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An Investigation of Middle School Students' Spatial Reasoning Skills

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Abstract

In recent years, there has been a growing interest in spatial reasoning as a component of mathematics education, with many countries incorporating it into their mathematics curriculum. The study of spatial reasoning in the learning areas of geometry presents an essential opportunity for improvement of students within the realm of mathematics education. The purpose of this survey research is to examine middle school students spatial reasoning skills. A study was conducted to analyze the spatial reasoning skills of 947 middle school students. The Spatial Reasoning Test was utilized to assess the sub-components of spatial visualization, spatial orientation, and mental rotation. Based on the results, there was no significant difference between male and female students in relation to their overall test scores. However, a statistically significant difference was observed when analyzing the scores of the sub-components and grade levels. Anticipated outcomes of the investigation are expected to provide support and guidance for the preparation of educational tasks and instruction aimed at enhancing students' spatial reasoning abilities.

Keywords:

Spatial Reasoning, Middle School Students, Mental Rotation, Spatial Orientation, Spatial Visualization

Introduction

The concept of spatial reasoning is one that is approached from a variety of disciplinary perspectives. Despite being explored in disciplines other than mathematics, spatial reasoning has been an integral part of mathematics education research and the mathematics curriculum for decades. There have been various definitions of spatial reasoning, including spatial ability, spatial perception, spatial reasoning, three-dimensional thinking, and spatial perception (Clements & Battista, 1992; NCTM, 2000; Olkun, 2003). In the literature, the terms spatial reasoning, spatial skills, and spatial ability are frequently used interchangeably. Since the concept of ability is used to express inherent ability, the term spatial reasoning skill was chosen for this research. In recent years, spatial reasoning skills, which are considered part of geometry education, have become increasingly essential, and it has been discovered that geometry teaching plays a crucial role in the development of spatial reasoning skills (Clements & Sarama, 2011). The inadequacy of teachers' geometry content knowledge (Clements & Sarama, 2011) and the reduction of middle school geometry instruction to the properties and relationships of two- and three-dimensional shapes (Sinclair & Bruce, 2015) may also impact the teaching of spatial reasoning skills.

When examining the teaching of spatial reasoning concepts in Turkey from the past to the present, the concept of symmetry, which is one of the sub-topics, was first included in the 1968 mathematics curriculum, and in the 2009 mathematics curriculum, it was intended to be taught by associating it with geometric shapes, and it was explicitly stated that it was taught within the scope of the transformation geometry sub-learning area (Memişoğlu & Tapan-Broutin, 2018). In the mathematics curriculum, spatial reasoning skills are developed through the sub-learning areas 'spatial relations' at the elementary school level, 'transformation geometry' at the middle school level, and 'fundamental transformations at the analytical plane' at the high school level. The aforementioned sub-learning areas include the instruction of concepts such as expressions indicating location and direction, symmetry, line of symmetry, mirror symmetry, reflection, translation, image, center of rotation, angle of rotation, axis of symmetry, and center of symmetry (MoNE, 2018). In addition to these, spatial reasoning skills include drawing two-dimensional views of three-dimensional objects from different directions, creating structures based on drawings of their views from different directions, recognizing three-dimensional geometric objects and drawing their expansion, and producing images of points, line segments, and other shapes in the plane as a result of translation, reflection, and rotation (MoNE, 2018).

By acquiring geometric thinking skills, it is planned that students will be able to establish relationships between spatial reasoning skills such as critical thinking, creative thinking, and multi-dimensional thinking and other areas of mathematics (MoNE, 2018). The geometry learning area is an essential component of the mathematics curriculum and provides students with a significant opportunity to develop their spatial abilities. Numerous studies demonstrate the link between spatial reasoning and achievement in mathematics, engineering, science, and technology (STEM) (e.g. Fowler et al., 2022; Mix & Cheng, 2012; Shea et al., 2001; Wai et al., 2009).

The curriculum emphasizes the importance of developing spatial visualization and interpretation skills in all students in order for them to succeed in the mathematics course (MoNE, 2018; NCTM, 2000). Although spatial reasoning is included in our curriculum, many students struggle with spatial reasoning questions (Kabakçı & Demirkapı, 2016). The fact that concepts related to spatial reasoning have been studied for a shorter period of time than other concepts in the field of learning geometry calls for some modifications to the curriculum. Incorporating more tools, such as dynamic geometry software, into geometry instruction in recent years demonstrates the need for new goals in geometry education currently. It is also mentioned that success in international applications such as Programme for International Student Assessment (PISA) scores are correlated with spatial reasoning test scores, and that this correlation may be an undervalued strategy for improving performance on these examinations (Sorby & Panther, 2020). Lowrie and Logan (2018) recommend associating geometry concepts with spatial reasoning more in countries that excel at international student success assessments such as Trends in International Mathematics and Science Study (TIMMS) or PISA. From this perspective, the emphasis placed on geometry instruction will also contribute to the growth of students' spatial reasoning abilities. In order to cultivate students' spatial reasoning skills, it is first necessary to assess their current level of spatial reasoning ability so that teaching innovations can be planned.

Geometry teaching allows students to spatially reason about geometric concepts (Clements & Battista, 1992). Geometry enables students to understand, model, and manipulate the structure of objects, shapes, and space. Therefore, teaching geometry should be viewed as a significant opportunity to foster spatial reasoning in students. Rotating, reflecting, and situating two-dimensional shapes activates students' spatial visualization skills, and spatial visualization can be enhanced by associating this skill with concepts like the area of shapes and their positions on the analytical plane (Lowrie & Logan, 2018). As an example of the relationship between spatial reasoning skills and other learning areas, it has been observed that students with strong mental rotation skills perform better on algebraic thinking problems (Cheng & Mix, 2014). In order to increase achievement in other areas of mathematics learning, it is evident that spatial reasoning abilities must be developed. At both the primary and secondary school levels, it is important to develop geometric reasoning skills holistically by enhancing students' knowledge of geometry concepts, as opposed to simply developing spatial reasoning skills; therefore, appropriate learning environments should be associated with geometry concepts for the development of spatial reasoning (Fujita et al., 2020). The development of spatial reasoning skills should begin as early as possible (Casey et al., 2008), as good spatial reasoning skills lead to good geometry achievement and therefore mathematical success (Burte et al., 2017; Mulligan, 2015). In order to develop spatial reasoning, it is necessary to assess the current level of spatial reasoning ability among students. In addition, the level of students' spatial reasoning skills must be evaluated in order to construct an effective geometry education.

Although there is no consensus regarding the subcomponents it consists of as a complex concept and the definitions given, three fundamental subcomponents of spatial reasoning skill can be emphasized based on the concepts in primary and middle school mathematics curriculum: mental rotation, spatial orientation, and spatial visualization (Ramful et al., 2017). The purpose of this survey study is to determine the spatial reasoning skills of middle school students and provide findings to support the necessary preparation for the development of spatial reasoning. In addition, it was intended to determine which subcomponent of spatial reasoning may be responsible for difficulties in developing spatial reasoning skills, as well as whether these subcomponents vary by gender and grade level. To achieve these objectives, the following research questions will be answered:

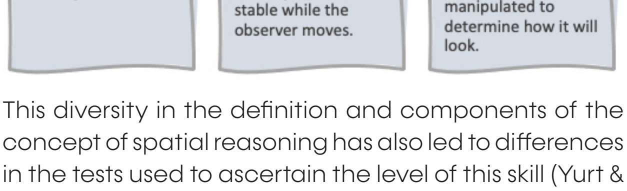
1. How well do middle school students incorporate spatial reasoning?
2. Do female and male middle school students score differently on spatial reasoning?
3. Are the spatial reasoning skill scores of middle school students different in terms of the grade level they attend?
4. Do female and male middle school students score differently on spatial visualization, spatial orientation, and mental rotation subcomponents of spatial reasoning?

Theoretical Background

Spatial reasoning can be defined as the capacity to create or manipulate images or shapes. This ability encompasses the understanding and manipulation of three-dimensional objects and their positions and relationships in space. Consequently, the creation or orientation of shapes or images is only a portion of the process. Success in mathematics, engineering, science, and technology requires the development of spatial reasoning. The spatial reasoning ability, which develops simultaneously with the geometric reasoning ability, is defined as "the ability to recognize, produce, analyze, operate on, and reflect on spatial objects, images, relations, movements, and transformations" (Battista et al., 2018). Following is a brief description of additional accepted definitions from the literature: While Lohman (1996) defines spatial reasoning as the ability to create a visual image, maintain a given shape, and transform it into another shape, McGee (1979) defines it as the ability to visualize three-dimensional objects and their movements. Van De Walle et al. (2012) defined it as the ability to perceive objects from various perspectives, comprehending the relationship between two-dimensional and three-dimensional structures, and imagining the open and closed forms of objects. Spatial reasoning was defined by Turğut (2007) as the capacity to mentally manipulate shapes and generate explanations by rearranging them. For instance, spatial reasoning is used when mentally animating, rotating, or relocating an object or shape. Finding the expansion of a cube, locating a given shape or location on a map, locating the reflection of a given point, and determining its symmetry all require spatial reasoning. Due to its varied and complex definitions, spatial reasoning is comprised of numerous subcomponents. These include spatial visualization, spatial orientation, mental rotation, spatial perception, spatial relations, mental rotation, and spatial cognition (Kayhan, 2005; Lohman, 1979; McGee, 1979; Okagaki & Frensch, 1994; Turğut, 2007;).

Although this study does not intend to investigate the subcomponents of spatial reasoning, it will adhere to a three-component theoretical framework: spatial orientation, spatial visualization, and mental rotation (Ramful et al., 2017), which are shown in Figure 1 below. Spatial orientation is the ability to envision how a particular object or group of objects will appear from various perspectives (McGee, 1979; Lohman, 1979; Lowrie & Logan, 2018). It requires the individual to mentally reposition himself in order to make sense of and interpret visual representations of objects, such as when using a map (Pietropaolo & Crusio, 2012). Second, spatial visualization is the ability to perform complex mental transformations, such as folding paper in the mind, and to imagine what an object or shape will become after being spatially transformed or changed into a different shape (Clements, 1998; Lohman, 1979; McGee, 1979; Ramful et al., 2017). The individual must be able to visualize the object's final form after multiple transformations. Lastly, mental rotation is a cognitive action that comes into play in situations such as imagining how a two- or three-dimensional object will appear when rotated from a particular angle (Lowrie & Logan, 2018; Okagaki & Frensch, 1994). This can occur with two distinct tasks: perspective tasks, in which the individual considers how the object will appear from a different angle, and comparison tasks, which deal with changes in the object itself as opposed to the individual's position or perspective (Fowler et al., 2022; Guillot et al., 2012).

Figure 1.
Subcomponents of spatial reasoning



This diversity in the definition and components of the concept of spatial reasoning has also led to differences in the tests used to ascertain the level of this skill (Yurt & Sünbül, 2012). In a number of studies conducted in the area of spatial reasoning, the relationships between this ability and various variables were investigated. The effect of spatial reasoning skills on mathematics achievement has been studied and debated for quite a while. There is a significant relationship between spatial reasoning skills and mathematics achievement, as shown by studies (Battista, 1990; Cheng & Mix, 2014; Kayhan, 2005; Turğut & Yılmaz, 2012).

Baki et al. (2011) concluded that teaching spatial visualization skills using virtual manipulatives and dynamic geometry software is more effective than the traditional method. Similarly, it has been demonstrated that teachers should utilize dynamic geometry software to enhance their students' spatial reasoning abilities (Güven & Kösa, 2008). In addition, research indicates that the use of a technologically prepared STEM program has a positive effect on the spatial abilities of seventh graders (Fowler et al., 2022). Additionally, it has been noted that incorporating real-world examples and computer programs in courses enhances students' spatial skills (Yıldız & Tüzün, 2011; Yolcu, 2008). According to Casey et al. (2008), there is a close relationship between spatial reasoning skills and success in geometry and mathematics, and mental rotation, spatial visualization, and building construction processes are the basis of this relationship. In their study of eighth grade students, Yıldırım Gül and Karataş (2015) concluded that there is a positive and significant relationship between students' geometry understanding levels, geometry achievement levels, and spatial reasoning abilities. Cheng and Mix (2014) reached the conclusion that activities aimed at fostering mental rotation skill, which is a subcomponent of spatial reasoning skill, improve the performance of students in early childhood, particularly in missing term problems. In addition, it has been determined that it is essential to design and evaluate spatial reasoning programs in order to enhance the mathematics learning of primary school students as they progress through the grade levels (Woolcott et al., 2022).

There are also studies that attempt to determine the relationship between spatial reasoning ability and other variables, including gender, pre-school education status, grade level, early involvement with mechanical games, teaching method, use of three-dimensional virtual environments, and spatial reasoning ability levels of teachers. These studies demonstrated that such variables influence the spatial abilities of students (Bartlett & Camba, 2023; Ben-Chaim et al., 1988; Sorby, 1999; Turğut, 2007; Yurt & Sünbül, 2012). Studies show that students' spatial reasoning skills develop as their grade level progresses (Akkaya Yılmaz, 2022; Turğut & Yılmaz, 2012). When the pre-school education status was examined, it was determined that the pre-school education of the individual had a positive effect on spatial reasoning skills and that mechanical games included in early childhood education had a positive effect on spatial reasoning skills (Akkaya Yılmaz, 2022; Turğut, 2007). Ben-Chaim et al. (1988) suggest that the teaching method influences spatial reasoning ability positively and that the seventh grade is the optimal time for spatial reasoning-based education. According to Yurt and Sünbül (2012), activities involving concrete objects have a positive influence on students' spatial reasoning abilities.

The majority of research examining the effect of the gender variable on spatial reasoning abilities demonstrates a positive difference in favor of males (Ben-Chaim et al., 1988; Sorby, 1999). Studies on the measurement of spatial reasoning with its subcomponents (Turğut et al., 2017; Voyer & Doyle, 2010) are also included in the literature, and in the mental rotation subcomponent, males perform better than females. The examination of spatial reasoning and its subcomponents has yielded varying results depending on the gender variable in several studies (Kaya, 2019; Seng & Chan, 2000;). In contrast to these studies, others have shown that there is no difference between male and female pupils in terms of mental rotation skill, which is a subcomponent of spatial skills (e.g. İrioğlu & Ertekin, 2012; Yıldız, 2009). However, in a recent study, Bartlett and Camba (2023) obtained results that contradict the studies that found results in favor of girls or boys on spatial reasoning skills. They assert that the previous findings are due to the masculine structure of the tests or the development of gender roles and spatial reasoning skills together. Moè (2009) concluded that students' perspectives on spatial reasoning influence the results of the spatial rotation test, a subcomponent of spatial reasoning. Moreover, Ramful et al. (2017) and Turğut (2007) have demonstrated that distinct sub-components of spatial reasoning are interrelated.

Studies indicate that students' spatial reasoning skills are inadequate (Uygan & Turğut, 2012) and that personal and environmental factors are responsible for this deficiency (Turğut & Yılmaz, 2012). In addition to the relational or survey studies summarized in this section, there are studies examining the effects of numerous teaching methods designed to improve spatial reasoning skills on spatial reasoning (Atasoy et al., 2019; Casey et al., 2008; Gün & Atasoy, 2017; Uygan, 2011; Yıldız & Tüzün, 2011). Yıldız (2009) asserted that the use of a three-dimensional virtual environment improved spatial visualization ability, and Turhan (2010) claimed that computer-aided perspective drawings had a positive effect on students' attitudes toward mathematics, technology, and geometry. Skill in spatial reasoning can be acquired and enhanced through specially designed interventions; therefore, it is dependent on experience (Lowrie et al., 2019; Uttal et al., 2013). For instance, concrete models and computer applications can improve the spatial reasoning skills of sixth-grade students (Yolcu, 2008), and the use of concrete materials and three-dimensional media has a significant influence on mental rotation and spatial visualization skills (Yıldız & Tüzün, 2011). Alternatively, it has been established that by constructing dynamic items with augmented reality, students can observe objects from various angles, resulting in active learning (Anggraini et al., 2020). High-level cognitive skills are required for spatial reasoning, so related concepts can be embodied in two- or three-dimensional visuals or objects (Baki, 2000). The relationship between spatial reasoning ability and mathematics achievement is consistent and strengthens over time (Resnick et al., 2019; Resnick et al., 2020).

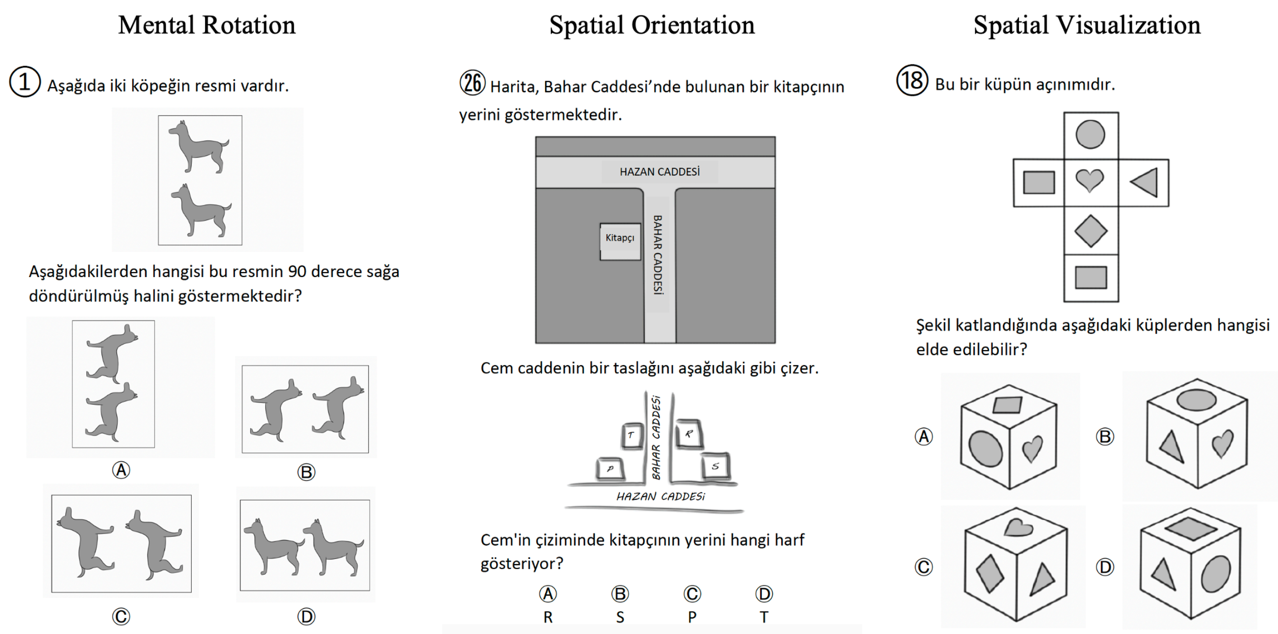
Method

In this study, one of the quantitative research approaches, survey research, was employed. Survey research is a research method that tries to describe the characteristics of a certain group in detail through variables (Gravetter & Forzano, 2018). This survey explores the spatial reasoning abilities of middle school students. The spatial reasoning skills of middle school students in the 5th, 6th, 7th, and 8th grades are examined in detail using the three subcomponents of spatial reasoning, spatial visualization, spatial orientation, and mental rotation, which are explained in detail in the above theoretical framework. All students from a middle school compose the sample. Students differ in age from 10 to 13 years old. In accordance with the research permission granted by the Provincial Directorate of National Education, 947 middle school students were recruited and the test was administered simultaneously in the entire school on the previously scheduled date. Before the allocated practice time, clear test information was provided to the teachers in the teachers' room, and they were asked to check the students' answer sheets to prevent marking errors. The application was completed within an hour of class time, and the test forms brought by the teachers were collected and organized during the subsequent break.

This study's data collection tool is the spatial reasoning test, which describes the spatial reasoning skills of middle school students with the three subcomponents mentioned. The data collection tool includes a total of 30 items, consisting of ten items designed to measure three separate components. Ramful et al. (2017) designed the Spatial Reasoning Test (SRT) and obtained an internal reliability value of .845. In addition, the SRT correlates with all three components as follows: mental rotation (.71), spatial orientation (.41), and spatial visualization (.66). Prior to the application, SRT was translated from its original language, English, into Turkish, and in certain items, attention was given to include Turkish names of places and people so that the context would be compatible with Turkish. Since SRT is intended for middle school students, attention has been paid to include clear and simple expressions in both the original and the translation. The Turkish SRT was presented to an expert in mathematics education research, and his professional opinion was requested. After the corrections were made based on their feedback, the test was prepared as 32 pages in total, including the pages where coding and demographic information were requested, with one item per page, identical to the original test. Figure 2 provides examples of items, one for each of the three subcomponents:

Figure 2.

Sample questions for subcomponents of mental rotation spatial orientation, and spatial visualization



The data obtained by the implementation of SRT was analyzed in detail with the Jamovi program, which is a R (R Core Team, 2022) based application (The Jamovi Project, 2023). SnowIRT, one of Jamovi's modules, was employed for Rasch analysis (Seol, 2023). Various data representations, including descriptive statistics and histograms or box plots, were also constructed and analyzed for the participants' SRT total scores, gender, grade level, and spatial reasoning subcomponents.

The data obtained from SRT were modelled using the unidimensional one-parameter logistic model known as the Rasch model with the marginal maximum likelihood method (de Ayala, 2009). There are some assumptions of conducting Rasch analysis: unidimensionality, local independence and monotonicity. Yen's Q3 statistic was measured to check assumption of local independence (Yen, 1984). When the residual correlation matrix was also examined, the assumption of local independence was achieved because the residual values of the items were below .20. In other words, none of the items in test are related to each other.

Findings

The findings obtained in this section were analyzed in accordance with the study's research questions. Table 1 displays the minimum and maximum values, arithmetic mean, median, standard deviation, skewness, and kurtosis values of the total scores of 947 students who were administered the scale.

Table 1.
Summary of total scores

N	Min	Max	Mean	Median	SD	SE	Skewness	Kurtosis
947	1.00	28.0	13.4	13.0	4.91	0.160	0.488	2.74

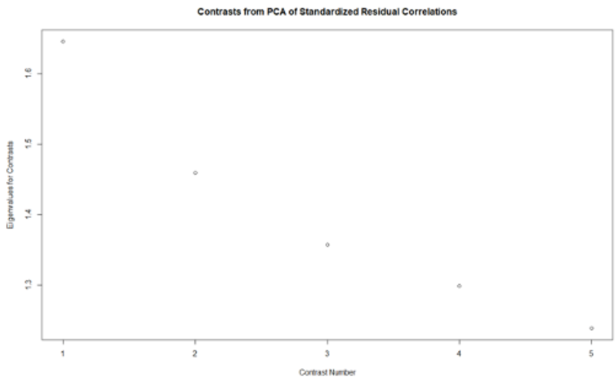
The dichotomous Rasch model was used to conduct item analyses of the SRT, which is used to understand how items and participants operate simultaneously. As shown in Table 2, the items were coded with 1 (for correct results) and 0 (for incorrect results) and dichotomous Rasch model was used to analyze these dichotomous item data. According to Table 2, it can be said that the assumption of local independence was not violated (Christensen et al., 2017).

Table 2.
Yen's Q3 statistic based on pearson correlation

Mean	Max	Min	Max_abs	Min_abs	Q3
-0.0329	0.136	-0.135	0.136	1.08e-4	0.169

We conducted principal components analysis of standardized residual correlations (PCA of residuals in R to check the assumption of unidimensionality in dichotomous Rasch model. As shown in the Figure 3 all of the contrasts are smaller than 2.00 (Linacre, 2016). Then, it can be said that the unidimensionality assumption was not violated.

Figure 3.
Contrasts from PCA of standardized residual correlations



The fact that the infit and outfit values are close to one indicates that the items are well-prepared, as shown in Table 3. These values satisfy the criteria for item fit and demonstrate that each item contributes to the comprehension of spatial reasoning ability. In addition, logit values indicating the item's difficulty level displayed for each item. Positive values emphasize more difficult items, while negative values highlight easier ones.

Table 3.
Item Statistics

	Proportion	Measure (logit)	SE Measure	Infit	Outfit
ZD1	0.599	-0.753	0.0715	1.032	1.037
ZD4	0.617	-0.840	0.0720	0.947	0.926
ZD7	0.461	-0.103	0.0708	0.944	0.930
ZD10	0.362	0.382	0.0734	0.974	0.957
ZD13	0.472	-0.153	0.0706	0.950	0.937
ZD16	0.189	1.421	0.0889	0.987	0.951
ZD19	0.214	1.240	0.0851	0.915	0.903
ZD22	0.299	0.720	0.0769	0.888	0.884
ZD25	0.287	0.786	0.0777	1.044	1.104
ZD28	0.231	1.127	0.0830	1.023	1.149
UY2	0.859	-2.332	0.0972	0.931	0.920
UY5	0.799	-1.870	0.0855	0.902	0.817
UY8	0.800	-1.878	0.0857	0.968	0.961
UY11	0.501	-0.287	0.0705	0.963	0.950
UY14	0.688	-1.206	0.0750	0.882	0.826
UY17	0.641	-0.961	0.0728	0.907	0.873
UY20	0.749	-1.545	0.0795	1.091	1.311
UY23	0.570	-0.616	0.0709	0.856	0.815
UY26	0.388	0.255	0.0724	0.978	0.973
UY29	0.388	0.255	0.0724	1.090	1.135
UG3	0.695	-1.240	0.0754	1.005	1.042
UG6	0.316	0.627	0.0758	0.994	1.052
UG9	0.321	0.598	0.0755	1.055	1.068
UG12	0.326	0.570	0.0752	0.921	0.911
UG15	0.399	0.197	0.0721	1.101	1.108
UG18	0.322	0.593	0.0754	1.167	1.257
UG21	0.175	1.527	0.0914	1.182	1.508
UG24	0.268	0.897	0.0793	1.075	1.164
UG27	0.184	1.461	0.0898	1.015	1.141
UG30	0.231	1.127	0.0830	1.085	1.361

The person-item map and graphs displaying the infit-outfit values of the items were depicted in Figure 4, below.

The WrightMap depicted in Figure 5 was created based on the findings obtained, and Figure 5 depicts how the data were distributed based on the difficulty levels of the items. The person-item map, named the WrightMap in honor of Rasch measurement advocate Ben Wright, displays individuals (in terms of their abilities) and items (in terms of their difficulty) along a common (usually vertical) axis marked by a scale (Callingham & Bond, 2006). On the WrightMap logit scale, individuals' abilities and item difficulties are represented by estimates. Individuals in the same position on the logit scale (for instance, assuming item difficulty is 0.6) are aligned to form a long bar at the level of 0.6 on the scale, and according to the Rasch model, each individual (individuals shown in the bar) will have a 50% chance of responding to the relevant item correctly (Callingham & Bond, 2006). This map reveals that the second item (UY2) for the spatial orientation component is the least difficult, while the twenty-first item (UG21) for the spatial visualization component is the most difficult.

Table 4 provides the expected score curves for each item derived by applying the Rasch model. The expected score curves of the items reveal the progression of the item statistics in Table 3, as well as the difficulty levels of the items. Table 4 also shows the monotonicity of Rasch analysis which was achieved.

Figure 4.
Person-item map and Infit-Outfit values for the items

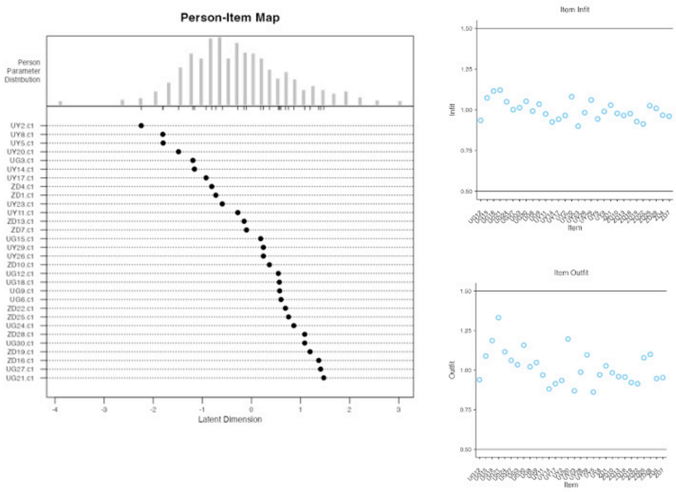


Figure 5.
WrightMap

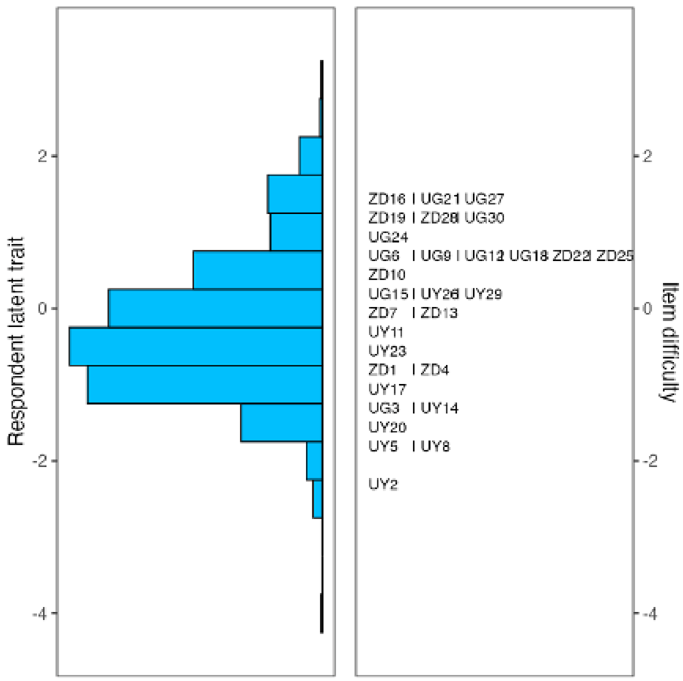
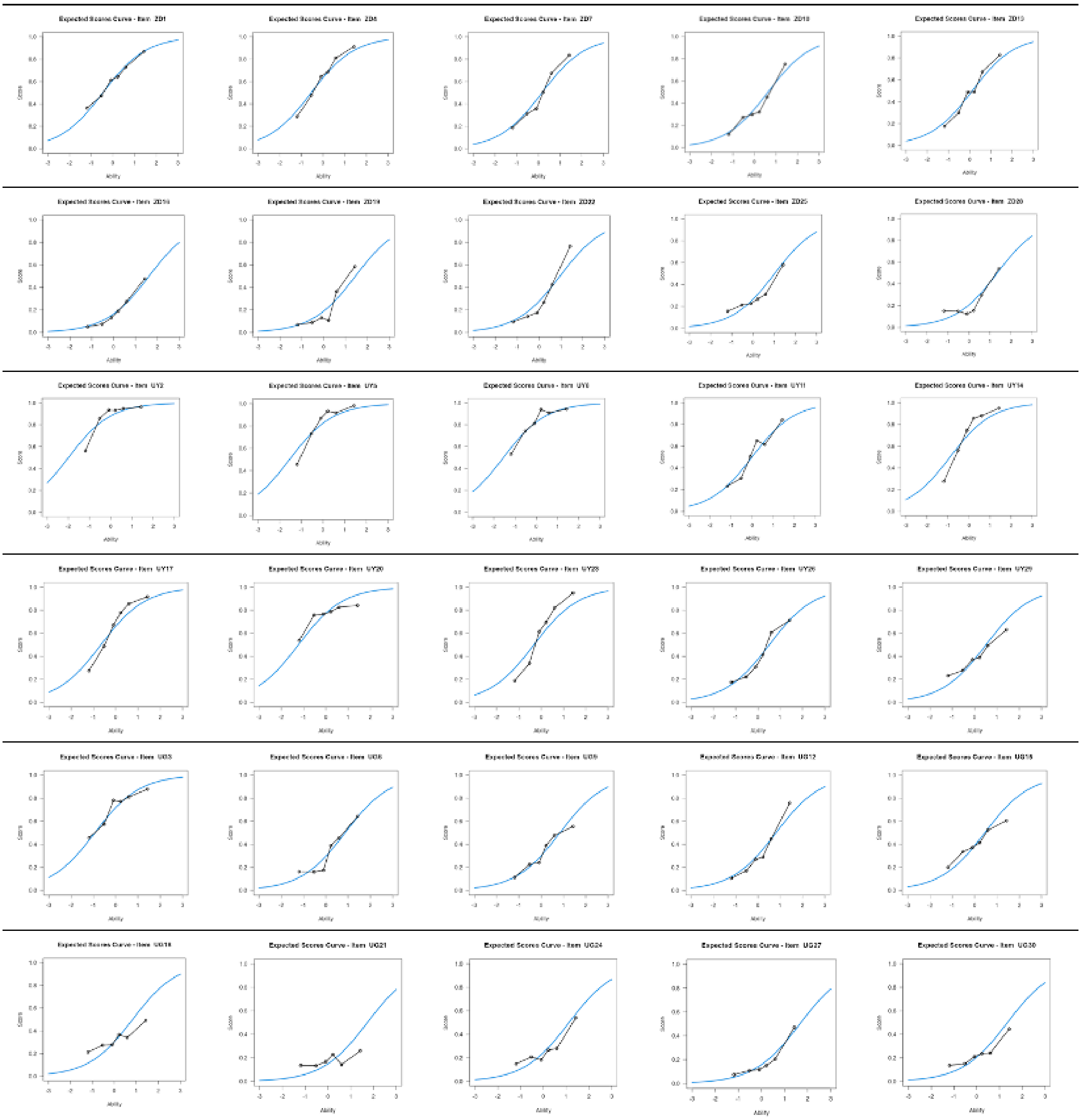


Table 4.

Expected score curve for all items



A. Findings regarding Reliability

The results of the test conducted to ascertain the reliability of SRT scores are provided in Table 5 below. The obtained Cronbach α value (α = .770) shows that the test results are reliable.

Since it is very close to the original reliability values (α =.849) of Ramful et al. (2017), SRT can be considered statistically reliable. Table 6 provides the results of the analysis demonstrating the contribution of each item to the reliability index.

B. Confirmatory Factor Analysis

The results of the confirmatory factor analysis conducted to determine whether the components specified in the original test (mental rotation, spatial orientation, and spatial visualization) were also maintained in the Turkish version of the SRT are presented in Table 7 as a validity indicator.

The fact that the p values for each item in Table 7 are less than α =.05 indicates that the described factors have been preserved and are consistent with the original test. According to Ramful et al. (2017), it has been confirmed that the SRT is an effective measurement instrument for all three components of spatial reasoning ability. Ramful et al. (2017) demonstrated that the 30-item SRT can assess mental rotation, spatial orientation, and spatial visualization independently. This part was conducted according

Table 5.
Reliability Statistics

	Mean	SD	Cronbach's α	McDonald's ω
Scale	0.445	0.164	0.770	0.771

Table 6.
Item Reliability Statistics

			If item dropped	
	Mean	SD	Cronbach's α	McDonald's ω
ZD1	0.599	0.490	0.766	0.766
ZD4	0.617	0.486	0.761	0.762
ZD7	0.461	0.499	0.759	0.760
ZD10	0.362	0.481	0.761	0.762
ZD13	0.472	0.499	0.760	0.761
ZD16	0.189	0.392	0.763	0.764
ZD19	0.214	0.411	0.760	0.760
ZD22	0.299	0.458	0.757	0.757
ZD25	0.287	0.453	0.766	0.767
ZD28	0.231	0.422	0.766	0.767
UY2	0.859	0.349	0.765	0.766
UY5	0.799	0.401	0.762	0.762
UY8	0.800	0.400	0.765	0.766
UY11	0.501	0.500	0.761	0.762
UY14	0.688	0.463	0.758	0.759
UY17	0.641	0.480	0.759	0.760
UY20	0.749	0.434	0.772	0.773
UY23	0.570	0.495	0.754	0.756
UY26	0.388	0.487	0.761	0.762
UY29	0.388	0.487	0.768	0.769
UG3	0.695	0.461	0.766	0.767
UG6	0.316	0.465	0.763	0.764
UG9	0.321	0.467	0.766	0.767
UG12	0.326	0.469	0.758	0.759
UG15	0.399	0.490	0.769	0.769
UG18	0.322	0.468	0.773	0.773
UG21	0.175	0.380	0.774	0.776
UG24	0.268	0.443	0.768	0.769
UG27	0.184	0.387	0.765	0.766
UG30	0.231	0.422	0.769	0.770

Table 7.
Factor Loadings

				%95 Confidence interval			
Factor	Indicator	Estimation	SE	Lower	Upper	Z	p
Mental Rotation	ZD1	1.000 [a]					
	ZD4	1.351	0.216	0.9280	1.773	6.26	<.001
	ZD7	1.622	0.245	1.1411	2.102	6.61	<.001
	ZD10	1.405	0.220	0.9738	1.837	6.38	<.001
	ZD13	1.467	0.229	1.0173	1.916	6.39	<.001
	ZD16	1.064	0.171	0.7285	1.400	6.21	<.001
	ZD19	1.362	0.205	0.9608	1.763	6.65	<.001
	ZD22	1.640	0.241	1.1676	2.113	6.80	<.001
	ZD25	0.933	0.171	0.5985	1.267	5.47	<.001
	ZD28	0.920	0.163	0.6001	1.240	5.63	<.001
Spatial Orientation	UY2	1.000 [a]					
	UY5	1.418	0.173	1.0790	1.757	8.20	<.001
	UY8	0.953	0.144	0.6700	1.236	6.60	<.001
	UY11	1.632	0.207	1.2269	2.037	7.90	<.001
	UY14	1.827	0.213	1.4102	2.245	8.59	<.001
	UY17	1.799	0.214	1.3796	2.218	8.41	<.001
	UY20	0.544	0.135	0.2787	0.810	4.02	<.001
	UY23	1.983	0.230	1.5332	2.433	8.64	<.001
	UY26	1.416	0.191	1.0425	1.789	7.43	<.001
	UY29	0.841	0.161	0.5263	1.156	5.23	<.001
Spatial Visualization	UG3	1.000 [a]					
	UG6	1.293	0.212	0.8776	1.709	6.10	<.001
	UG9	0.941	0.181	0.5874	1.296	5.21	<.001
	UG12	1.783	0.264	1.2661	2.301	6.76	<.001
	UG15	0.878	0.181	0.5238	1.232	4.86	<.001
	UG18	0.448	0.148	0.1584	0.737	3.03	0.002
	UG21	0.153	0.113	-0.0675	0.374	1.36	0.174
	UG24	0.825	0.166	0.4996	1.150	4.97	<.001
	UG27	0.887	0.159	0.5750	1.198	5.58	<.001
	UG30	0.681	0.150	0.3871	0.975	4.54	<.001

[a] fixed parameter

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to the steps of confirmatory factor analysis, and the standard factor loadings that each item contributed to each factor were reported in the model data fit report. The obtained correlation values for mental rotation scores (MRS), spatial orientation scores (SOS), and spatial visualization scores (SVS) were also shown in Table 8 below.

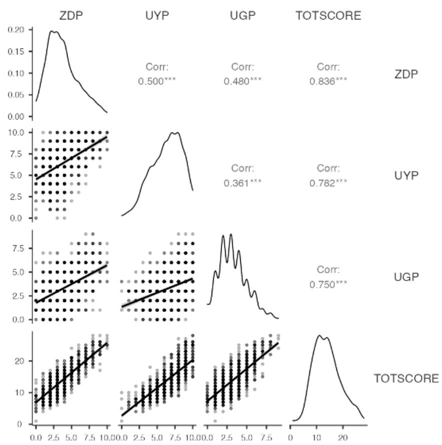
Table 8.
Correlation Matrix

		MRS	SOS	SVS	TOTSCORE
MRS	Pearson's r	—			
	p-value	—			
	95% CI Upper	—			
	95% CI Lower	—			
SOS	Pearson's r	0.500 ***	—		
	p-value	<.001	—		
	95% CI Upper	0.547	—		
	95% CI Lower	0.451	—		
SVS	Pearson's r	0.480 ***	0.361 ***	—	
	p-value	<.001	<.001	—	
	95% CI Upper	0.528	0.415	—	
	95% CI Lower	0.430	0.304	—	
TOTSCORE	Pearson's r	0.836 ***	0.782 ***	0.750 ***	—
	p-value	<.001	<.001	<.001	—
	95% CI Upper	0.854	0.805	0.776	—
	95% CI Lower	0.816	0.755	0.720	—

Not. * p <.05, ** p <.01, *** p <.001

There is a statistically significant relationship between MRS, SOS, SVS, and total scores, as shown in Table 8. The correlation values range from 0.361 to 0.836. As with the original spatial reasoning skill test, these values are statistically significant, demonstrating the construct validity of the data collection tool (Ramful et al., 2017). Figure 6 depicts the correlations between MRS, SOS, SVS, and total scores (TOTSCORE), in addition to the table presented previously.

Figure 6.
Correlation among the variables of MRS, SVS, SOS and TOTSCORE



The results of the model fit analysis of SRT were presented in Table 9 below.

Table 9.
Ki-squared Test for exact fit

χ^2	df	p
559	402	<.001

Since the p value in Table 9 is less than.05, it is evident that the model defined with the three mentioned components has an acceptable level of fit. According to this model, χ^2 (chisquare) / degrees of freedom (df) = 559 / 402 equals 1.39. The fact that the value is less than 3 indicates that the model's goodness of fit is acceptable, but since it is insufficient, Table 10 provides additional goodness-of-fit measures.

Table 10.
Fit measures

			RMSEA 90% CI	
CFI	TLI	RMSEA	Lower	Upper
0.934	0.928	0.0203	0.0161	0.0242

Based on the results presented in Table 10, it can be concluded that the test is highly compatible with the specified model. CFI, TLI, and RMSEA values indicate that there is no problem with the model's fit. For example, as an item fit measure more appropriate for large samples, RMSEA (root mean square error of approximation) values of .06 or below suggests a strong level of model fit (Tabachnick & Fidell, 2019).

C. Is there a difference in total scores between girls and boys?

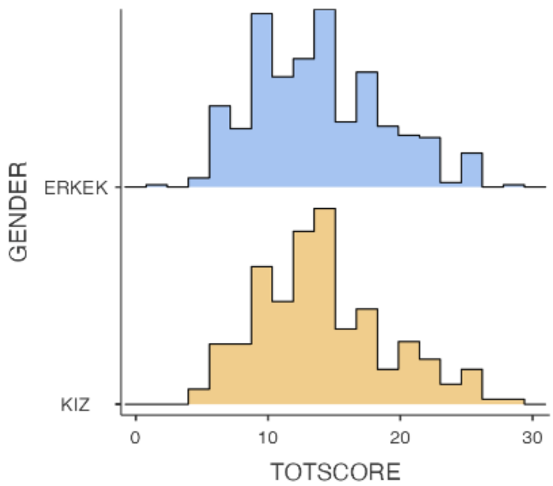
Descriptive statistics for the research question "Is there a difference between the total scores of girls and boys?" were presented in Table 11 and the corresponding histogram was depicted in Figure 7.

Table 11.
Descriptive Statistics

	Gender	N	Missing	Mean	Median	SD	Minimum	Maximum
TOTSCORE	MALE (ERKEK)	499	0	13.8	13	4.86	1	28
	FEMALE (KIZ)	448	0	14.1	14.0	4.97	4	28

Histograms of the distribution of the total scores obtained by male and female students were shown in Figure 7 below.

Figure 7.
Distribution of the total scores of females and males (histogram)



The Kolmogorov-Smirnov test of normality was used to test the normality assumption in order to determine whether the groups of male and female students exhibited a normal distribution, and the Levene test was used to test the homogeneity of variances; the results obtained were presented in Tables 12 and Table 13 below.

The Levene test result for the homogeneity of variances was shown in Table 13 below. The obtained p value indicates that the variances were not distributed homogeneously.

According to the results of these tests, the normality assumption of the parametric tests could not be satisfied, so the Mann-Whitney U test was employed to compare the groups. The test results were displayed in Table 14 below.

The null hypothesis that "there is no significant difference between girls and boys in terms of total scores" could not be rejected based on the data presented in the table above. In other words, there is no statistically significant difference between girls' and boys' total scores.

D. Is there a difference between the grade levels in terms of total scores?

Table 15 provides descriptive statistics in order to determine whether there is a difference between grade levels, which is the next question of the study. Examining Table 15 reveals that the number of students in each grade level in the sample was evenly distributed, and that the mean scores range from 12.2 to 15.2.

Table 12.
Normality Tests

		Statistics	p
TOTSCORE	Shapiro-Wilk	0.975	<.001
	Kolmogorov-Smirnov	0.0769	<.001
	Anderson-Darling	6.73	<.001

Table 13.
Homogeneity of Variances Test

		F	df	df2	p
TOTSCORE	Levene	0.0601	1	945	0.806
	Variance ratio	0.957	498	447	0.629

Table 14.
Results of Mann-Whitney U Test

		Statistics	df	p	Mean difference	SD difference		Effect size
TOTSCORE	Student's t	-0.901	945	0.368	-0.288	0.320	Cohen's d	-0.0586
	Mann-Whitney U	108605		0.450	-2.92e-5		Rank biserial correlation	0.0284

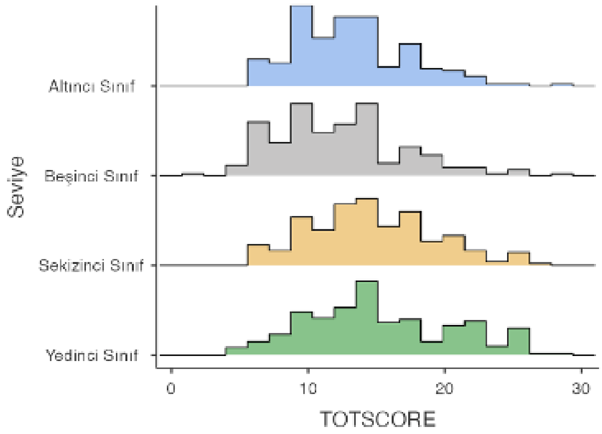
Not. H_a $\mu_{KIZ} \neq \mu_{ERKEK}$

Table 15.
Descriptive statistics

									Shapiro-Wilk	
	Grade level	N	Missing	Mean	Median	SS	Min.	Max.	W	p
TOTSCORE	5th grade (Beşinci sınıf)	207	0	12.2	11	4.68	1	28	0.965	<.001
	6th grade (Altıncı sınıf)	222	0	13.0	12.0	4.13	6	28	0.960	<.001
	7th grade (Yedinci sınıf)	288	0	15.2	14.0	5.35	4	28	0.971	<.001
	8th grade (Sekizinci sınıf)	230	0	14.7	14.0	4.62	6	27	0.978	0.001

Figure 8 displays histograms illustrating the distribution of total scores for each grade level.

Figure 8.
Distribution of total scores of the groups by grade levels (histogram)



The results of the analyses for the normality assumption and the homogeneous distribution of variances were presented in Tables 16 and Table 17 below. The results of the Kolmogorov-Smirnov test, which is appropriate for large samples, indicate that the groups are not normally distributed ($p < .001$, $\alpha =.05$).

Table 16.
Normality tests

		Statistics	p
TOTSCORE	Shapiro-Wilk	0.981	<.001
	Kolmogorov-Smirnov	0.0698	<.001
	Anderson-Darling	5.25	<.001

As seen in Table 17, the assumption of homogeneity of variances according to Levene test findings could not be provided, either.

Table 17.
Homogeneity of variances test

		Statistics	df	df2	p
TOTSCORE	Levene	6.40	3	943	<.001
	Bartlett	17.2	3		<.001

Since these assumptions could not be met, the non-parametric Kruskal-Wallis ANOVA test was employed for analysis. The test results presented in Table 18 demonstrate that at least two grade levels differ significantly.

Table 18.
Kruskal-Wallis ANOVA

	χ^2	df	p	ε^2
TOTSCORE	55.9	3	<.001	0.0591

The results of the pairwise comparison tests were displayed in Table 19 in order to determine which two groups are different.

Table 19.
Pairwise comparisons

		W	p
Fifth grade	Sixth grade	-3.02	0.142
Fifth grade	Seventh grade	8.80	<.001
Fifth grade	Eighth grade	7.79	<.001
Sixth grade	Seventh grade	6.66	<.001
Sixth grade	Eighth grade	5.51	<.001
Seventh grade	Eighth grade	1.30	0.793

As seen in Table 19, there is a significant difference between the fifth grades and the seventh and eighth grades in terms of total scores, while there is no significant difference between the fifth and sixth grades in terms of total scores ($p=.142$, $\alpha =.05$). There was no significant difference between the seventh and eighth grades in terms of their total scores ($p=.793$, $\alpha =.05$).

E. Is there a difference between the total scores according to the components of spatial reasoning?

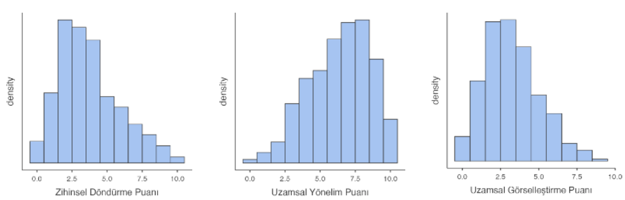
When we analyze the SRT scores according to the sub-components of spatial reasoning, we obtain descriptive statistics for each student's mental rotation score (MRS), spatial orientation score (SOS), and spatial visualization score (SVS) in Table 20 below.

Table 20.
Descriptive statistics

								Shapiro-Wilk	
	N	Missing	Mean	Median	SD	Min.	Max.	W	p
MRS	947	0	3.73	3	2.19	0	10	0.941	<.001
SOS	947	0	6.38	7	2.18	0	10	0.958	<.001
SVS	947	0	3.24	3	1.80	0	9	0.952	<.001

Figure 9 below presents the histograms illustrating the distributions of MRS, SOS and SVS scores.

Figure 9.
Distributions of MRS, SOS and SVS scores (histogram)



The Friedman test was used instead of repeated measures ANOVA for the non-parametric groups to determine whether there is a statistically significant difference between the arithmetic means of the scores obtained from the three components; the results are presented in Table 21. Separate comparisons of this group's MRS, SOS, and SVS reveal a statistically significant difference ($p < .001$, $\alpha = .05$). According to the representations in Figure 9, MRS and SVS have a similar distribution and the mean is lower than SOS.

Table 21.
Friedman

χ^2	df	p
1009	2	<.001

In Table 22, pairwise comparisons of these three scores reveal statistically significant differences between any pair of scores. The values in Table 22 validate the representations in Figure 9.

Tablo 22.
Pairwise comparisons (Durbin-Conover)

			Statistics	p
Mental rotation score (MRS)	-	Spatial orientation score (SOS)	36.21	<.001
Mental rotation score (MRS)	-	Spatial visualization score (SVS)	7.10	<.001
Spatial orientation score (SOS)	-	Spatial visualization score (SVS)	43.32	<.001

F. Is there a gender difference in the total scores derived from the components?

The difference between male and female students' scores on MRS, SOS, and SVS was investigated. First, Table 23 presents the descriptive statistics of the groups.

Table 23.
Group descriptive statistics

	Group	N	Mean	Median	SD	SE
MRS	MALE	499	3.90	3.00	2.20	0.0983
	FEMALE	448	3.54	3.00	2.16	0.1021
SOS	MALE	499	6.68	7.00	2.13	0.0954
	FEMALE	448	6.06	6.00	2.18	0.1032
SVS	MALE	499	3.10	3.00	1.77	0.0792
	FEMALE	448	3.39	3.00	1.82	0.0859

First, the normality test and the Levene test were used to determine whether the groups displayed a normal distribution and whether the variances were homogeneously distributed, respectively. The outcomes of these tests are presented in Tables 24 and 25 below.

Table 24.
Normality tests

		Statistics	p
Mental Rotation Score (MRS)	Shapiro-Wilk	0.954	<.001
	Kolmogorov-Smirnov	0.1231	<.001
	Anderson-Darling	13.86	<.001
Spatial Orientation Score (SOS)	Shapiro-Wilk	0.973	<.001
	Kolmogorov-Smirnov	0.0939	<.001
	Anderson-Darling	7.47	<.001
Spatial Visualization Score (SVS)	Shapiro-Wilk	0.969	<.001
	Kolmogorov-Smirnov	0.1206	<.001
	Anderson-Darling	9.18	<.001

The Kolmogorov-Smirnov test results presented in Table 24 demonstrate that the assumption of normality could not be met.

Table 25.
Homogeneity of variances test

		Statistics	df	df2	p
Mental Rotation Score (MRS)	Levene's	0.0199	1	945	0.888
	Bartlett's	0.124	1		0.724
Spatial Orientation Score (SOS)	Levene's	0.3409	1	945	0.559
	Bartlett's	0.282	1		0.595
Spatial Visualization Score (SVS)	Levene's	0.8563	1	945	0.355
	Bartlett's	0.366	1		0.545

Table 25 demonstrates that the variances are not distributed homogeneously. Accordingly, the Kruskal-Wallis test was conducted on non-parametric data sets, and the outcomes are presented in Table 26 below.

Table 26.
Kruskal-Wallis ANOVA

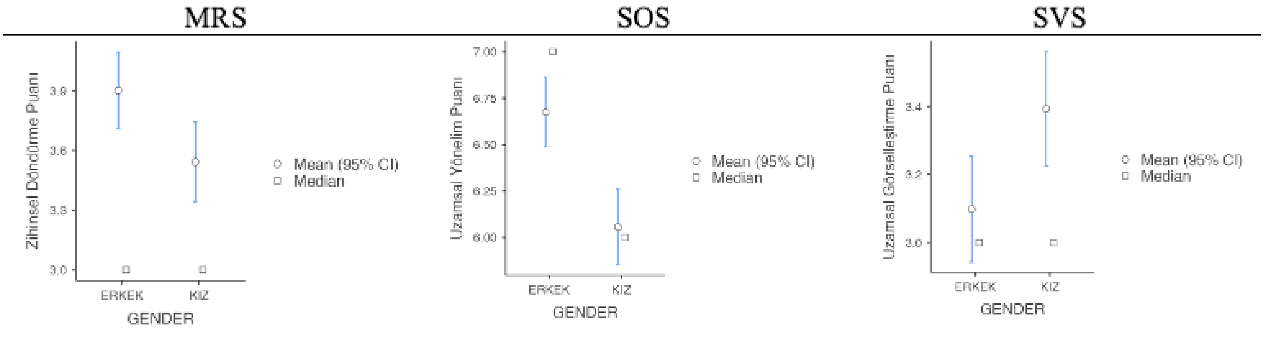
	χ^2	df	p	ε^2
Mental Rotation Score (MRS)	5.88	1	0.015	0.00622
Spatial Orientation Score (SOS)	19.55	1	<.001	0.02066
Spatial Visualization Score (SVS)	5.39	1	0.020	0.00570

We can conclude that there is a statistically significant difference between female and male students' MRS, SOS, and SVS based on Table 26's p values (respectively $p = .015$, $p < .001$, $p = .020$). The difference between male and female pupils is depicted visually in Figure 10 below.

As shown in Figure 10, there is a statistically significant difference between male and female students MRS, SOS, and SVS scores. Although male students score higher on mental rotation and spatial orientation, female students score higher on spatial visualization.

Figure 10.

Distribution of students' MRS, SOS and SVS by gender



Discussion and Conclusion

SRT, which was developed by Ramful et al. (2017) to measure spatial reasoning ability with its three sub-components, was shown to obtain valid and reliable results when translated into Turkish. The construct validity of the test was shown by the correlation values between the MRS, SOS, SVS, and total scores and the values obtained from confirmatory factor analysis. Furthermore, the test can be claimed to be valid for mental rotation, spatial orientation, and spatial visualization components.

When analyzing the descriptive statistics of the total scores of 947 secondary school students to whom SRT was administered, the mean is low. When compared to the mean values of Ramful et al. (2017), the lower average (13.4) suggests that students' spatial reasoning abilities may be improved. This result indicates that spatial reasoning skills in middle schools should be developed through the use of alternative teaching techniques and strategies or innovative approaches (Baki, 2000; Cheng & Mix, 2014; Lowrie & Logan, 2018; Yolcu, 2008).

Gender variable

According to the study's findings, there was no significant difference between male and female students' total spatial reasoning scores, but there was a significant difference between male and female students' spatial reasoning subcomponent scores. Numerous early research using spatial reasoning abilities tests showed that males outperformed females (Harris, 1978; Maccoby & Jacklin, 1974). However, this study's conclusion that there is no significant gender difference in spatial reasoning abilities is consistent with the findings in several recent studies (Kaya, 2019; Turğut & Yılmaz, 2012; Uzun, 2019). Bartlett & Camba (2023) found that, as the number of studies measuring spatial reasoning has increased, the variation of spatial reasoning ability by gender in the results of the tests used in the majority of studies measuring spatial reasoning has become very small and insignificant. The difference between genders emerges in the sub-components of spatial reasoning skill in the findings reported here. It was determined, for instance, that male students performed better on the mental rotation subcomponent. This finding is consistent with the findings of Voyer and Doyle (2010) and Turğut et al. (2017). When Bartlett and Camba (2023) analyzed the studies that demonstrated a significant difference based on the gender variable and the tests used in these studies, they offered various explanations for this phenomenon. It is claimed that the alleged difference may be due to the fact that the test used was constructed in a way that makes a difference according to the gender variable, the development of gender roles, and spatial reasoning skills (Connell, 2021); the difference found in early studies may be due to the fact that other studies have been cited for years and have influenced these studies (Bartlett & Camba, 2023). In addition, the results of previous studies can be explained by factors such as the society's changing perspective on gender roles and spatial reasoning, which acts as a self-fulfilling prophecy (Bartlett & Camba, 2023). In addition, Moè (2009) found that female students who was convinced they were capable at mental rotation performed better than male students who believed rotation to be difficult. It has been suggested that female students' beliefs about mental rotation have no effect on their performance on the spatial rotation subcomponent, whereas male students' beliefs have a negative effect on their performance (Moè, 2009).

In addition to scoring lower on mental rotation, female students also scored lower on the spatial orientation component. Males have lower spatial visualization scores than females. While there is no statistically significant difference between genders in terms of total score, the difference between subcomponents suggests that these components alone are insufficient to explain spatial reasoning ability (Bartlett & Camba, 2023). In addition, it can be argued that this finding may be the result of cognitive development differences between individuals of different genders, which may also be reflected in the subcomponents of spatial reasoning abilities.

Grade level variable

According to the findings, there was a significant difference in total scores between the fifth and seventh and eighth grades, but there was no significant difference between the fifth and sixth grades and the seventh and eighth grades. In this case, we can argue that the fifth and sixth grades are at a comparable level, as are the seventh and eighth grades. In addition, the total test scores of students in the seventh and eighth grades are substantially higher than those of students in the fifth and sixth grades. Early childhood education and living experiences impact spatial skills (Akkaya Yılmaz, 2022; Turğut, 2007). From this perspective, it is reasonable to anticipate that the student's spatial reasoning skills will improve as the level progresses and will continue to improve over time. Examining the research's findings reveals that spatial reasoning skills improve with increasing grade level. This finding is consistent with the outcomes of prior research (Turğut & Yılmaz, 2012; Akkaya Yılmaz, 2022). The inclusion of learning objectives requiring spatial reasoning skills in the middle school mathematics curriculum, the increase in the number of learning objectives, and the consequent increase in the time allocated to the development of spatial reasoning skills may all contribute to the development of this skill. We can also explain that questions requiring spatial reasoning are encountered more frequently by 7th and 8th grade students during the high school transition exam period, whose spatial reasoning skill scores are anticipated to increase as the level progresses. In addition, the fact that spatial reasoning skill is associated more with other mathematical concepts such as coordinate plane, line, equation, and geometric objects in the 7th and 8th grade mathematics curriculum and the fact that various mathematical concepts are learned as the grade level increases (Akkaya Yılmaz, 2022) play a significant role in this outcome. In addition, Ben-Chaim et al. (1988)'s claim that the seventh-grade level is ideal for developing spatial reasoning may have contributed to this result. It can be said that it is essential to increase the teaching environments and opportunities that contribute to the development of spatial reasoning skills, as well as the activities that support them. From this perspective, it can be argued that it is essential to devote more time to activities aimed at developing spatial reasoning skills in younger age groups and that it is necessary to design learning environments to foster the development of spatial reasoning skills (Turğut & Yılmaz, 2017).

Components of spatial reasoning skill

The results of pairwise comparisons (MRS-SOS, MRS-SVS, SOS-SVS) of the total scores derived from the spatial reasoning skill components indicate that there is a statistically significant difference between each pair. This result is consistent with Ramful et al. (2017)'s findings. The average scores for mental rotation and spatial visualization are lower than those for spatial orientation. Although mental rotation and spatial orientation demand similar skills, mental rotation requires the movement of the object and the mental reconstruction of its elements, so it is similar to spatial orientation in this regard (Turğut & Yılmaz, 2012). The result of this study supports this conclusion. In addition, it was determined that the cumulative scores for each of these components were related to one another and to the overall score.

Implications

The findings of this study can be assessed by math teachers and curriculum designers. Teachers of mathematics can take into consideration the components highlighted here when selecting appropriate activities for acquiring spatial reasoning skills and can determine their students' level by applying SRT. Teachers can take a deliberate approach to selecting and designing the most appropriate teaching environment, knowing that the development of spatial reasoning skills is critical to their students' success (Sorby & Panther, 2020) in national exams such as high school entrance exams or international exams such as PISA and TIMSS.

Specialist faculty members assigned by the Ministry of National Education as one of the groups that design or develop the mathematics curriculum can also precisely target each component of spatial reasoning skills, ascertain the appropriate learning objectives, and propose relevant activities. The fact that spatial reasoning skill is closely related to mathematics achievement (Mix & Cheng, 2012) is further evidence of the need to investigate its origins, nature, and scope. Future research may concentrate on identifying these connections and demonstrating how and at what level they exist.

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