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A Test Development Study on Spatial Visualization for Second-Grade Primary School Students

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Abstract

This study aims to develop a new spatial visualization test (SVT) for second grade primary school students. The study employed the survey design, and the test was developed in accordance with the test development steps. According to the findings obtained as a result of the pilot study, the items were generally high difficulty levels, and they were very good items. Exploratory and confirmatory factor analysis findings confirmed the three sub-dimensions (mental integration, mental rotation, and paper folding) measuring spatial visualization skills. SVT, which was reduced to 10 items, was administered to 396 students; the KR-20 internal consistency coefficient was 0.63, the average difficulty index was 0.35 and the average discrimination index was 0.48. As a result of the study, a valid and reliable test on spatial visualization for second grade primary school students was obtained and it was concluded that students' spatial visualization was at a low level.

Keywords:

Mental Rotation, Paper Folding, Spatial Visualization, Test development, Factor, Tetrachoric factor analysis.

Introduction

Frequently used in daily life, spatial skills are a set of skills based on envisioning and mental visualization. This ability is very critical for solving real-world problems and is also employed in identifying the problem, drawing an organized path, and determining the solution steps (Turğut & Yılmaz, 2012). Hendroanto et al. (2015) defined the concept of spatial ability as the ability to understand, manipulate, reorganize, and interpret visually and summarized all the definitions of spatial ability and briefly stated that it is a mental ability. The National Council of Teachers of Mathematics (NCTM, 2000) noted that spatial ability is a fundamental skill for students and emphasized the importance of this concept.

The availability of several definitions of spatial ability has brought along many components. An analysis of published research suggests that researchers used different components in their studies. Lohman (1996) mentioned the existence of two major components in his study. These components are spatial relations and spatial visualization. A different classification was made by McGee (1979) and

Tartre (1990). McGee (1979) stated that the concept of spatial ability consists of a combination of spatial visualization as the most generally accepted component and spatial orientation in addition to it, as in many previous studies. Tartre (1990), based on McGee's study, referred to the spatial ability concept consisting as a combination of visualization and orientation factors. Similarly, Lord (1985) mentioned the existence of spatial visualization and spatial orientation components for the concept of spatial ability. Linn and Petersen (1985) also mentioned four different components and one of the components was spatial visualization. As it is understood from all these studies on spatial ability, the instruments that measure spatial ability skills appear with the name or component of spatial visualization. Accordingly, the concept of spatial ability and the concept of spatial visualization have been used interchangeably.

McGee (1979) defined the concept of spatial visualization as one's manipulation of a picture presented to an individual in his/her mind, and rotating, folding, or reversing it. Indeed, spatial visualization is a complex concept that includes spatial orientation and mental rotation (Linn & Petersen, 1985). A review of literature presents many spatial visualization tests. The most generally accepted test among these is the "MGMP Spatial Visualization Test (Middle Grades Mathematics Project: Spatial Visualization)" developed by Winter et al. (1989) and adapted into Turkish by Turğut (2007). Other spatial visualization tests in the literature include Purdue Spatial Visualization Test (PSVT) (Guay, 1977), Embedded Figures Test (Witkin et al., 1977), Surface Development Test (Thurstone & Thurstone, 1949), Daily Occupational Test (Eliot & Smith, 1983), and Cube Formation Test (Alias et al., 2002). The questions used to measure spatial visualization skills in Dokumacı Sütçü and Oral's (2019) study and the spatial visualization questions in Hawes et al.'s (2017) study were taken as reference and different types of questions measuring spatial visualization skills were used in the current study.

Different question patterns were used to measure spatial visualization skills in the relevant literature. Mental integration and mental decomposition questions (Hawes et al., 2017; Dokumacı Sütçü & Oral, 2019); paper folding questions (Ekstrom, 1976; French et al., 1963; Kyllonen et al., 1984; Linn & Petersen, 1985; Thurstone & Thurstone, 1949) and mental rotation questions (Guay, 1977; Quaiser-Pohl, 2003; Shepard & Metzler, 1971) are the questions used to measure spatial visualization skill. In the spatial visualization skill test developed for this study, mental integration, paper folding, and mental rotation questions were used to measure this skill.

Reviewing the literature on mental integration questions, we observed that the most appropriate study for primary school level was conducted by Hawes et al. (2017) and Dokumacı Sütçü and Oral (2019). There is a wider network of publications in the literature on paper folding questions. The paper folding test, developed by Ekstrom (1976) and adapted into Turkish by Delialioğlu (1996), has been accepted as one of the important tests in measuring this skill. On the other hand, Linn, and Petersen (1985), Kyllonen et al. (1984) and French et al. (1963) also tried to measure spatial visualization skills with paper folding questions. Paper folding questions involve folding the paper once in a certain direction, punching holes in it and determining its final appearance. The most notable studies in the literature on mental rotation questions include Quaiser-Pohl (2003), Guay (1977), Shepard and Metzler (1971) and Peters et al. (1995). In these studies, the test questions were designed as questions requiring the ability to rotate shapes or objects in two- or three-dimensional space in the mind and then to rotate/animate the resulting image in the mind. The above-mentioned tests are mostly old and have been used in the field of technology and engineering, and do not address students at primary school level. The lack of adequate spatial visualization tests in the literature addressing the levels of primary school students has revealed the need to develop a new test. To this end, this study was conducted to develop an up-to-date and original test suitable for the level of primary school students.

In the proposed test, mental integration questions were prepared making use of the questions in the studies of Hawes et al. (2017) and Dokumacı Sütçü and Oral (2019); mental rotation questions were prepared making use of the questions in the studies of Hawes et al. (2017), Lowrie et al. (2019) and Quaiser-Pohl (2003); and paper folding questions were prepared making use of the questions in the study of Linn and Petersen (1985). Thus, spatial visualization questions were prepared for the sample determined within the scope of the research in accordance with the second-grade level through a comprehensive literature review. This Spatial Visualization Test (SVT) aims to diagnose and determine the spatial visualization skills of second-grade primary school students. Accordingly, this research study sought to answer the following research questions:

1- What are the validity and reliability findings of "Spatial Visualization Test for Second-Grade Primary School Students" developed in the study?

2- What is second grade students' spatial visualization level?

3- Is there a significant difference between second grade students' spatial visualization sub-scores?

Method

Research Design

This study, which aims to develop a test to measure the spatial visualization skills of second-grade students, employed the cross-sectional survey model. A cross-sectional study occurs at one point in time and provides a picture of what the researcher wants to study (Allen, 2017). The main purpose of survey studies is to produce quantitative data and various statistics about situations and events over large groups (Creswell, 2009). In this study, students' spatial visualization skills were measured at one point in time with the SVT, developed by the researchers.

Research Population and Sample

The population of the study consisted of second-grade primary school students studying in the 2021-2022 academic year. The sample of the study consisted of 396 second-grade primary school students studying in different public schools in the provinces/districts of Türkiye at each academic achievement level. The 396 students constituting the sample were selected from the accessible population through the simple random sampling method. In this method, the selection process for the sample from the population is carried out in accordance with the principle of randomness, that is, the selection status of the units that can be selected for sampling is independent of each other (Büyüköztürk et al., 2014). Participants were selected from provinces in the eastern, central, and western regions of the country. In addition, while forming the sample, 10% of the accessible population, 10 times the number of items in the test, or more than 10 times the number of test items were reached based on the sample number resulting from the G-power analysis (Pallant, 2020).

Ethical Approval

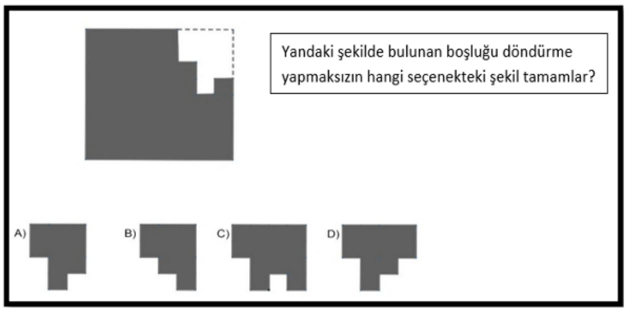
The ethical approval was obtained from the Social Sciences and Humanities Scientific Research Ethics Committee of Necmettin Erbakan University, dated 16.09.2021 with the decision number 2021/448.

Instrument Development Process

The SVT, which was used as a data collection tool, was developed in accordance with the steps of test development including the steps of determining the purpose of the test, determining the scope of the test, determining the question type, determining the number and duration, determining the validity of the test, piloting the test, reliability, and item analysis (Özçelik, 2013).

The aim of the test is to determine the spatial visualization skills of second-grade students. To form the scope of the developed test, the sub-dimensions of the test were determined in the light of the relevant literature and the learning outcomes in the primary school mathematics curriculum. Four multiple-choice questions were prepared for each sub-dimension (mental integration, mental rotation, and paper folding). The developed questions were categorized as easy, medium, and difficult according to their difficulty levels. Mental integration questions, including two easy, one difficult and one medium level questions, were developed by taking the questions in Hawes et al. (2017) and Sütçü and Oral's (2019) studies as examples. Mental rotation questions were developed as two difficult, one easy, and one intermediate level questions based on Hawes et al. (2017), Lowrie et al. (2019), and Quaiser-Pohl (2003). The paper folding questions were prepared making use of Linn and Petersen's (1985) study with two difficult, one easy and one intermediate level questions. Sample items belonging to the sub-dimensions are presented below Figure 1, Figure 2 and Figure 3:

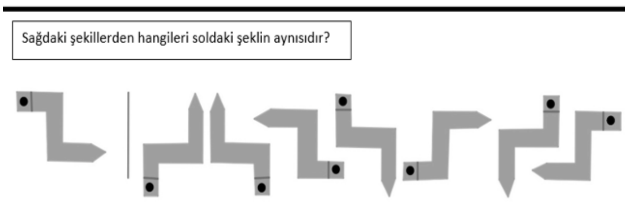
Figure 1.
Sample item for mental integration



(Which option completes the gap in the adjacent figure without making a rotation?)

The mental integration questions consisted of questions requiring the ability to complete incomplete shapes and to combine small shapes into a large shape, as shown in Figure 1.

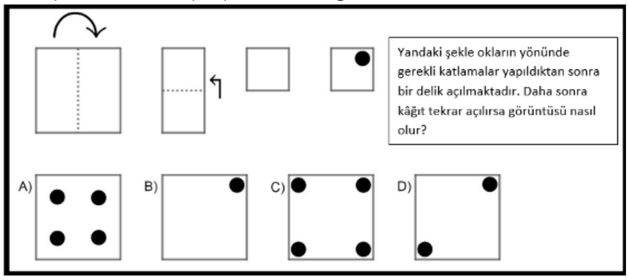
Figure 2.
Sample item for mental rotation



(Which of the figures on the right is the same as the figure on the left?)

Mental rotation questions consisted of questions requiring the ability to determine the new state of the object by performing mental rotation in accordance with the instructions as shown in Figure 2.

Figure 3.
Sample item for paper folding



(After making the necessary folds in the direction of the arrows in the adjacent figure, there will be a hole in the paper. If the paper is then opened again, what will it look like?)

Folding lines and folding directions are shown in the paper folding questions as shown in Figure 3. All paper folding questions in the test consisted of questions that required folding skills in accordance with the instructions.

Data Collection and Analysis

Each participant's test was numbered and recorded using the Microsoft Office Excel program. Each question answered correctly in the test was recorded as 1 (one) point and each question answered incorrectly or left blank was recorded as 0 (zero) point. The highest score to be obtained from the test was 12 and the lowest score to be obtained was 0. Exploratory and confirmatory factor analyses were conducted to ensure the construct validity of the test. The tetrachoric factor analysis was performed with the "Factor" program developed by Lorenzo-Seva and Ferrando (2006). This program provides both Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) results. The descriptive statistics of the students' spatial visualization total scores and the scores of the spatial visualization sub-dimensions were analyzed with the SPSS 22.0 package program. All these analyses conducted as a result of the application of this developed test were carried out to obtain better results and contribute to the literature by giving accurate and consistent results.

Validity and Reliability

The developed test was first piloted with 296 students. As a result of the pilot application, the test was finalized, and applied with the participants. For the content validity, a specification table for the objectives in the curriculum was prepared before the application, a question pool was created in the light of the relevant literature, and then expert opinion was obtained. In line with the opinions of two mathematics education experts and a primary school teacher, the coefficient of agreement was calculated as 0.90. Criterion and construct validity of the study were also checked. Difficulty and discrimination indices were also examined for the validity study of the test. The item difficulty index (p) takes a value between "0" and "1" and when this value is close to 1, it means that the questions are easy and when it is close to 0, it means that the questions are difficult. It is ideal for the questions to be of medium difficulty. The difficulty index values of the items in the measurement tool should be between 0.3 and 0.7 (Büyüköztürk et al., 2014).

The item discrimination index (r) takes a value between "-1" and "+1", and a value close to 1 indicates a higher level of discrimination. A negative discrimination index means that the question is reverse discriminative, that is, the students in the lower group are more successful than the students in the upper group, which indicates that the question does not work. The discrimination index should be 0.30 and above, questions below 0.30 should be corrected, questions with a discrimination level below 0.20 and negative questions should be discarded from the measurement tool (Büyüköztürk et al., 2014). The discrimination index is calculated by subtracting the number of participants from the upper group who answered the question correctly from the number of participants from the lower group who answered the question correctly and dividing by the number of participants in the upper or lower group.

Exploratory and confirmatory factor analyses were conducted to measure the construct validity of the test. Factor analysis is of two types: exploratory factor analysis and confirmatory factor analysis. Scales have equal intervals and achievement tests have an ordinal structure. Therefore, since achievement tests are ordinal scales coded by giving "1" point to the correct answer and "0" point to the wrong answer according to the classical test theory, it is appropriate to perform tetrachoric factor analysis in determining the factor structure, unlike the scales. Within the scope of EFA, KMO value and sig. value of Barlett's test are given. The KMO value obtained because of factor analysis is an indicator of both sampling adequacy and normal distribution. The KMO value should be 0.60 and above (Seçer, 2017). The fact that the sig. value in the KMO table is less than 0.05 means that the data set is suitable for conducting factor analysis and the data are significant. When these two conditions are met, factor analysis data can be interpreted. The Eigenvalues of the factors are expected to be "1" and above, and all factors are expected to explain at least 40% of the total variance (Seçer, 2017). Within the scope of CFA, Chi-squared/ Degrees of Freedom and other fit index values are calculated. For the factor structure obtained as a result of EFA to be confirmed in CFA, the "Chi-squared/ Degree of Freedom" value is expected to be less than 5 (Seçer, 2017). The validity and reliability analysis findings of the test are given in the Findings section.

Findings

The findings regarding the research question, "What are the validity and reliability findings of "Spatial Visualization Test for Second-Grade Primary School Students" developed in the study?", are provided below.

Findings regarding the Validity of the Spatial Visualization Test

Exploratory factor analysis and confirmatory factor analysis were used for construct validity in the study. Table 1 shows the exploratory factor analysis findings of the test.

Table 1.
Exploratory Factor Analysis Results of the Spatial Visualization Test

Item	Factor 1 (M. I.)	Factor 2 (M. R.)	Factor 3 (P. F.)
1	0.312		
4	-		
8	0.529		
11	0.353		
2		0.525	
5		0.729	
7		0.812	
10		0.992	
3			0.406
6			0.598
9			-
12			0.855
			Total Variance: % 61.549

The exploratory factor analysis results presented in Table 1 demonstrated that the 61% variance in the test was explained with three sub-dimensions. The factor loadings of the items related to these factors ranged between 0.312 and 0.529 in the mental integration sub-dimension, between 0.525 and 0.992 in the mental rotation sub-dimension, and between 0.406 and 0.855 in the paper folding sub-dimension. The item factor load should be at least .30 (Seçer, 2017, p. 166). Since items 4 and 9 were not explained under any factor, we decided to remove them from the test. The findings of the confirmatory factor analysis of the developed test are given in Table 2.

Table 2.
Confirmatory Factor Analysis Results of the Spatial Visualization Test

Fit Indices	Observed Values	Result
χ2	87.421	-
χ2/ df	3.49	Excellent Fit
RMSEA	0.064	Excellent Fit
GFI	0.972	Excellent Fit
AGFI	0.938	Excellent Fit
NNFI	0.956	Excellent Fit
CFI	0.980	Excellent Fit

As presented in Table 2, 0.90 was regarded as the acceptable cut-off value and 0.95 was regarded as the excellent cut-off value for the Chi-square Goodness, GFI (Goodness of Fit Index), RMSEA (Root Mean Square Error of Approximation), CFI (Comparative Fit Index) and AGFI (Adjusted Goodness of Fit Index) fit indices for confirmatory factor analysis (Meydan & Şeşen, 2011). For RMSEA, a value less than 0.08 was accepted as an acceptable fit value. According to the confirmatory factor analysis findings, the fit indices were found to be significant (x^2 = 87.421, df = 25, p > 0.05; x^2/df=3.49). The fit index values were RMSEA = 0.064, NFI = 0.956, CFI = 0.980, AGFI=0.938, GFI = 0.972. Accordingly, the confirmatory factor analysis revealed that the three-dimensional structure gave a good fit. It can be said that the test was developed as a reliable and valid measurement tool with a three-dimensional structure including mental integration, mental rotation and paper folding.

Findings regarding the Item Analysis of Spatial Visualization Test

The values obtained as a result of item analysis to ensure the construct validity of the questions in the developed test are given in Table 3.

Table 3.
Findings Related to Item Analysis of the Spatial Visualization Pilot Test

Item	pj	Difficulty Level	rj	Discrimination Assessment
1	0,922	Easy	0,299	Needs Revision
2	0,543	Medium	0,486	Very good
5	0,203	Difficult	0,569	Very good
4	0,414	Medium	0,378	Good
5	0,203	Difficult	0,295	Needs Revision
6	0,424	Medium	0,502	Very good
7	0,063	Difficult	0,454	Very good
8	0,6	Medium	0,554	Very good
9	0,431	Medium	0,414	Very good
10	0,122	Difficult	0,434	Very good
11	0,564	Medium	0,437	Very good
12	0,354	Difficult	0,527	Very good

As Table 3 demonstrates, most of the test items had a medium-level difficulty. In addition, items 1 and 5 were found to be items whose discrimination values needed to be revised according to the criteria. This pilot test with 296 students revealed that the items were generally at medium and difficult levels and very good items in terms of discrimination. The KR-20 internal consistency coefficient of the test was calculated as 0.57. The average difficulty index of the test was 0.41 and the average discrimination index of the test was 0.44.

As a result of the pilot application, two items that needed to be corrected were revised (1st and 5th items) and two items were removed from the test according to the factor analysis findings (4th and 9th items) and the finalized 10-item SVT was applied to 396 students. As a result of this application, the construct validity item analysis findings are presented in Table 4.

Table 4.
Item Analysis Results regarding the Final Form of the Spatial Visualization Test

Item number	Pj	Difficulty Level	rj	Discrimination Assessment
1	0,919	Easy	0,260	Needs Revision
2	0,497	Medium	0,448	Very good
3	0,351	Difficult	0,596	Very good
5	0,166	Difficult	0,299	Good
6	0,414	Medium	0,533	Very good
7	0,050	Difficult	0,369	Very good
8	0,542	Medium	0,583	Very good
10	0,118	Difficult	0,434	Very good
11	0,550	Medium	0,451	Very good
12	0,318	Difficult	0,562	Very good

The findings of the analysis of the items presented in Table 4 revealed that the items were generally medium and difficult in terms of difficulty index and very good in terms of discrimination. The KR-20 internal consistency coefficient of the final test was calculated as 0.63. The item discrimination index of the first item was found to be acceptable (very close to 0.30). The average difficulty index of the final test was 0.35 and the average discrimination index was 0.48. The reliability values of the pilot test and the final test are presented in Table 5.

Table 5.
Reliability Analyses of Pilot Test and Final Test

	Item	N	Average Difficulty	Average Discrimination	KR-20
Pilot	12	297	0,41	0,44	0,57
Final Test	10	396	0,35	0,48	0,63

Table 5 shows that the reliability values increased from 0.57 to 0.63 after the two items were removed from the test. As a result of all these analyses and measurements, we can argue that the SVT for second grade primary school students developed by the researchers is a reliable and valid measurement tool with a three-factor structure including mental integration, mental rotation, and paper folding.

The findings related to the second research question, "What is second grade students' spatial visualization level?", are presented below.

Descriptive Statistics regarding Spatial Visualization Test

The findings of the analyses conducted to determine the level of spatial visualization of second grade students are presented in Table 6.

Table 6.
Descriptive Statistics regarding Spatial Visualization Test

	N	Min	Max	Mean	SD
Mental Integration	396	0,00	3,00	2,012	0,843
Mental Rotation		0,00	4,00	0,833	0,843
Paper Folding		0,00	3,00	1,083	1,041
Total		0,00	10,00	3,929	2,005

Table 6 shows the participant students' scores for the sub-dimensions of the SVT. Accordingly, the mean total score of the second-grade students for spatial visualization ($\bar{X}$= 3,929; sd=2,005) is low. The mean scores in the mental integration sub-dimension ($\bar{X}$ = 2.01; *sd* = 0.84), mental rotation sub-dimension ($\bar{X}$ = 0.83; sd = 0.84), and paper folding sub-dimension ($\bar{X}$ = 1.08; sd = 1.04) are below the average. According to the mean spatial visualization scores of the second-grade students, we can argue that the students showed the best performance in the questions belonging to the mental integration sub-dimension and the lowest performance in the questions belonging to the mental rotation sub-dimension.

The findings related to the third research question, "Is there a significant difference between second grade students' spatial visualization sub-scores?", are presented below.

To answer this research question, the results of the repeated measures ANOVA test conducted to determine whether there is a statistically significant difference between the mean scores of the second-grade students in the sub-dimensions of the SVT are presented in Table 7.

A statistically significant difference was found between the second-grade students' mean scores in the sub-dimensions of the spatial visualization test, as presented in Table 7 ([F395,2 = 262,124], $p < .05$). In terms of the effect size, this significant difference was of medium size (η^2 = 0.399) (Cohen, 1988). As a result of the comparisons made with Bonferonni test, a significant difference was found between mental integration and mental rotation, mental integration and paper folding, mental rotation and paper folding scores (p = .00). Looking at the means of the sub-dimensions, the significant difference between mental integration

Table 7.
Results regarding Spatial Visualization Test

Variables	Variance Source	Sum of Squares	*Sd*	Mean Squares	*F*	*p*	Significant Difference	η^2
Spatial visualization	Between Subjects	529,340	395	1,340	262,124	0,00	1-2 1-3 2-3	0,399
	Measurement	305,820	2	152,910				
	Error	460,847	790	0,583				
	Total	1,296,007	1.187					

p<0.05 significant
1: mental integration 2: mental rotation 3: paper folding

and mental rotation was in favor of mental integration scores ($\bar{X}$ = 2.012; *sd* = 0.843). The significant difference between mental integration and paper folding was also in favor of mental integration scores ($\bar{X}$ = 2,012; *sd* = 0,843). The significant difference between mental rotation and paper folding scores was in favor of paper folding scores ($\bar{X}$ = 1,083; *sd* = 1,041).

Conclusion and Discussion

This study reports the development of a spatial visualization test for second-grade primary school students, and their spatial visualization levels were also investigated. An analysis of the related literature revealed that the tests that require high-level thinking skills such as spatial visualization are simplified and applied to primary school and preschool level students (Dokumacı Sütçü & Oral, 2019; Quaiser-Pohl, 2003). Accordingly, the questions used in the spatial visualization tests in the literature were transformed into a new test to address second-grade students in the current study. The reliability of the Purdue Spatial Visualization Test developed by Guay (1977) was 0.80; the reliability of the Spatial Visualization Test developed by Alias et al. (2002) was 0.55; the reliability of the Spatial Visualization Test in Two-Dimensional Geometry developed by Olkun and Altun (2003) was 0.77; and the reliability of the MGMP Spatial Visualization Test adapted into Turkish by Turğut (2007) was 0.81. The reliability of the Spatial Visualization Test developed in this study was calculated as 0.63. This value suggests that the reliability is quite acceptable when evaluated in terms of tests coded as true-false and the number of items in the test (Seçer, 2017).

The results demonstrated that the sub-dimensions of the SVT developed within the scope of the current study are like the sub-dimensions of Linn and Petersen (1985), Gorska and Leopold (1998) and Burton and Fogarty's (2003) tests. The literature accommodates many spatial visualization definitions (Hauptman, 2010; Hendroanto et al., 2015; Linn & Petersen, 1985; Lohman, 1996), spatial visualization tests (Purdue SVT, MGMP, Daily Occupational Test, Embedded Figures Test), spatial visualization components (Burton & Fogarty, 2003; Caroll, 1993; Gorska & Leopold, 1998; Guilford et al., 1952 Kimura, 1999; Lohman, 1996; Linn & Petersen, 1985; Lord, 1985; McGee, 1979; Tartre, 1990; Thurstone & Thurstone, 1949), indicating that this topic is significant and has attracted the attention of many researchers. However, the very broad perspectives in all these studies have prevented the drawing of clear boundaries for research. It is thought that conducting studies within clear boundaries will be more beneficial for other researchers. The scope of the test in this study was composed of mental rotation, mental integration and paper folding factors, and was confirmed by exploratory and confirmatory factor analyses.

Significant differences were found between second-grade students' spatial visualization scores among the three sub-dimensions. The second-grade students scored the highest in the questions in the mental integration sub-dimension and the lowest in the questions belonging to the mental rotation sub-dimension. In line with this result, mental rotation was determined as the skill that students had the most difficulty within the studies of Yılmaz and Yenilmez (2019) and Turgut and Yılmaz (2012). In Sezen Yüksel's (2013) study, participants' mental rotation scores were found to be higher than other sub-dimensions. There was a significant difference between mental integration skills and paper folding skills in favor of the mental integration sub-dimension. On the other hand, there was a significant difference between paper folding skills and mental rotation skills in favor of paper folding scores. Among these three sub-dimensions, the sub-dimension in which the participants were most accurate was determined as the mental integration sub-dimension. Lowrie et al. (2019) put forward an opinion that explains this situation in their study; mental rotation is a more complicated skill that requires a higher level of spatial visualization. In addition, Lowrie et al. (2019) argue that students should have skills such as paper folding to answer mental rotation questions. Accordingly, we can argue that paper folding is a more primal and prerequisite skill than mental rotation. The result of another study, which contradicts this result, is that students' mental rotation skill averages were higher than the other sub-dimensions of the study (Sezen Yüksel, 2013). According to Sezen Yüksel (2013), mental rotation skill is a prerequisite for spatial visualization and mental cutting sub-dimension. It was also found that mental rotation ability explained 90% of spatial ability, while spatial visualization ability explained 50% of spatial ability. According to Çakmak et al. (2014), 10% of spatial visualization can be explained by origami-based education enriched with paper folding activities.

Recommendations and Limitations

Future research may investigate the parameters according to which the spatial visualization sub-dimension scores differ. The relationship between this test and different mathematical skill variables can also be investigated. In this study, a factor related to three-dimensional elements was not identified because three-dimensional thinking is not fully developed in second grade students. We suggest that future research may develop the test further by adding a three-dimensional thinking factor at different grade levels. The study's limitations include the fact that it was conducted in a few regions in Turkey and focused solely on the primary school level. For practitioners, we recommend using this test in diagnosing second-grade students' spatial visualization, determining their spatial visualization levels and in the developing their spatial visualization skills. In addition, by practicing with items parallel to the items in the spatial visualization test, students' spatial-abstract thinking can be improved. A comparative analysis of the study, which utilizes tests working with different dimensions, and a discussion of the sub-dimensions of the spatial visualization test will contribute significantly to the related field.

Declaration of the Author(s)

Declaration of researchers' contribution rate: The authors contributed equally to the study.

Ethical Committee Decision: The ethical approval was obtained from the Social Sciences and Humanities Scientific Research Ethics Committee of Necmettin Erbakan University, dated 16.09.2021 with the decision number 2021/448.

Conflict of interest: The authors declare no conflict of interest.

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References

Alias, M., Black,T.R., Gray, D.E. (2002), Effect of Instructions on Spatial Visualisation Ability in Civil Engineering Students, *International Education Journal*, 3 (1), 1-12.

Allen, M. (Ed.). (2017). *The SAGE encyclopedia of communication research methods*. SAGE publications.

Burton, L., & Fogarty, G. (2003), The Factor Structure of Visual Imagery And Spatial Abilities, *Intelligence*, 31, (3), 289-318. https://doi.org/10.1016/S0160-2896(02)00139-3

Büyüköztürk, Ş., Kılıç-Çakmak, E., Akgün, Ö., Karadeniz, Ş., & Demirel, F. (2014), *Bilimsel Araştırma Yöntemleri*, Pegem Akademi Yayıncılık.

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor-analytic studies* (No.1), Cambridge University Press

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Second Edition. Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers

Creswell, J. W. (2009). "Mapping the field of mixed methods research", *Journal of mixed methods research,* 3(2), 95-108

Çakmak, S., M. Işıksal ve Y. Koç (2014)." Investigating effect of origami-based instruction on elementary students spatial skills and perceptions", *Journal of Educational Research*, 107(1), 59–68. https://doi.org/10.1080/00220671.2012.753861

Delialioğlu, Ö. (1996), *Contribution of Students' Logical Thinking Ability on Achievement in Secondary Physics*, Master Degree Thesis, ODTÜ Fen Bilimleri Enstitüsü, Ankara.

Dokumacı Sütçü, N., & Oral, B. (2019), Uzamsal Görselleştirme Testinin Geliştirilmesi: Geçerlik ve Güvenirlik Çalışmaları, *Kastamonu Eğitim Dergisi*, 27(3), 1179–1195. https://doi.org/10.24106/kefdergi.2826

Ekstrom, R. B. (1976), Kit of factor-referenced cognitive tests, *Educational Testing Service*.

Eliot, J.,& Smith, I.M., (1983), *An International Directory of Spatial Tests*, Windsor, The NFER-Nelson Publishing Company Ltd., United Kingdom.

French, J. W., Ekstrom, R. B., & Price, L. A. (1963). *Manual for kit of reference tests for cognitive factors* (revised 1963). Educational Testing Service Princeton NJ.

Gorska, R., & Leopold, C. (1998), Gender differences in visualization skills – An international perspective, *Engineering Design Graphics Journal*, 62(3), 9–18.

Guay, R. B. (1977), Factors Affecting the Development of Two Spatial Abilities Basic to Technical Drawing, *Journal of Industrial Teacher Education*, 14(3), 38-43.

Guilford, J. P., Fruchter, B. and Zimmerman, W. S. (1952), Factor analysis of the Army Air Forces Shepard Field battety of experimental aptitude tests, *Psychometrika*, 17: 45–68.

Hauptman, H. (2010). "Enhancement of spatial thinking with Virtual Spaces 1.0.", *Computers & Education*, 54(1), 123-135. https://doi.org/10.1016/j.compedu.2009.07.013

Hawes, Z., Moss, J., Caswell, B., Naqvi, S., & MacKinnon, S. (2017), Enhancing Children's Spatial and Numerical Skills through a Dynamic Spatial Approach to Early Geometry Instruction: Effects of a 32-Week Intervention, *Cognition and Instruction*, 35(3), 236– 264 https://doi.org/10.1080/07370008.2017.1323902

Hendroanto, A., Budayasa, I. K., Abadi, A., Galen, F. V., & Van Eerde, H. A. A. (2015). Supporting Students? Spatial Ability In Understanding Three-Dimensional Representations. In: The Third South East Asia Design/Development Research International Conference, 18 Apr - 19 Apr 2015, Palembang.repository.unsri.ac.id

Kyllonen, P.C., Lohman, D.F., & Snow,R.E., (1984), Effects of Aptitudes, Strategy Training, and Task Facets on Spatial Task Performance, *Journal of Educational Psychology*, 76 (1), 130-145. https://doi.org/10.1037/0022-0663.76.1.130

Linn, M. C., & Petersen, A. C. (1985), Emergence and characterization of sex differences in spatial ability: A meta-analysis, *Child development*, 1479-1498. https://doi.org/10.2307/1130467

Lohman, D. F. (1996), *Spatial Ability and G. Human Abilities: Their Nature and Assessment*, DP Tapsfield, 97–116.

Lord T.R., (1985), Enhancing The Visuo-Spatial Aptitude of Students, *Journal of Resarch in Science Teaching*, 22:395-405. https://doi.org/10.1002/tea.3660220503

Lorenzo-Seva, U., & Ferrando, P. J. (2006), FACTOR: A computer program tofit the exploratory factor analysis model, *Behavior research methods*, 38(1), 88-91.https://doi.org/10.3758/BF03192753

Lowrie, T., Logan, T., & Hegarty, M. (2019), The Influence of Spatial Visualization Training on Students' Spatial Reasoning and Mathematics Performance, *Journal of Cognition and Development*, 20(5), 729–751. https://doi.org/10.1080/15248372.2019.1653298

McGee, M. G., (1979), Human Spatial Abilities: Psychometric Studies And Environmental, Genetic, Hormonal, And Neurological Influences, *Psychological Bulletin*, 86 (5), 889-918. https://doi.org/10.1037/0033-2909.86.5.889

Meydan, C. H., & Şeşen, H. (2011). *Yapısal eşitlik modellemesi* AMOS uygulamaları. Detay Yayıncılık.

NCTM (National Council of Techers of Mathematics) (2000), *Principles and standards for School Mathematics*. Reston. VA: Author

Olkun, S., & Altun, A. (2003), İlköğretim öğrencilerinin bilgisayar deneyimleri ile uzamsal düşünme ve geometri başarıları arasındaki ilişki, *The Turkish Online Journal of Educational Technology*, 2(4), 86-91.

Özçelik, D.A. (2013). *Test Hazırlama Kılavuzu*, Pegem Akademi, Ankara.

Pallant, J. (2020). *SPSS Survival Manual: A Step by Step Guide to Data Analysis Using IBMSPSS*, Routledge.

Peters, M., Laeng, B., Latham, K., Jackson, M., Zaiyouna, R. and Richardson, C. A Redrawn (1995), Vandenberg & Kuse Mental Rotations Test: Different Versions and Factors that affect Performance, *Brain and Cognition*, 28, 39-58. https://doi.org/10.1006/brcg.1995.1032

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. https://doi.org/10.1207/S15327574IJT03032

Seçer, İ. (2017). *SPSS ve LISREL ile Pratik Veri Analizi: Analiz ve Raporlaştırma*, Anı Yayıncılık.

Sezen Yüksel, N. (2013), *Uzamsal Yetenek Bileşenleri ve Uzamsal Yeteneğin Geliştirilmesi Üzerine*, Doktara Tezi, Hacettepe Üniversitesi, Ankara.

Shepard, R.N.,& Metzler, J. (1971), Mental Rotation of Three- Dimensional Objects, *Science New Series*, 171, 701- 703. https://doi.org/10.1126/science.171.3972.701

Tartre, L.A., (1990), Spatial Orientation Skill and Mathematical Problem Solving, *Journal for Research in Mathematics Education*, 21 (3), 216- 229. https://doi.org/10.5951/jresematheduc.21.3.0216

Thurstone, T. G., & Thurstone, L. L. (1949), *Mechanical aptitude II description of group tests*, Chıcago Unıv II Psychometrıc Lab.

Turğut, M. (2007), *İlköğretim II. kademede öğrencilerin uzamsal yeteneklerinin incelenmesi*, Yayımlanmamış yüksek lisans tezi, Dokuz Eylül Üniversitesi, İzmir.

Turğut, M., & Yılmaz, S. (2012), İlköğretim 7. ve 8. Sınıf Öğrencilerinin Uzamsal Yeteneklerinin İncelenmesi, *Dicle Üniversitesi Ziya Gökalp Eğitim Fakültesi Dergisi*, (19), 69-79.

Winter, J. W., Lappan, G., Fitzgerald, W. ve Shroyer, J., (1989), *Middle Grades Mathematics Project: Spatial Visualization*, NY: Addison-Wesley.

Witkin, H. A., Moore, C. A., Goodenough, D. R., & Cox, P. W. (1977), Field-dependent and field-independent cognitive styles and their educational implications, *Review of educational research*, 47(1), 1-64. https://doi.org/10.3102/00346543047001001

Yılmaz, E.B. & Yenilmez, K. (2019, September 26-28), *Ortaokul 7. ve 8. sınıf öğrencilerinin Uzamsal Görselleştirme Becerilerinin İncelenmesi*, 4th International Symposium of Turkish Computer and Mathematics Education, İzmir – Full Test