this test prepared with 32 items was demonstrated in a research conducted with a total of 307 undergraduate students from two different state universities who study in mathematics and mathematics education programs.

Cronbach’s $\alpha$ coefficients belonging to mental rotation test was found as .81.It is precipitated that this value is suitable according to comparetation with other test developing studies (Vandenberg and Kuse 1978; Burton and Fogarty 2003; Campos 2012; Kabakci-Yurdakul et al. 2014).

In the next step for validity of the test, relationship between another test (Vandenberg and Kuse 1978) that measured mental rotation ability was examined. The correlation coefficient was found as 0.81. The correlation coefficient is a higher value of the correlation coefficient obtained from the Campos and Campos-Juanatey (2014) study. In their studies they compared measure of the ability to rotate mental images test (MARMI) (Campos 2012), object-spatial imagery and verbal questionnaire (Blazhenkova and Kozhevnikov 2009) . The correlation coefficient between MARMI and each of the three scales of the object-spatial imagery and verbal questionnairewas found as 0.50, 0.60 and 0.48.

Finally, within the scope of Confirmatory Factor Analysis, test items were found to be grouped under a single dimension. In accordance with goodness of fit indices acquired during this analysis and modification recommendations, 3 items were removed from the test, giving the test its final form. In accordance with modification suggestions, the goodness of fit statistics achieved by interconnecting 14th and 26th items; also 21st and 23rd items indicated a perfect harmony and this provided an evidence for the correct implementation of validity and reliability process for the test. As for the inter-connection pro-

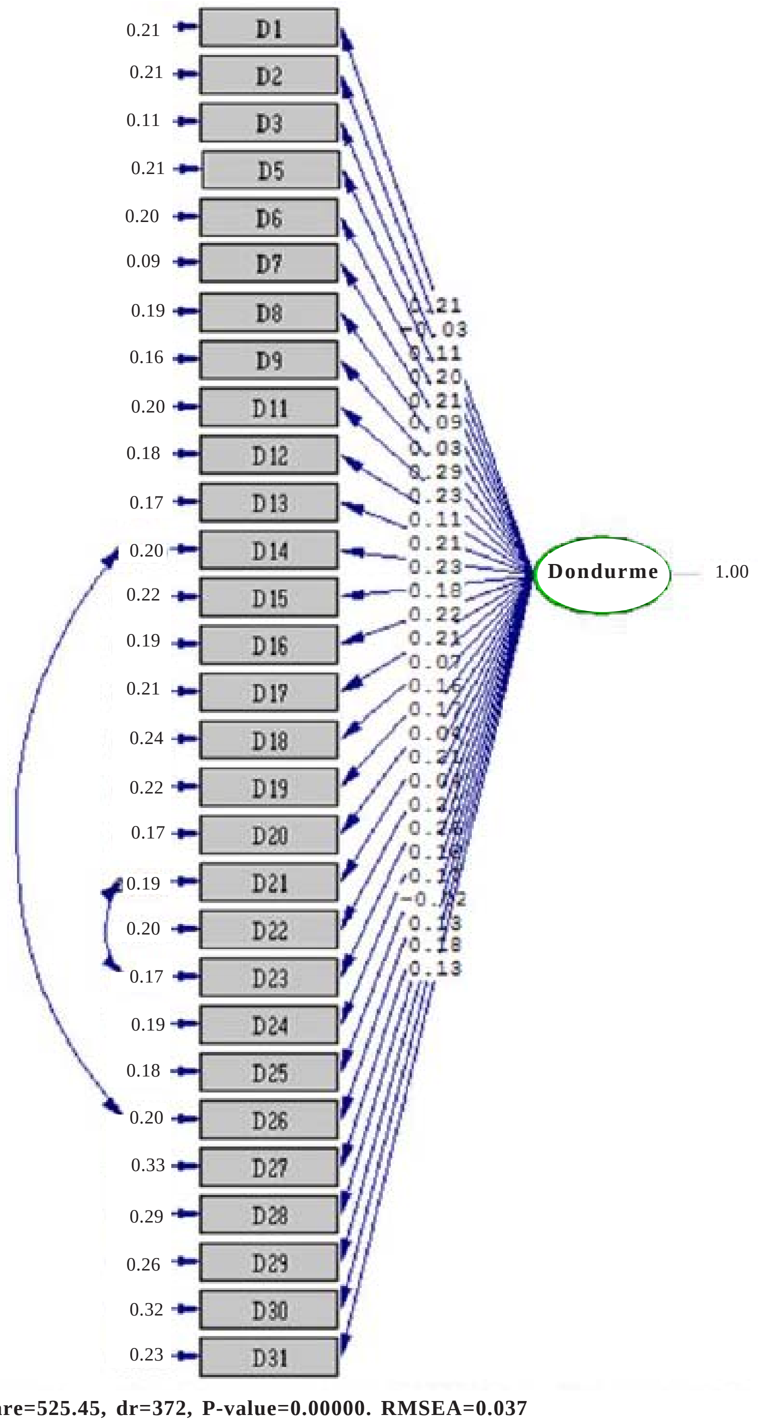



**Fig. 8. Path diagram for Mental Rotation Test**

cess of these items, any disadvantage was not found since they were grouped under a single dimension.

## CONCLUSION

Mental rotation ability is one of the components of spatial ability. However, in the literature analysis applied tests towards determining this ability can be applied to all groups indiscriminately because of their nature. Starting from this situation, as distinct from mental rotation tests applied in the literature, this paperincluded mathematical context and it was objected to establish a test which set undergraduate students as its target group mainly. As a result of the reliability analysis, Cronbach $\alpha$ coefficient of the scale was found to be .81.

In order to provide evidence for validity of the test, test's relationship between another test that measured mental rotation ability and was proven by several other studies from the literature was examined. Positive and meaningful correlation was found between data obtained from applying the two tests in question. In the other part of test validation studies, analysis of both tests was applied in terms of whether they provided the same characteristics from the point of predetermined variable. In this context, "gender" variable was considered. As a result of the application, it was concluded that both tests showed a significant difference by gender, moreover, this difference was in favor of men for both tests.

## RECOMMENDATIONS

Being one of the important components of spatial ability, the ability of mental rotation seems to increase success in many disciplines.In this paper, it is aimed to measure mental rotating ability by different questions include mathematical context and contribute literature in this subject. According to obtained results; it is seen that this developed test is reliable and valid and also displayed high correlation between other tests in literature.

It can be said that we can develop different viewpoint on mental rotating ability from this situation. Studies in recent years show that spatial ability is interacting with mathematical success as other components; spatial visualization and mental cutting. Therefore, it is anticipated that in further researches to be carried out in accordance with this paper will give possibility to evaluate mental rotation abilities of students from a distinct approach. Based on the test developed within the scope of this research, it is suggested that researchers develop tests that are based on distinct components of spatial ability indigenous to different fields.

## REFERENCES


Addepalli S 2005. *Effects of Mental Rotation, Visual Aids and Training on Inspection Performance During Airport Baggage Inspection*. Master Thesis,. India: Jawaharlal Nehru Technological University.

Alias M, Black TR, Gray DE 2002. Effect of Instructions on Spatial Visualisation Ability in Civil Engineering Students.International Education Journal, 3(1): 1-12. From<http://ehlt.flinders.edu.au/education/iej/articles/v3n1/Alias/paper.pdf> (Retrieved on 3 December 2010).

Battista MT, Wheatley GH, Talsma G 1982. The importance of spatial visualization as cognitive development for geometry learning in pre-service elementary teachers. *Journal for Research in Mathematics Education*, 13(5): 332- 340.

Blazhenkova O, Kozhevnikov M 2009. The New Object- Spatial- Verbal Cognitive Style Model: Theory and Measurement. Applied Cognitive Psychology, 23(5): 638- 663. From <http://onlinelibrary. wiley. com/doi/10.1002/acp.1473/pdf> (Retrieved on 2 April 2015).

Bock RD, Kolakowski D 1973. Further Evidence of Sex-Linked Major-Gene Influence on Human Spatial Visualization Ability. American Journal of Human Genetics, 24: 1-14. From<http://www.ncbi.nlm. nih. gov/pmc/articles/PMC1762227/pdf/ajhg00446-0003.pdf> (Retrieved on 20 January 2012).

Bölcskei A, Kovacs AZ, Kusar D 2013. New Ideas in Scoring the Mental Rotation Test. Journal of Built Environment, 1(1): 59- 69. From <http://epa.oszk. hu/02400/02446/00001/pdf/EPA02446_jbe_2013_01_059- 069.pdf> (Retrieved on 5 January 2014).

Burton LJ, Fogarty GJ 2003. The factor structure of visual imagery and spatial abilities. *Intelligence*, 31: 289-318.

Çaliskan ÝÖ, Kaptan F 2009. Constructing science process skills test. *Çagdas Egitim Dergisi*, 34(369): 27-34.

Campos A 2012. Measure of the Ability to Rotate Mental Images. Psicothema, 24(3): 431-434. From <http://www.psicothema. com/pdf/4035.pdf>. (Retrieved on 29 March 2015).

Campos A, Campos-Juanatey 2014. Mental Rotation and Object-Spatial- Verbal Cognitive Stiles. Revista de Estudios e Investigacion, 1(1): 100-102. From< http://revistas.udc.es/index.php/reipe/article/view/31/13> (Retrieved on 29 March 2015).

Cheng YL, Mix KS 2014. Spatial Training Improves Children's Mathematics Ability. Journal of Cognition and Development, 15(1): 2-11. From <http://www.tandfonline.com/doi/pdf/10.1080/15248 372. 2012.725186> (Retrieved on 2 April 2015).

Çokluk Ö, Sekercioglu G, Büyüköztürk Þ 2010.*Çok Deðiþkenli Istatistik, (SPSS ve Lisrel Uygulamalari)*. Ankara: Pegem Akademi Publishing.

Cronbach LJ 1951. Coefficient Alpha and the Internal Structure of Tests.Psychometrika, 16(3): 297-334. From <http://psych.colorado.edu/~carey/Courses/PSYC5112/Readings/alpha_Cronbach.pdf> (Retrieved on 2 May 2010).

Delgado AR, Prieto G 2004. Cognitive Mediators and Sex-Related Differences in Mathematics. Intelligence, 32: 25- 32. From <http://www. thinkingskillsclub. com> (Retrieved on 02 December 2013).

Feyzioglu B, Demirdag B, Akyildiz M, Altun E 2012. Ortaögretim Ögrencilerine Yönelik Bilimsel Süreç BecerileriT esti Gelistirilmesi: Geçerlikve Güvenirlik Çalismasi. *Kuram ve Uygulamada Egitim Bilimleri*, 12(13): 1887-1906.

Gergelitsová Š 2007. Computer Aided Development of Spatial Abilities, WDS'07 Proceedings of Contributed Papers, 246- 250.From<http://www.mff.cuni.cz/veda/konference/wds/proc/pdf07/WDS07_141_m8_Gergelitsova.pdf> (Retrieved on 10 November 2009).

Goldstein D, Haldane D, Mitchell C 1990. Sex Differences in Visual-Spatial Ability: The Role of Performance Factors.Memory and Cognition, 18(5): 546–550. From <http://www.springerlink.com/content/q72t6q966k2x4212/fulltext.pdf> (Retrieved on 10 May 2010).

Gorska R, Sorby SA, Leopol C 1998. Gender Differences in Visualization Skills-An International Perspective. Engineering Design Graphics Journal, 62(3): 9-18. From <http://edgj.org/index.php/EDGJ/article/view/115/111> (Retrieved on 2 December 2009).

Gözüm S, Aksayan S 2003. Kültürlerarasi Ölçek Uyarlamasiiçin Rehber II: Psikometrik Özelliklerve Kültürlerarasi Karsilastirma. *Hemsirelikte Arastirma Gelistirme Dergisi*, 1: 3- 14.

Hegarty M, Waller DA 2005. Individual differences in spatial abilities. In: P Shah, A Miyake (Eds.):*The Cambridge Handbook of Visuospatial Thinking.* New York: Cambridge University Press, pp. 121-169.

Heil M, Jansen-Osmann P 2008. Gender differenc-es in mathematical performance and mental rotation in 8 years old boys and girls. *European Journal of Developmental Science*, 2: 195-201.

Kabakçi-Yurdakul I, Ursavas ÖF, Becit-Ýsçitürk G 2014. An Integrated Approach for Preservice Teachers' Acceptance and use of technology: UTAUTPST Scale. Eurasian Journal of Educational Research, 55: 21-36. From <http://dx.doi.org/10.14689/ejer. 2014. 55. 2> (Retrieved on 30 March 2015).

Kimura D 1999. *Sex and Cognition.* 1st Edition. Cambridge, Mass.: MIT Press.

Kosslyn SM, Behrmann M, Jeannero M 1995. The Cognitive Neuroscience of Mental Imagery. Neuropsychologia, 33(11): 1335- 1344. From <http://www. iwitts.com/html/okagaki.pdf> (Retrieved on 10 May 2010).

Linn MC, Petersen AC 1985. Emergence and Characterization of Sex Differences in Spatial Ability: A Meta- Analysis. Child Development, 56(6): 1479-1498. From <http://www.jstor.org/stable/pdfplus/1130467.pdf> (Retrieved on 3 April 2011).

Moé A 2009. Are Males Always Better Than Females In Mental Rotation? Exploring A Gender Belief Explanation. Learning and Individual Differences, 19: 21–27. From <http://www.sciencedirect.com/science/article/pii/S1041608008000216> (Retrieved on 20 October 2011).

Newcombe N, Bandura, MM, Taylor DG 1983. Sex Differences in Spatial Ability and Spatial Activities. Sex Roles, 9(3), 377-386.From <http://www.temple.edu/psychology/newcombe/documents/.pdf> (Retrieved on 30 October 2011).

Okagaki L, Frensch PA 1994. Effects of Video Game Playing on Measures of Spatial Performance: Gender Effects in Late Adolescence. Journal of Applied Developmental Psychology, 15: 33-58. From <http://www.iwitts.com/html/okagaki.pdf> (Retrieved on 5 June 2010).

Oostermeijer M, Boonen AJH, Jolles J 2014. The Relation Between Children's Constructive Play Activities, Spatial Ability, and Mathematical Word Problem-Solving Performance: A Mediation Analysis in Sixth-Grade Students. Frontiers in Psychology, 5: 1-7. From <http://journal.frontiersin.org/article/10.3389/fpsyg.2014.00782/full> (Retrieved on 30 March 2015).

Peters M 2005. Sex Differences and the Factor of Time in Solving Vandenberg and Kuse Mental Rotation Problems.Brain and Cognition: 57: 176-184. From< http://www.sciencedirect.com/science/article/pii/S0278262604002398> (Retrieved on 12 May 2011).

Peters M, Laeng B, Latham K, Jackson M, Zaiyouna R, Richardson C 1995. A redrawn Vandenberg and Kuse Mental Rotations Test: Different versions and factors that affect performance. *Brain and Cognition*, 28: 39-58.

Quaiser-Pohl C 2003. The Mental Cutting Test "Schnitte" and Picture Rotation Test- Two New Measures to Assess Spatial Ability. International Journal of Testing, 3(3): 219-231. From <http://userpages. uni-koblenz. de/~quaiser/files/Publikationen/IJT0303 pp. 219-231.pdf> (Retrieved on 22 April 2010).

Shepard RN, Metzler J 1971. Mental Rotation of Three-Dimensional Objects.Science, New Series, 171: 701-703. From <http://www.jstor.org/stable/pdfplus/1731476. pdf> (Retrieved on 7 February 2010).

Stafford RE 1961. Sex Differences in Spatial Visualization as Evidence of Sex-linked Inheritance.Perceptual and Motor Skills,13: 428. From <http://www. amsciepub. com/doi/pdf/10.2466/pms. 1961. 13.3. 428> (Retrieved on 12 September 2011).

Thompson JM, Nuerk HC, Moeller K, Kadosh RC 2013. The Link between Mental Rotation Ability and Basic Numerical Representations.ActaPsychologica, 2: 234- 331.From <http://www.sciencedirect.com/science/article/pii/S0001691813001200#> (Retrieved on 29 March 2015).

Tosto MG, Hanscombe KB, Haworth CMA, Davis OSP, Petrill SA, Dale PS, Malykh S, Plomin R, Kovas Y 2014. Why do Spatial Abilities Predict Mathematical Performance? Developmental Science, 17(3): 462- 470. From <http://onlinelibrary.wiley.com/doi/10.1111/desc.12138/epdf> (Retrieved on 2 April 2015).

Vandenberg SG, Kuse AR 1978. Mental rotations, a group test of three- dimensional spatial visualization. *Perceptual and Motor Skills*, 47: 599- 604.

Voyer D, Voyer SD, Bryden MP 1995. Magnitude of Sex Differences in Spatial Abilities: A Meta-Analysis and Consideration of Critical Variables. Psychological Bulletin, 117: 250-270. From< http://psycnet. apa. org/index. cfm?fa=buy. option To Buy HYPER LINK “http://psycnet.apa.org/index. cfm? fa= buy. optionToBuy&id=1995-20087-001”and HYPER LINK“http://psycnet.apa.org/index. cfm? fa=buy. optionToBuy&id=1995-20087-001”id= 1995-20087-001> (Retrieved on 30 March 2009)

Wohlschläger A, Wohlschläger A 1998. Mental and Manual Rotation. Journal of Experimental Psychology: Human Perception and Performance, 24(2): 397-412. From <http://wexler.free.fr/library/files/wohlschl % E4ger%2 0(1998)% 20mental%20and% 20 manual% 20rotation.pdf> (Retrieved on 9 June 2010).