RELATIONSHIP BETWEEN SPATIAL AND NUMBER DEVELOPMENT: SPATIAL LOCATION KNOWLEDGE STRONGLY PREDICTS NUMERICAL SKILLS OF PRESCHOOLERS THAN MENTAL ROTATION

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF SOCIAL SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

HÜSEYİN YALÇINER

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
THE DEPARTMENT OF PSYCHOLOGY

AUGUST 2025

Approval of the thesis:

RELATIONSHIP BETWEEN SPATIAL AND NUMBER DEVELOPMENT: SPATIAL LOCATION KNOWLEDGE STRONGLY PREDICTS NUMERICAL SKILLS OF PRESCHOOLERS THAN MENTAL ROTATION

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ABSTRACT

RELATIONSHIP BETWEEN SPATIAL AND NUMBER DEVELOPMENT: SPATIAL LOCATION KNOWLEDGE STRONGLY PREDICTS NUMERICAL SKILLS OF PRESCHOOLERS THAN MENTAL ROTATION

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August 2025, 59 pages

Space helps clarify abstract mathematical symbols such as "+" or "-" signs and understand concepts used in mathematics. Many studies demonstrate the predictive role of spatial skills (mental rotation, spatial visualization, and spatial perception) in math development. However, these spatial skills do not fully represent spatial thinking, even though they capture a significant portion. Another critical portion of spatial thinking is spatial language, which involves understanding and describing an object's different spatial features. Spatial language, as well, demonstrated to be associated with various spatial performances. The relationship between spatial language and math development remains overlooked despite the significance of spatial words used to help spatial thinking and also to produce number words. This study investigated the association between preschoolers' spatial language, mental rotation, and several mathematical abilities. Results show a significant relationship between spatial language and both symbolic math and counting abilities, either in isolation or interaction with mental rotation. Specifically, location production skills, rather than comprehension significantly predicted math performance. However, mental rotation

alone does not predict any math skills. Overall, these results align with findings that spatial language and numbers are closely related to each other and add to the literature suggesting that our mental architecture for processing numbers is closely related to our interaction with spatial locations.

Keywords: number development; spatial skills; spatial language; mental rotation; preschoolers

ÖZ

MEKANSAL VE SAYI GELİŞİMİ ARASINDAKİ İLİŞKİ: MEKANSAL KONUM BİLGİSİ OKUL ÖNCESİ ÇOCUKLARIN SAYISAL BECERİLERİNİ ZİHİNSEL ROTASYONDAN DAHA GÜÇLÜ BİR ŞEKİLDE ÖN GÖRMEKTEDİR

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Ağustos 2025, 59 sayfa

Uzam, "+" veya "-" işaretleri gibi soyut matematiksel sembolleri ve matematikte kullanılan konseptleri kavramamıza yardımcı olmaktadır. Birçok çalışma uzamsal becerilerin (zihinsel döndürme, mekansal görselleştirme ve mekansal algı) matematik gelişimindeki yordayıcı rolünü göstermektedir. Ancak bu uzamsal beceriler uzamsal düşünmenin önemli bir kısmını kapsasa dahi tam olarak uzamsal düşünmeyi temsil etmemektedir. Uzamsal düşünmenin diğer bir önemli kısmı bir nesnenin farklı mekansal özelliklerini anlamayı ve açıklamayı da içeren uzamsal dildir. Sayısal kelimeleri üretirken faydalanılan uzamsal kelimelerin önemine rağmen uzamsal dil ile matematik gelişimi arasındaki ilişki yeterince araştırılmamıştır. Bu çalışma, okul öncesi çocukların uzamsal dil, zihinsel rotasyon ve farklı matematik becerileri arasındaki ilişkiyi araştırmaktadır. Sonuçlar, uzamsal dilin tek başına ya da zihinsel rotasyon etkileşimi ile birlikte hem sembolik hem de sayma becerileri ile anlamlı bir şekilde ilişkili olduğunu göstermiştir. Özellikle uzamsal anlama becerisinden ziyade uzamsal üretim matematik performansını anlamlı bir şekilde yordamaktadır. Ancak zihinsel rotasyon herhangi bir matematik becerisini tek başına yordamamaktadır. Genel olarak, bu sonuçlar uzamsal dil ve sayıların birbiriyle yakından ilişkili olduğuna

dair bulgularla uyumludur ve sayıları işlemeye yönelik zihinsel yapımızın uzamsal dil etkileşimimizle yakından ilişkili olduğunu öne süren bulgulara katkıda bulunmaktadır.

Anahtar Kelimeler: sayı gelişimi; uzamsal beceriler; uzamsal dil; zihinsel döndürme; okul öncesi

To the child I once was, who never imagined coming this far

ACKNOWLEDGMENTS

First of all, this thesis was prepared not only with my work but also with the help of others. This thesis was prepared with the great guidance of my advisor, Assist. Prof. Dilay Z. Karadöller. Her support throughout the entire process guided me to the end of my thesis, and my gratitude to her cannot be simply expressed in words. I am honoured to be her student and will always follow her steps in my academic journey.

Also, I would like to thank you to the Assoc. Prof. Başak Şahin-Acar and Prof. Dr. Tilbe Göksun for being in my thesis committee and for their suggestions to make this work better. With the help of their advice, I firmly believe that this work now provides very valuable insights to the studies related to this area.

Indeed, this work was created with the help of parents and children. Therefore, I would like to express my eternal gratitude to the parents and their children, who were always supportive and helped to make this work possible.

If you are in a part of a lab that asks you critical questions, then you can look at your research more comprehensively. I am fortunate to be in the Multimodal Language & Cognitive Development lab. I want to thank you for their great questions and improving the work I had. Special thanks to Ebru Özden, Nesrin Bulut, and Süheyla Ülker for their assistance with the data collection and coding process in this work.

Last but not least, in this process, I acknowledged that family is everything. When I had difficulty moving on, my family was always there to support me. Therefore, I would like to extend my deepest thanks to my father, Murat, my mother, Zeynep, and my brother, Kaan, for motivating me to accomplish my purpose. Additionally, my

dearest girlfriend, Buse, who is also working on her thesis, helped alleviate my anxious thoughts and feelings during this process and inspired me to always believe in my ability to do my best. I am very lucky to have in my life.

TABLE OF CONTENTS

PLAGIARISM iii

ABSTRACT iv

ÖZ vi

DEDICATION viii

ACKNOWLEDGMENTS ix

TABLE OF CONTENTS xi

LIST OF TABLES xiii

LIST OF FIGURES xiv

CHAPTERS

1. INTRODUCTION 1

1.1. Numerical Development 3

1.2. Spatial Skills and Numerical Development 4

1.3. Spatial Language and Numerical Development 6

1.4. The Present Study 8

1.5. Predictions 9

2. METHOD 11

2.1. Participants 11

2.2. Stimuli 12

2.2.1 Ghost Task 12

2.2.2. Spatial Location Knowledge Task 12

2.2.3. Symbolic Calculation Task 14

2.2.4. Non-symbolic Numerosity Comparison Task 15

2.2.5. Object Counting Task 16
2.3. Procedure 16
2.4. Results 17
2.4.1. Preliminary Analysis 17
2.4.2. Data Analysis Plan 17
2.4.3. Main Analysis 18
3. DISCUSSION 25
3.1. Limitations and Future Directions 31
REFERENCES 33
A. APPROVAL OF THE METU HUMAN SUBJECTS ETHICS COMMITTEE 42
B. INFORMED CONSENT 43
C. TURKISH SUMMARY / TÜRKÇE ÖZET 45
D. THESIS PERMISSION FORM / TEZ İZİN FORMU 59

LIST OF TABLES

TABLE 1. DESCRIPTIVE STATISTICS 21
TABLE 2. CORRELATION MATRIX 22
TABLE 3. FIXED EFFECTS FOR SYMBOLIC, NONSYMBOLIC AND COUNTING 23

LIST OF FIGURES

FIGURE 1. GHOST TASK EXAMPLE 12

FIGURE 2. SPATIAL LOCATION KNOWLEDGE TASK EXAMPLE 13

FIGURE 3. SYMBOLIC CALCULATION TASK EXAMPLE 14

FIGURE 4. NON-SYMBOLIC ABILITY TASK EXAMPLE 15

FIGURE 5. COUNTING TASK EXAMPLE 16

FIGURE 6. SPATIAL LOCATION KNOWLEDGE AND SYMBOLIC 19

FIGURE 7. INTERACTION BETWEEN MRT AND SL ON SYMBOLIC 20

FIGURE 8. LOCATION PRODUCTION, LOCATION COMPREHENSION AND SYMBOLIC 20

FIGURE 9. SPATIAL LOCATION KNOWLEDGE AND COUNTING 20

FIGURE 10. LOCATION PRODUCTION, LOCATION COMPREHENSION AND COUNTING ... 21

CHAPTER 1

INTRODUCTION

Early mathematical abilities are crucial for children to succeed in STEM disciplines (i.e., Science, Technology, Engineering, and Mathematics) later in their lives (Ritchie & Bater, 2013; Watts et al., 2014). Children's relationship with numbers starts very early, even before developing an understanding of number words. Preverbal infants can process numerical quantities in terms of their magnitudes through mental representations (Barth et al., 2009). People tend to conceptualize abstract concepts (e.g., numerical quantities) by relying on concrete domains such as physical space (Winter et al., 2015). Space has the potential to serve in disambiguating the symbols used in mathematics (e.g., "+" or "-" signs) and understanding mathematical concepts. In fact, our representation of numbers aligns with our embodied left-right space in which small numbers are represented on our left side and the big numbers are on our right side (i.e., The SNARC effect, Dehaene et al., 1993). A growing body of research showed a strong link between spatial and mathematical skills, mostly focusing on visuospatial skills such as "mental rotation", "spatial perception", and "spatial visualization" (Casey et al., 2015; Gunderson et al., 2012; Geer et al., 2019). Although visuospatial skills cover a significant portion of spatial thinking, it does not capture spatial thinking abilities as a whole. Another core aspect of spatial thinking is spatial language, which involves understanding the relationship between an object's spatial characteristics, relative positions, and how they are referred to with appropriate terms

(Gilligan-Lee et al., 2021). Moreover, studies have demonstrated a close link between spatial language and children's spatial reasoning, highlighting that knowing the spatial locations associated with their performance on different spatial tasks (see Christie & Gentner, 2014; Turan et al., 2021). However, the association between spatial language and math has been understudied despite the close relationship between locations, spatial reasoning, and numbers. The current study investigates how preschoolers' different mathematical abilities have a stronger relationship with their mental rotation and/or spatial language skills.

Children acquire basic mathematical concepts such as counting principles during preschool years, and then they show a rapid improvement in their knowledge of those concepts (Uyanık & Kandır, 2010). They frequently perform counting in many situations and mostly tend to count up to higher numbers from their memories. Their spatial and language abilities (e.g., LeFevre et al., 2010) at early ages relate to the development of numerical skills (Casey et al., 2015; Gunderson et al., 2012). Previous studies largely draw their data from school-aged children and investigate their counting skills from memory, mainly reporting longitudinal relationships between space and number development. However, how various mathematical performances (especially those measured through counting tasks that do not require memorization) are related to spatial skills, as well as their concurrent relationship, needs to be examined. In order to provide data on the above-mentioned gaps, the main objective of this study is to further our understanding of the influence of spatial skills and spatial language on different mathematical performances.

In the sections that follow, we review the previous empirical and theoretical foundations on numerical development and its relationship with spatial skills and spatial language. Following this review, we will introduce our specific predictions on

how and in what ways spatial skills and/or spatial language relate to children's numerical performance.

1.1. Numerical Development

Children improve in their knowledge of numbers when their verbal skills about numbers increase. They learn numbers slowly and sequentially as they first learn number words for "one" followed by "two" and "three" (Sarnecka et al., 2007). During this learning process, they try to understand the logic and the purpose of counting procedures and start to count when asked to report the object's number (e.g., counting three apples; see Wynn, 1992). Previous studies categorize children as either subset or cardinal knowers based on their number knowledge (Sarnecka et al., 2007; Sarnecka & Lee, 2009). When children at the subset knower level are asked to count and give objects, they can count and correctly give objects up to four, whereas children at the cardinal knower level can count and give objects above and beyond four (Sarnecka et al., 2007). The most important breakthrough in their number knowledge occurs when they learn the cardinality principle, which refers to knowing that the last number word used when counting represents the total number of set sizes. They acquire this principle around the age of four, and then, they build on this knowledge and learn to match higher set sizes with bigger numbers more quickly (Ceylan & Aslan, 2018; Wynn, 1992). However, children can still understand the different quantities of objects and have been found to estimate which number is larger than the other one, even if they did not know its exact meaning (e.g., Gunderson et al., 2015). Empirical evidence for this claim comes from studies that asked children to compare the quantities of dots on the screen, or objects on the card showed that children could estimate the quantity (e.g., more or less) of dots/objects without counting (Gunderson et al., 2015). This ability is explained by the approximate number system (ANS), which refers to

humans' ability to estimate larger quantities existing from birth (Izard et al., 2009). Previous work has shown a close link between ANS acuity and symbolic number abilities, such that ANS acuity in earlier ages facilitates the learning of counting principles and calculation skills in preschoolers (Libertus et al., 2011; Starr et al., 2013). Similar to the ANS, children's symbolic understanding of Arabic numerals also plays a crucial role in early numerical cognition. It helps children to make connections between number words and their exact quantities (Kolkman et al., 2013). Furthermore, it has been demonstrated that early symbolic skills lead to improvements in later math performance at school (Jordan et al., 2010).

1.2. Spatial Skills and Numerical Development

Concrete domains (e.g., space) are frequently used by people to understand and learn abstract concepts such as mathematics (Winter et al., 2015). Spatial skills contribute to the understanding of structures and symbols in geometry and mathematics, such as "+" or "-" signs (Mix et al., 2016). Linn and Petersen (1985) identified three distinct spatial skills: mental rotation, spatial visualization, and spatial perception. Several studies have shown how different types of spatial skills relate to mathematical development (Casey et al., 2015; Li & Geary, 2013; Geer et al., 2019). It has been found that while early visuospatial and mental rotation abilities predict later math performance, children's spatial perception abilities, in turn, are predicted by subsequent changes in their math performance (Geer et al., 2019). It has also been demonstrated that developmental gains in visuospatial memory from first to fifth grade predicts better outcomes in mathematics achievement even when children's other working memory capacities (i.e., phonological memory, intelligence, processing speed, and central executive) were controlled (Li & Geary, 2013). These studies were primarily conducted with school-aged children, and only a few examined the

relationship between spatial skills and mathematical performance in the preschool period. Few longitudinal studies focusing on preschool children investigated their spatial skills via mental rotation predicted better scores on symbolic calculation, and counting abilities later in life (see Cheng & Mix, 2014; Gunderson et al., 2012; Mix et al., 2016; Verdine et al., 2017). To our knowledge, only one study investigated the relationship between mental rotation and non-symbolic abilities and reported no significant associations (Gunderson et al., 2012). Therefore, further investigation is needed to understand this relation.

Recall that children show a significant improvement in their counting abilities (subset vs. cardinal level) during the preschool period. Therefore, it is important to investigate how spatial skills at preschool age influence their counting abilities. Studies have found that although children learn to count up to large numbers at subset knower level, they often do not know exactly what number words refer to; yet, they can still recall the correct number sequence from memory (Sarnecka & Carey, 2008). Zhang and colleagues (2014) found that knowing the correct order of the counting sequence during preschool ages is important in mediating the relationship between spatial visualization (i.e., combining pieces to complete a shape) and arithmetic development in third grade. However, counting ability not only relates to the memorization of counting sequences of number words but also to conceptual understanding of number words. Therefore, exploring how spatial skills influence the conceptual understanding of number words in counting is crucial.

Conceptual Metaphor Theory (CMT; Lakoff & Johnson, 1980) provides theoretical support for spatial skills leading to number development. According to CMT, different metaphors we use daily are based on different cognitive domains, such as space and number, and space metaphors are the source of number metaphors. People

tend to use these metaphors when talking about numbers (Winter et al., 2015). For example, “more is up” is a metaphor used to mean that if there is more of something, it becomes higher in space. Given that if there is more water in the glass, the water level in the glass rises. Similarly, words such as “high” or “low” are used to compare the quantities between numbers (e.g., “four is higher than three”), which clearly shows that space metaphors (source) are used in number metaphors. Another example comes from our tendency to use our right hand when talking about big numbers, but to use our left hand when talking about small numbers. This body-anchored positioning of numbers demonstrated an embodied close relationship between spatial locations, such as the body’s left-right and the number sequence (Dehaene et al., 1993; Imbo et al., 2012; Yang et al., 2014). Based on the above-mentioned literature, space and number stand as two interrelated domains, and people benefit from the language of space to produce number words.

1.3. Spatial Language and Numerical Development

Spatial language refers to interpreting objects’ spatial characteristics, relative positions, and how they are referred to with suitable phrases, as well as, it plays a crucial role in numerical development (Georges et al., 2021). Studies found that preschoolers’ linguistic skills, including comprehensive language, receptive vocabulary, and verbal reasoning, were related to their numerical knowledge (LeFevre et al., 2010; Peng et al., 2020). Moreover, de Smedt and Turan (2022) stated that not only general vocabulary development but also the development of special vocabulary related to quantitative (e.g., few or many) and spatial (e.g., above, next to, or before) terms is critical for children’s mathematical abilities. Relatedly, production and comprehension of spatial language supports the development of verbal number skills in children (Georges et al., 2021). Three studies have looked directly at the relationship

between spatial language and math performance in preschool children. Hawes and colleagues (2017) found a significant relationship between spatial language and mathematical performance (symbolic number comparisons) in 6-year-olds. Since the measurement of spatial language was based on shape recognition and positional language in this study, the results are not applicable to assess the degree to which mathematics is specifically linked to an understanding of spatial relations. Another study conducted by Gilligan Lee and colleagues (2021) measured children's understanding of spatial relations (e.g., left, right, below, above) and several other mathematical performances. They reported that spatial language accounts for unique changes in mathematical outcomes when controlled for spatial skills. For standardized math performance, spatial language explained 15% variation in math performance, and it does not predict non-symbolic math performance when all other spatial skills are controlled (Gilligan Lee et al., 2021). In addition, Chan and colleagues (2025) examined the bidirectional relationship between spatial language and numeracy skills and reported that preschoolers' number line estimation at Time 1 predicted their spatial language knowledge at Time 2. However, their spatial language knowledge at Time 1 did not predict their scores on number line estimates and number ordering. They suggested that children with higher numeracy skills may benefit from this knowledge to utilize more spatial language in their daily interactions so that they can enhance their understanding of relational terms.

A theory of Magnitude (ATOM) demonstrates this close relationship between numbers and spatial relations (Walsh, 2003). According to ATOM, magnitude systems originate not from a single brain region but from the interaction of different regions sharing common neural resources in our brain. Walsh suggested that space and numbers are processed within this magnitude system, and both spatial and numerical

concepts, such as length, volume, numerosity, and distance, are included in this system. In one study, for instance, participants were shown different digits (high vs. low) in a computerized task and instructed to initiate either grip opening or closure (Andres et al., 2004). It was found that participants initiated grip opening in response to larger digits, but they initiated grip closure in response to smaller digits. In another study, this time, digits were presented with different object sizes (60mm vs. 50mm), and the participants' hand movements toward objects were observed. The results showed that when their hands got closer to the object, their grip aperture adjusted to the actual size of the object, regardless of the digit magnitudes (Andres et al., 2008). The results clearly show that during motor movements, we move by using quantitative information together with spatial information, and that space and numbers are the two main domains that are close to each other.

1.4. The Present Study

Previous evidence demonstrated a strong relationship between spatial abilities (e.g., mental rotation) and mathematical performance in children (see Casey et al., 2015; Li & Geary, 2013; Geer et al., 2019). However, these studies draw their data from school-aged children and focus on investigating mathematical abilities such as counting from memory, and they investigate mathematical development in longitudinal ways. Considering the importance of early mathematical skills for later achievements, first, it is also important to determine the extent to which preschool children's success in different mathematical tasks is concurrently related to other skills. Second, it is important to investigate whether other types of counting tasks, which require active engagement with objects and conceptual understanding of the number words, relate to their spatial abilities. Furthermore, the relationship between spatial language and different math performances in preschoolers has not been studied

before, despite the strong evidence of spatial encoding of numbers (Dehaene et al., 1993; Lakoff & Johnson, 1980). Although previous work suggests that spatial language predicts symbolic abilities (see Hawes et al., 2017), there are also controversial findings due to the difference in how these studies operationalized their measurement of spatial language and the reversed relationship between spatial language and numeracy skills (Chan et al., 2025; Gilligan-Lee et al., 2021). In order to fill these gaps, the present study aimed to examine the relationship between spatial skills and spatial location knowledge (knowing the spatial relations between objects) and different mathematical skills of children. To do so, we presented 4- and 5-year-old children with tasks that measure their symbolic calculation, non-symbolic numerical comparisons, and object counting, along with tasks assessing their mental rotation and spatial location knowledge.

1.5. Predictions

Based on the previous work demonstrating a significant relationship between spatial skills and mathematical development (e.g., Liu & Zhang, 2022; Lonnemann et al., 2021), we expected to find a significant relationship between mental rotation and all three mathematical abilities (symbolic calculations, non-symbolic numerosity comparisons, and object counting). As demonstrated in previous studies, mental rotation ability predicted symbolic, and counting abilities (see Gunderson et al., 2012; Mix et al., 2016). Although there are limited findings regarding the associations between mental rotation and non-symbolic abilities, previous studies showed the link between spatial and non-symbolic representations (de Hevia & Spelke, 2010; Pinel et al., 2004). However, we did not have any expectations about the extent to which different mathematical performances would be predicted more or less strongly by children's mental rotation ability.

Considering the limited and somewhat controversial relationship between spatial language and mathematical abilities (see Chan et al., 2025; Gilligan-Lee et al., 2021; Hawes et al., 2017), we expected to find a significant relationship between spatial language and mathematical performances, except for non-symbolic ones. Turan and De Smedt (2022) reviewed the emergence of a concept called "mathematical language" and its relationship with math ability. They argued that quantitative (e.g., few, many, less) and spatial (e.g., besides, next to, in between) words can be defined as mathematical language and have an influence on children's verbal counting, ordering numerals, and cardinality skills (see also Hornburg et al., 2018). Moreover, Gilligan-Lee and colleagues (2021) reported that spatial language predicted children's symbolic abilities but did not predict non-symbolic ones. Additionally, Hawes and colleagues (2017) illustrated that spatial language predicted symbolic number comparisons but not non-symbolic comparisons. Since the previous studies do not include object counting as a component of math performance and used different methods to assess spatial language, we do not have any apriori predictions regarding which mathematical performances would be predicted more or less strongly by children's spatial language knowledge.

CHAPTER 2

METHOD

Ethical approval permission was obtained from the Middle East Technical University Human Research Ethics Committee (numbered 324-ODTUİAEK-2023). In addition, to conduct the study in school environment, research consent from the Ministry of Education was obtained (numbered 54850036-605.01-E.528).

2.1. Participants

Our sample included 60 children (26 girls; 34 boys) (Mage = 4;6; SDage = 5.21; Age Range = 3;10 – 5;9).[1] According to the information obtained from parents, children did not have any kinds of mental or developmental disorders. Data from an additional 2 children were excluded from the study because of the children's inattention (n = 1) and the experimenter error (n = 1). We also checked for outliers in mental rotation and spatial location knowledge, and each data point for mental rotation and spatial location knowledge was within three standard deviations above or below the group mean. Among these participants, 8 of the children do not attend preschool.

[1] We employed linear effect models which account for item and subject variations and offer a robust statistical analysis when compared to traditional methods, such as ANOVA or regression analysis (Bolker et al., 2009). In any case, to ensure the reliable estimation of the probability, we conducted a G*Power analysis with two predictors, having a medium effect size (α = .05) and a power of 0.80, and found that N = 68 is the required number of observations. By considering the strength of our statistical approaches in handling low sample sizes, we determined that the number of observations is sufficient for the analysis.

2.2. Stimuli

2.2.1 Ghost Task

The ghost task was used to measure the mental rotation ability of preschoolers. It was developed for children who are between 3-5 ages (Frick et al., 2013). The task involves six training and twenty-one test phases. In the training phase, papers containing various transparent and physically touchable shapes (keys, ship, sock, etc.) are rotated, and children are asked to find the appropriate one from two options. After that, in the test phase, they were asked to mentally rotate the various ghost shapes to find the fitting object (see Figure 1). Raw scores were calculated based on the total accuracy of the answers given by the participants.

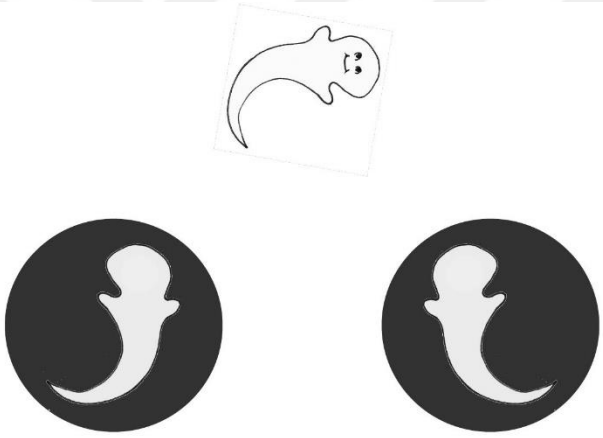


Figure 1. *Ghost Task Example*

2.2.2. Spatial Location Knowledge Task

Spatial location knowledge task was developed to measure preschoolers' knowledge of the location terms (Gilligan Lee et al., 2021). There were two phases: location production and location comprehension. Both the production and comprehension phases have always started with training, and the researcher explained the task to the children. At first, they saw a picture of a frog and a lake, and the frog was standing next to the lake. The researcher prompted the child by asking, "*Where does the frog stand?*".

If the children could not produce "next to," the researcher helped the child by saying, "*Here, the frog stands next to the lake*." Later, they saw a picture of the child and a couch, and the child was standing behind the couch. The researcher asked the same question to ensure that children understood the task correctly. In the comprehension section, the children saw two different pictures this time. The books were on the table in one picture, and in the other one, the books were next to the table. The researcher asked the child to show which picture that depicted the books on the table. If the child gave a incorrect answer, the researcher corrected them by showing the correct picture. The test phase in location production involved six questions on *in*, *above*, *next to*, *between*, *in front of*, and *behind* spatial relations. Children were asked to tell the correct locations (e.g., the plane is *above* the cloud) of an object in relation to another (See Figure 2). The test phase in location comprehension involved six questions asking the following locations: *in front of*, *on*, *behind*, *next to*, *between*, and *in*. Children were asked to choose the picture out of three or four options showing the correct location (e.g., which picture shows the toy *on the* cupboard). Children were not given any feedback during the test phases of location production and location comprehension and were told they did a great job when the tasks were finished. Their responses were video-recorded for later scoring.



Figure 2. *Spatial Location Knowledge Task Example*

2.2.3. Symbolic Calculation Task

This task was developed to measure children's symbolic calculation skills (Gilmore et al., 2007). It requires children to subtract or add a certain number of objects and determine which side has more object in total. We adapted the task by using a picture of a cat called Maviş and a dog called Pamuk instead of pictures of children, as we thought this would be more attractive to preschoolers. The training phase introduced Maviş and Pamuk, each with a box above them containing symbolic numbers. There were four addition and four subtraction test trials. Children were first received the addition trials, followed by the subtraction trials. Before the addition trials began, the experimenter introduced the characters and asked the addition questions: "Pamuk has

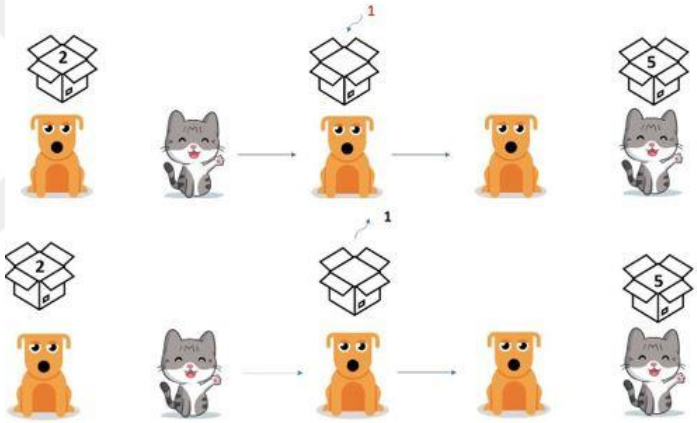


Figure 3. *Symbolic Calculation Task Example*

2 balls in its box. Pamuk is getting 1 more ball. Maviş has 5 balls in its box. Which one do you think has more balls in its box?" ("Pamuk'un kutusunda 2 topu vardır. Pamuk 1 top daha alıyor. Maviş'in kutusunda ise 5 topu vardır. Hangisinin kutusunda daha çok topu vardır?") Before the subtraction trials, the experimenter asked the subtraction questions for practicing: "Pamuk has 2 two balls in its box. Pamuk is taking 1 ball out of the box. Maviş has 5 balls in its box. Which one do you think has more balls in its box?" ("Pamuk'un kutusunda 2 topu vardır.

Pamuk 1 topunu kutusundan çıkartıyor. Maviş'in kutusunda ise 5 topu vardır. Hangisinin kutusunda daha çok topu vardır? ") Although children sometimes responded by showing the pictures with their hands, they were motivated to respond verbally by saying *maviş*, p*amuk, dog, or cat*. The researcher noted down their responses for later scoring.

2.2.4. Non-symbolic Numerosity Comparison Task

The non-symbolic numerosity comparison task was developed to measure children's abstract representation of numbers (Barth et al., 2006). The task included two arrays of blue and red dots, each having equal sizes. The number of dots in trials ranged from 6 to 60. Participants were asked to determine whether there were more or less dots by looking at the screen for five seconds. Children first received the practice trials where the arrays and dots were introduced to the them. Researcher first showed the left array with blue dots. Next, this array was covered with a gray one, and the right array containing red dots was shown next to this gray array (see Figure 4).



Figure 4. *Non-Symbolic Ability Task Example*

Next, a black screen appeared, and the children were expected to respond to which color dots had more or less in them. Regardless of the child's response, the researcher reviewed the correct answer together with the child to ensure that they understood the task correctly. There were a total of six experimental trials, three of which asked which color had more and three of which asked which color had less.

2.2.5. Object Counting Task

This task was used to assess children's counting abilities (Gibson et al., 2018). It involved a puppet, beads and sticks and cards having differing number of dots in them. In the task, children were asked to help a puppet who requires a specific number of beads to get ready for school. Children helped the puppet by counting sets of dots on the card and placing them onto the stick (See Figure 5.) There were nine cards, including different numbers of dots ranging from one to nine. The children were shown cards in the fixed order of 5,8,3,6,9,4,1,7,2 dots. This order was predefined by researchers to randomly generate numbers from 1 to 9. After the card was shown, the



Figure 5. *Counting Task Example*

child was asked to count the dots on the card and place the beads. After placing the beads, the researcher asked, "Is it done?" to ensure the child was finished. They were allowed to count and replace the beads as much as they wanted until they said, "I finished." Later, the beads were taken from the stick, and they were shown the next card.

2.3. Procedure

The experiment took place in a quiet room either in the children's houses or at the preschools they attended. First, children engaged in mental rotation (i.e., Ghosts Task) and spatial location knowledge tasks (i.e., Spatial Location Production and Spatial

Location Comprehension Tasks). Next, they engaged in object counting, symbolic, and non-symbolic ability tasks. The tasks were administered in the same order for each participant. All sessions were video-recorded for later transcription and coding. Upon completion of the study, children received a certificate of participation and stickers.

2.4. Results

2.4.1. Preliminary Analysis

The current study investigates how preschoolers' different mathematical abilities relate to mental rotation skills and spatial location knowledge. Descriptive statistics for the spatial and mathematical variables can be found in Table 1. First, we ran a correlational analysis to see associations between all study variables, including symbolic calculation, non-symbolic numerosity comparison, counting, mental rotation, and spatial location knowledge (See Table 1). Correlation analysis showed that spatial location knowledge significantly correlated with both symbolic ($r = 0.36$, $p < .01$) and counting abilities ($r = 0.60$, $p < .001$). Specifically, location production significantly correlated with both symbolic ($r = 0.40$, $p < .01$) and counting abilities ($r = 0.56$, $p < .001$), whereas location comprehension significantly correlated only with counting ability ($r = 0.49$, $p < .001$). Moreover, mental rotation ability significantly correlated with both symbolic ($r = 0.28$, $p < .05$) and counting ability ($r = 0.31$, $p < .05$). However, neither mental rotation nor spatial location knowledge significantly correlated with non-symbolic ability (all $ps > .05$). See Table 2.

2.4.2. Data Analysis Plan

We conducted generalized linear mixed-effect models using R 4.4.1 (R Core Team, 2022). Specifically, we used *lme4* (version 1.1.35.1; Bates et al., 2015), *plot_model* (version 2.8.15; Lüdecke, 2020), and *johnson_neyman* (version 1.1.5; Long, 2019) functions to see and visualize both the mixed and moderation effects. We

performed three linear mixed-effect models to examine the factors predicting children's symbolic, non-symbolic, and counting abilities. The analysis included preschoolers' mental rotation and spatial location knowledge scores as fixed factors. These scores were standardized in the data to improve the statistical analysis. Moreover, the trials for each dependent variable and the participants were entered into the model as random intercepts to account for variability arising from differences between participants and the content of the trials. To find the best model to fit our data, we run and compare models with (1) the interaction between mental rotation and spatial location knowledge, (2) only the fixed effects of mental rotation and spatial location knowledge without their interaction, and (3) either mental rotation or spatial location knowledge alone. Among these three models, the model with the interaction term between mental rotation and spatial location knowledge produced the best fits for all dependent variables (symbolic, non-symbolic, and counting abilities). [2]

2.4.3. Main Analysis

For symbolic math ability, the results of the glmer model revealed a fixed effect of spatial location knowledge (β = 0.33, SE = 0.11, p = 0.003). It means that spatial location knowledge significantly predicted symbolic math ability and each one unit increase in spatial location knowledge leads to 0.33 unit increase in symbolic math ability. Moreover, the model also revealed an interaction between mental rotation and spatial location knowledge on symbolic math ability (β = 0.29, SE = 0.13, p = 0.027), indicating that the predictive effect of spatial location knowledge on symbolic math ability becomes stronger as mental rotation ability increases (See Figure 6 and Figure

[2] Age in month was also added to the interaction model as a control variable predicting symbolic, non-symbolic, and object counting abilities. However, it did not significantly improved the model fit for symbolic ($\chi^2(1) = 0.64$, $p = .42$), non-symbolic ($\chi^2(1) = 3.51$, $p = .06$), and object counting abilities ($\chi^2(1) = 1.15$, $p = .28$). Therefore, we decided not to add it as a controlling variable in our analysis.

7). Following the significant associations between spatial location knowledge and symbolic math ability, we further analyzed whether location production scores and/or location comprehension scores have similar effects on symbolic math ability. We found that location production significantly predicted symbolic math ability ($\beta = 0.31$, $SE = 0.14$, $p = 0.023$), whereas location comprehension did not ($\beta = -0.06$, $SE = 0.18$, $p = 0.748$) (See Figure 8).

For non-symbolic math ability, neither spatial location knowledge ($\beta = 0.30$, $SE = 0.20$, $p = 0.13$) nor mental rotation ($\beta = 0.14$, $SE = 0.22$, $p = 0.5$), or the interaction between the two ($\beta = 0.12$, $SE = 0.23$, $p = 0.6$) have any significant effects. For the object counting ability, there was a fixed effect of spatial location knowledge ($\beta = 1.4$, $SE = 0.32$, $p < .001$). Specifically, each one unit increase in spatial location knowledge leads to a 1.4 unit increase in object counting ability (See Figure 9). However, there was no significant effect of mental rotation ability ($\beta = 0.31$, $SE = 0.33$, $p = 0.34$) and the interaction between spatial location knowledge and mental rotation ability ($\beta = 0.14$, $SE = 0.34$, $p = 0.68$) on object counting ability. Following the significant main effect of spatial location knowledge on object counting ability, we analysed whether location production and/or location comprehension scores have similar effects on object counting ability. We found that location production significantly predicted the

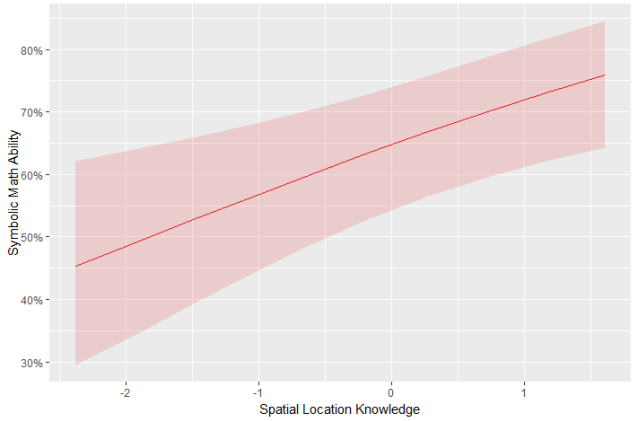


Figure 6. *Spatial Location Knowledge and Symbolic*

object counting ability (β = 1.11, SE = 0.37, p = 0.003), whereas location comprehension did not (β = 0.47, SE = 0.45, p = 0.297) (See Figure 10)

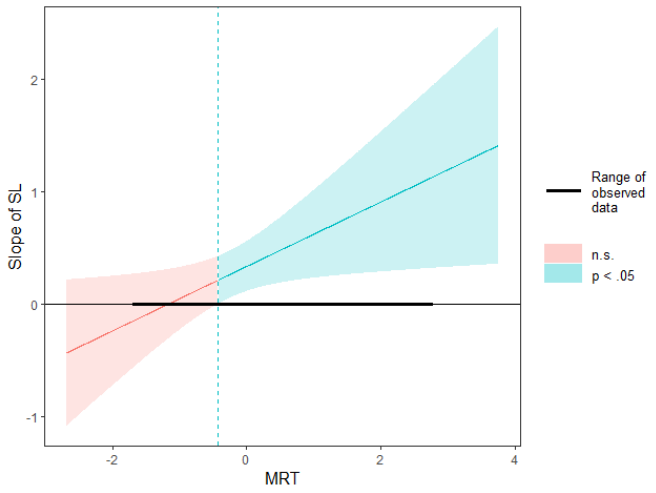


Figure 7. *Interaction between MRT and SL on Symbolic*

Note. *The range of observed values of MRT is [-1.68, 2,75]*

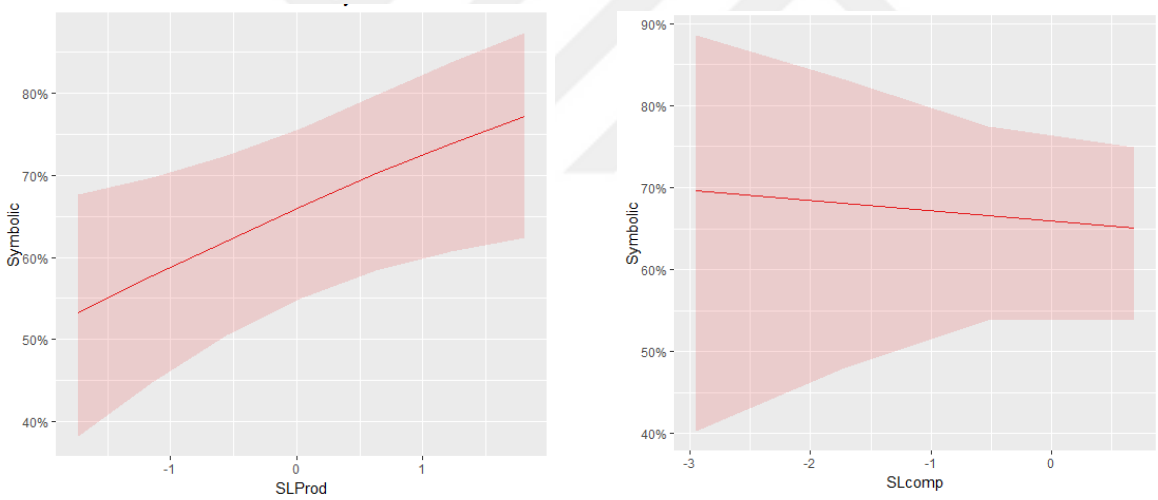


Figure 8. *Location Production, Location Comprehension and Symbolic*

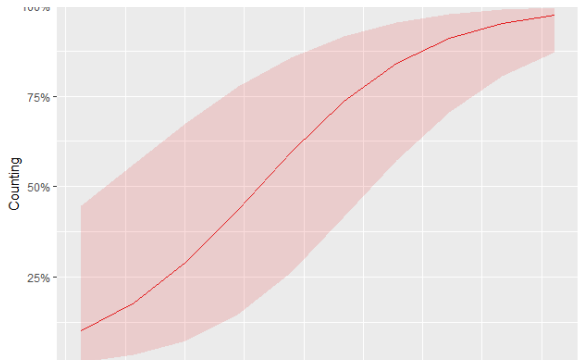


Figure 9. *Spatial Location Knowledge and Counting*

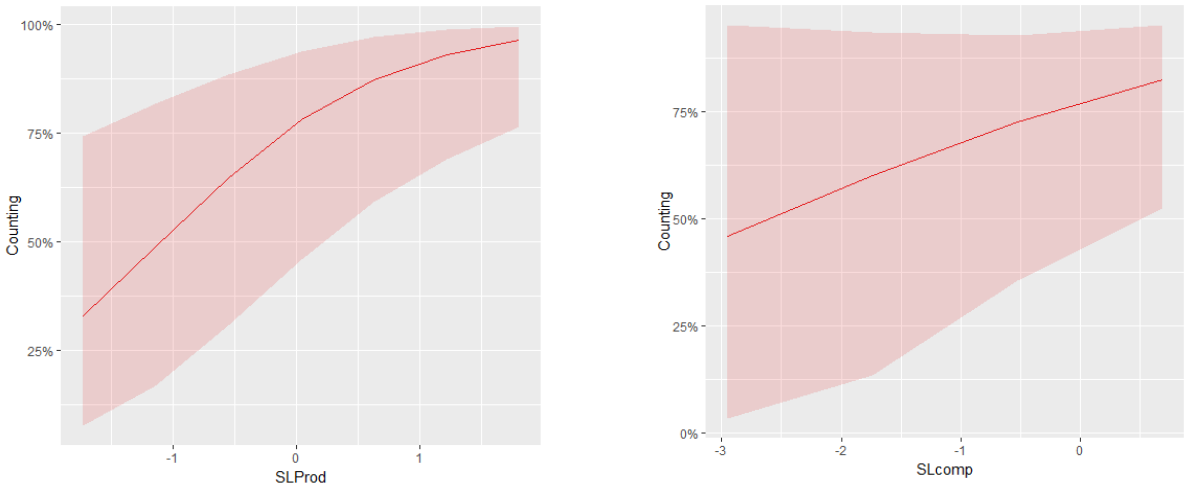


Figure 10. *Location Production, Location Comprehension and Counting*

Table 1. Descriptive Statistics

	N	Mean	Standard Deviation	Minimum	Maximum
Age in Months	60	54.0	5.21	46	69
Mental Rotation	60	11.9	2.96	7	20
Spatial Location Total	60	8.37	2.28	3	12
Spatial Location Production	60	2.93	1.71	0	6
Spatial Location Comprehension	60	5.43	0.83	3	6
Symbolic Ability	60	5.22	1.46	3	8
Non-Symbolic Ability	60	4.60	1.39	0	6
Counting	60	5.67	2.56	0	9

Table 2. Correlation Matrix

	Age in Months	Mental Rotation	Spatial Location Total	Spatial Location Production	Spatial Location Comprehension	Symbolic Ability	Non-Symbolic Ability	Counting
Age in Months	-							
Mental Rotation	0.32*	-						
Spatial Location Total	0.33*	0.33*	-					
Spatial Location Production	0.31*	0.30*	0.95***	-				
Spatial Location Comprehension	0.25	0.29*	0.78***	0.56***	-			
Symbolic Ability	0.27*	0.28*	0.36**	0.4**	0.16	-		
Non-Symbolic Ability	0.29*	0.19	0.21	0.19	0.18	0.33*	-	
Counting	0.33*	0.31*	0.6***	0.56***	0.49***	0.47***	0.33**	-

*Notes. *p < .05, ** p<.01, *** p<.001*

Table 3. Fixed Effects for Symbolic, Nonsymbolic and Counting

Symbolic Ability Fixed Effects	β(SE)	z	p
(Intercept)	0.61 (0.22)	2.730	**0.00634**
Mental Rotation	0.03 (0.12)	0.285	0.77602
Spatial Location Knowledge	0.33 (0.11)	2.954	**0.00314**
Mental Rotation x Spatial Location Knowledge	0.29 (0.13)	2.198	**0.02792**

Non-Symbolic Ability Fixed Effects	β(SE)	z	p
(Intercept)	1.40 (0.23)	5.878	**<.001**
Mental Rotation	0.14 (0.22)	0.658	0.511
Spatial Location Knowledge	0.30 (0.20)	1.482	0.138
Mental Rotation x Spatial Location Knowledge	0.12 (0.23)	0.526	0.599

Object Counting Ability Fixed Effects	β(SE)	z	p
(Intercept)	1.25 (0.70)	1.793	0.073
Mental Rotation	0.31 (0.33)	0.942	0.346
Spatial Location Knowledge	1.44 (0.32)	4.517	**<0.001**
Mental Rotation x Spatial Location Knowledge	0.14 (0.34)	0.408	0.683

Note. *The table presents the fixed effects estimates from the linear mixed-effects model predicting symbolic, non-symbolic, and object counting abilities. The bold typeface indicates a significant effect.*

CHAPTER 3

DISCUSSION

This study examined the impact of different spatial skills (mental rotation vs. spatial location knowledge) on preschoolers' math performances (symbolic, non-symbolic, and object counting) with the aim of understanding how spatial language and mental rotation might influence preschoolers' different math abilities by considering the limitations of previous studies that did not use a variety of math tasks and focused solely on school-aged children. To uncover the factors predicting preschoolers' math abilities, we asked children to rotate the shapes mentally and produce and comprehend the spatial locations. They also did arithmetic calculations, object counting, and magnitude estimates. Our results showed that spatial language, predicts symbolic math abilities in isolation and interaction with mental rotation. It also has a strong predictive role in object counting ability. It suggests that when children perform arithmetic operations, such as in the case of symbolic calculation tasks, spatial language together with mental rotation, play active roles. However, spatial language alone predicts their performance when children engage in tasks that require determining number orders, such as counting the correct number of beads. The effect of spatial language on number skills is especially driven by children's spatial language production abilities rather than by comprehension. In addition, neither mental rotation nor spatial language significantly affects non-symbolic math performance. Below, we discuss our findings and unpack how each one of these adds

to our understanding of the relationship between the development of spatial and mathematical abilities of preschoolers.

First of all, we found a significant effect of spatial location knowledge on symbolic calculation ability. This result aligns with findings demonstrating a significant relationship between spatial language and symbolic math abilities (Hawes et al., 2017; Gilligan-Lee et al., 2021). While corroborating this previous evidence, we also demonstrate this relationship for the first time through a math task that is not mainly based on spatial properties. Previously, this relationship was demonstrated using a math task relying on a mental number line, which requires processing spatial information (Gilligan-Lee et al., 2021). Therefore, we, for the first time, showed that the relationship between spatial language and math performance is not only observed in spatially oriented math tasks but also in math tasks that do not require spatial skills. In addition, we found that the effects of spatial location knowledge on symbolic abilities increase when preschoolers' mental rotation ability also increases. This result corroborates the indirect relationship between spatial language and mathematics, which is potentially mediated by spatial skills such as mental rotation (Gilligan-Lee et al., 2021). It provides evidence for spatial thinking and its relationship with symbolic math performance by highlighting how different components of spatial thinking, such as mental rotation and spatial location knowledge, interact. Similar to studies showing the relationship between spatial skills, language abilities, and math performances (see Casey et al., 2015; LeFevre et al., 2010), our results support the idea that better language and spatial abilities enhance the understanding of problems and provide insights into the spatial layout of these problems during operations with symbolic numbers.

However, our findings revealed that neither spatial language nor mental rotation relates to non-symbolic numerosity comparison abilities. In comparison, previous studies have demonstrated a close link between spatial abilities and non-symbolic numerosity representations (see Dehaene et al., 1993; de Hevia & Spelke, 2010; Pinel et al., 2004), but no significant relationship has been reported between spatial language and non-symbolic numerical abilities (Hawes et al., 2017; Gilligan Lee et al., 2021). Although our results partially align with prior research regarding no association between spatial language and non-symbolic skills, they provide contradictory evidence for the previously reported association between space and non-symbolic magnitude representations. There might be several reasons behind the absence of a predictive relationship between spatial factors and non-symbolic abilities. For example, Matejko and Ansari (2016) found that children showed greater learning trajectories for symbolic tasks than for non-symbolic tasks during school. It implies that children may learn symbolic task strategies more easily than non-symbolic tasks. However, in our study, 28% of preschoolers (17 out of 60) had the top scores in non-symbolic performance. This rate was only 5% for symbolic (3 out of 60) and 21% for object counting (13 out of 60), which suggests that preschoolers in our data had better scores in non-symbolic tasks than symbolic and object counting tasks. Thus, extensive learning trajectories might not be the underlying reason for the lack of effect. Alternatively, in our tasks, language prompts might have provided more insights for symbolic calculation and object counting tasks, but not for non-symbolic tasks. For example, in symbolic and object counting tasks, children needed to understand the cues for spatial relations, “Pamuk has two balls *in* its box. Pamuk is taking one ball *out of the* box.” or “Can you count the dots *here* and then put the same number of beads *onto* the stick.” In a non-symbolic task, children were only asked which arrays

of dots were more/less. Moreover, the trials in these tasks were presented in shorter durations so that no defining features, such as location or size, were needed. Thus, children were expected not to rely on spatial skills and/or spatial language knowledge to estimate non-symbolic numerical magnitudes, unlike symbolic and object counting tasks, where these strategies are likely to be employed. Thus, in our study, the predictive effect of spatial language on these performances was observed except for the non-symbolic comparison performance.

When it comes to object counting ability, our results demonstrated that it was solely related to children's spatial language knowledge, but not mental rotation skills. To our knowledge, no prior study has examined the relationship between object counting and spatial language. This finding is the first to demonstrate their close relationship. However, no significant effect of mental rotation on object counting was observed, which was not in line with our prior hypothesis. One previous study conducted with preschoolers between 3-to-4 years old found that visuospatial skills measured by a spatial perception task at 3.5 years of age predicted counting sequence knowledge at 4 years of age (Liu & Zhang, 2022). In addition, Cornu and colleagues (2019) trained the visuospatial skills of children between 4-to-7 years old by creating a booklet with tasks that require figure completion, finding the correct pair, or rotation questions, and observed a strong relationship between visuospatial skills and counting abilities, even though there were no direct training effects. However, in our study, object counting ability was measured in a single session, and it required a conceptual understanding of number words (e.g., cardinality). Considering studies showing that early visuospatial/mental rotation skills predict later math performances (Geer et al., 2019; Verdine et al., 2014), mental rotation skills at an earlier age may facilitate the conceptual understanding of number words at later ages. This relationship may

become stronger when children engage with formal mathematical instruction once they start primary school. However, we could not test this longitudinal relationship in our data. An alternative reason for the lack of effect could be due to the complexity of mental rotation tasks for children younger than five years old (Frick et al., 2014; Noda, 2014). Yet, in order to eliminate such complexity due to our age range, we precisely selected the Ghost Task (Frick et al., 2013), which was developed to successfully measure spatial abilities for preschoolers between 4 and 5 years of age. Given that our mental rotation task was age-appropriate for our sample, the most plausible explanation for the lack of effect of mental rotation on object counting ability possibly underlines that mental rotation abilities are unrelated to the conceptual understanding of number words in object counting for this age group. Further studies should investigate the relationship between mental rotation and object counting by drawing evidence from other tasks that tap into other spatial skills.

The predictive effect of spatial location knowledge on symbolic numerosity comparison and counting skills was especially coming from children's spatial language production skills rather than their spatial language comprehension skills. That is, when compared to location comprehension, location production was found to be the only significant factor predicting symbolic and object counting abilities. This finding corroborates previous evidence showing that location production explained greater variance in mathematics outcomes (Gilligan-Lee et al., 2021). Given that location production provides verbal discourse for mathematical tasks requiring coding of spatial relations, such as placing the beads or arithmetic operations, our results also confirmed the importance of producing the locations rather than comprehending them. When we lend our focus on the developmental differences in location production and comprehesion, Farran and Atkinson (2016) reported a significant relationship between

spatial categorization and location production in 4-7 year olds, indicating that when children demonstrate a broader understanding of spatial categories, they also perform better in location production. However, this association was not observed between location comprehension and spatial categorization. Both verbal discourse for coding the spatial relations and association with the spatial categorization demonstrate the benefits of producing the locations, rather than comprehending them. Moreover, corroborating the earlier mastery of location comprehension abilities, in our data more than half of the children (37 out of 60) completed all the trials correctly for the location comprehension trials, whereas only a few children had completed all the trials for location production. Possibly, wider variation for location production scores could have predicted math performances better than location comprehension. All in all, this finding aligns well with existing evidence demonstrating that spatial language production and comprehension are two distinct skills of spatial language with location comprehension abilities appearing earlier in development (Farran & Atkinson, 2016; Gilligan-Lee et al., 2021) and location production is being the one that has been reportedly related to children's math outcomes (Gilligan-Lee et al., 2021).

Finally, considering the theoretical backgrounds of the close link between space and numbers, our results provide compelling evidence for CMT (Lakoff & Johnson, 1980) but not for ATOM (Walsh, 2003). As suggested by CMT, we benefit from the language of space to produce number words (e.g., five is *higher* than four). Everyday use of spatial terms such as next to, higher, or lower can be used to explain numerical relationships. Similarly, our findings demonstrate that knowing the spatial terms and using them conveniently helps children successfully navigate through arithmetic operations and number orders. However, ATOM argued that spatial relations (e.g., above, next to) and magnitude estimates, which also involve the comparisons of

uncountable items, are processed together in a magnitude system in our brain. Therefore, one should expect that children with better mental rotation as well as spatial location knowledge should perform better in comparing the magnitude of two arrays of dots in a shorter duration. However, our findings did not demonstrate a relationship between spatial relations and/or mental rotation predicting non-symbolic numerosity comparison.

3.1. Limitations and Future Directions

Although our research has demonstrated essential findings regarding the close relationship between spatial language and math performance, it is not without limitations. Children's success in math depends on child-related factors and environmental factors such as parental input, SES, or teacher-child relationships (Gunderson & Levine, 2011; Shi & Yong Tan, 2021). Our study did not control any of those environmental factors, but future research must examine their role together with child-related factors in investigating preschoolers' math performance.

Moreover, the current study includes several measurements of spatial and mathematical factors. These measures were taken from preschoolers one at a time. To consider the fatigue that may arise due to the workload of these tasks, we had to decrease the number of trials, especially with respect to the non-symbolic numerical comparison task. For this reason, it is recommended that future studies should make an adjustment in terms of children's engagement with the activities and the number of trials and/or variables to contribute to the current research.

In general, we provided valuable insights into the development of mathematical language demonstrated by De Smedt and Turan (2022). That is, how mathematical language comprises quantitative terms (e.g., few or many) and spatial terms (e.g., before, above, or near). Using these terms in daily life in appropriate ways may be

crucial for the development of mathematical language. Studies also show that mathematical language as well, predicts mathematical abilities in children (Toll & Van Luit, 2014; Purpura & Reid, 2016). Thus, children's success in math tasks cannot be fully understood without their mathematical language and spatial and linguistic skills, all of which have been demonstrated to play an active role in their math development.

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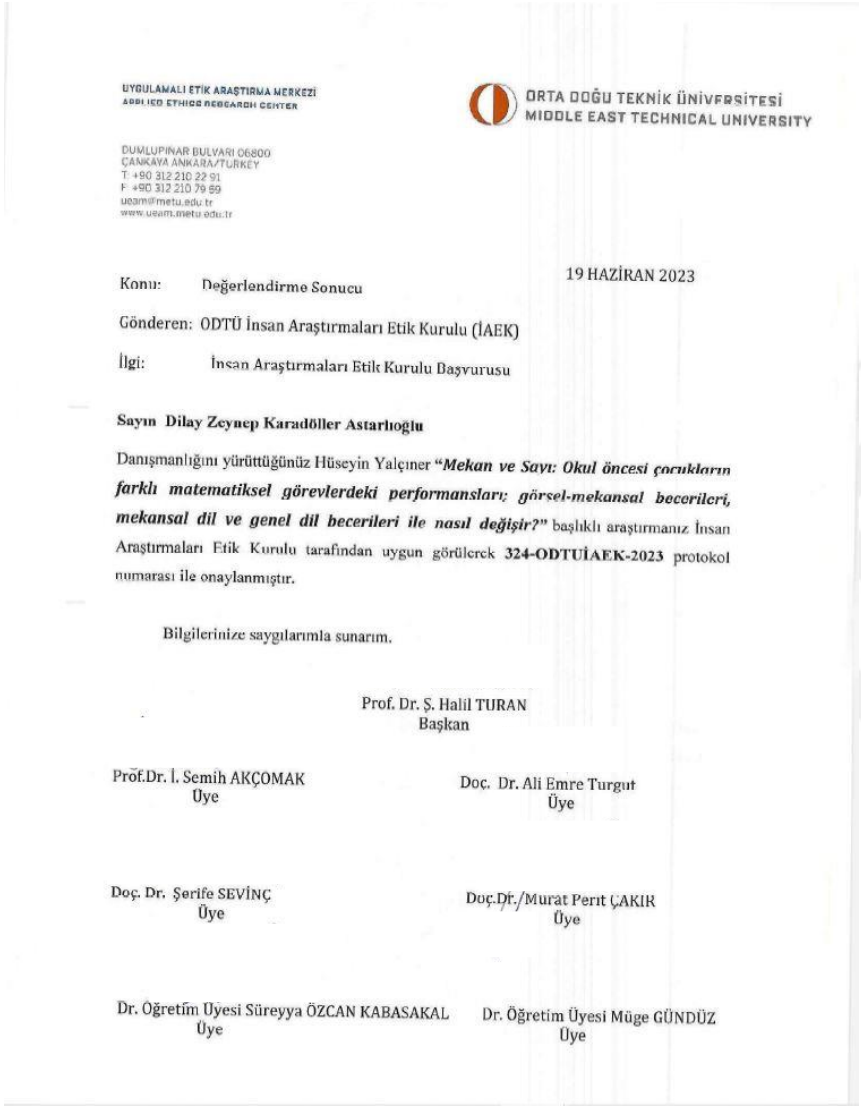
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APPENDICES

A. APPROVAL OF THE METU HUMAN SUBJECTS ETHICS COMMITTEE



UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
APPLIED ETHICS RESEARCH CENTER

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19 HAZİRAN 2023

Konu: Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Dilay Zeynep Karadöller Astarlıoğlu

Danışmanlığını yürüttüğünüz Hüseyin Yalçıner ***"Mekan ve Sayı: Okul öncesi çocukların farklı matematiksel görevlerdeki performansları; görsel-mekansal becerileri, mekansal dil ve genel dil becerileri ile nasıl değişir?"*** başlıklı araştırmanız İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek **324-ODTÜİAEK-2023** protokol numarası ile onaylanmıştır.

Bilgilerinize saygılarımla sunarım.

Prof. Dr. Ş. Halil TURAN
Başkan

Prof.Dr. İ. Semih AKÇOMAK
Üye

Doç. Dr. Ali Emre Turgut
Üye

Doç. Dr. Şerife SEVİNÇ
Üye

Doç.Dr. Murat Perit ÇAKIR
Üye

Dr. Öğretim Üyesi Süreyya ÖZCAN KABASAKAL
Üye

Dr. Öğretim Üyesi Müge GÜNDÜZ
Üye

B. INFORMED CONSENT

Veli Onay Mektubu

Sevgili Anne-Babalar,

Orta Doğu Teknik Üniversitesi Psikoloji Bölümü Yüksek Lisans öğrencisi olarak tez kapsamında "Okul öncesi çocukların farklı matematiksel görevlerdeki performansları, onların görsel-mekansal becerileri, mekansal dil ve genel dil becerileri ile nasıl değişir?" başlıklı araştırma çalışmasını yürütmekteyim.

Bu çalışmanın amacı nedir? Bu çalışmanın amacı okul öncesi dönemindeki çocukların matematik becerilerini etkileyen faktörlerin belirlenmesidir.

Sizin ve çocuğunuzun katılımcı olarak ne yapmasını istiyoruz?: Bu amaç doğrultusunda, çocuğunuzdan bazı nesneleri saymasını ve hesaplama içeren bazı sorulara cevap vermesini bekliyoruz. Çocuğunuzun cevaplarını video kaydı alarak toplayacağız. Katılmasına izin verdiğiniz takdirde çocuğunuzla okulda ders saatinde aktivitelerimizi yapacağız. Sizden çocuğunuzun katılımcı olmasıyla ilgili izin istediğimiz gibi, çalışmaya başlamadan çocuğunuzdan da sözlü olarak katılımıyla ilgili rızası mutlaka alınacak.

Çocuğunuzdan alınan bilgiler ne amaçla ve nasıl kullanılacak?: Çocuğunuzla birlikte gerçekleştirdiğimiz aktivitelerdeki cevapları kesinlikle gizli tutulacak ve bu cevaplar sadece bilimsel araştırma amacıyla kullanılacaktır. Çocuğunuzun ismi ve kimlik bilgileri, hiçbir şekilde kimseyle paylaşılmayacaktır. Araştırma sonuçlarının özeti tarafımızdan okula ulaştırılacaktır. Bu gerçekleştireceğimiz aktiviteler, çocukların matematik performanslarını etkileyen faktörlerin saptanmasında önemli bir katkıda bulunacaktır.

Çocuğunuz ya da siz çalışmayı yarıda kesmek isterseniz ne yapmalısınız?: Çocuğunuzun cevaplayacağı soruların onun psikolojik gelişimine olumsuz etkisi olmayacağından emin olabilirsiniz. Yine de, bu formu imzaladıktan sonra çocuğunuz ya da siz katılımcılıktan ayrılma hakkına sahipsiniz. Katılım sırasında sorulan sorulardan ya da herhangi bir uygulama ile ilgili başka bir nedenden ötürü çocuğunuz kendisini rahatsız hissettiğini belirtirse, ya da kendi belirtmese de araştırmacı çocuğun rahatsız olduğunu öngörürse, çalışmaya sorular tamamlanmadan ve derhal son verilecektir.

Bu çalışmayla ilgili daha fazla bilgi almak isterseniz: Araştırmayla ilgili sorularınızı aşağıdaki e-posta adresini kullanarak bize yöneltebilirsiniz.

e-posta:

Lütfen bu araştırmaya katılmak konusundaki tercihinizi aşağıdaki seçeneklerden size en uygun gelenin altına imzanızı atarak belirtiniz ve bu formu çocuğunuzla okula geri gönderiniz.

A) Bu araştırmaya tamamen gönüllü olarak katılıyorum ve çocuğum .....'nın da katılımcı olmasına izin veriyorum. Çalışmayı istediğim zaman yarıda kesip bırakabileceğimi biliyorum ve verdiğim bilgilerin bilimsel amaçlı olarak kullanılmasını kabul ediyorum.

Anne ya da Baba, Adı-Soyadı.....

İmza .....

B) Bu çalışmaya katılmayı kabul etmiyorum ve çocuğumun .....'nın da katılımcı olmasına izin vermiyorum.

Anne ya da Baba, Adı-Soyadı.....

İmza .....

C. TURKISH SUMMARY / TÜRKÇE ÖZET

BÖLÜM 1

GİRİŞ

Erken dönemde kazanılan matematiksel beceriler, çocukların ilerleyen yaşamlarında fen, teknoloji, mühendislik, ve matematik (STEM) alanlarında da başarılı olmalarını sağlar. Dolayısıyla okul öncesi dönem çocukların bazı becerileri kazanabilmesi için hayati bir öneme sahiptir (Ritchie & Bater, 2013; Watts vd., 2014). İnsanlar, soyut kavramları daha iyi anlayabilmek için somut ipucularından faydalanırlar (örn., mekansal özellikler) (Winter vd., 2015). Örneğin, mekan matematikte kullanılan "+", "-" gibi sembolleri daha kolay anlamamızı sağlamaktadır. Bu bağlamda matematiksel sembolleri ve sayıları kavrama noktasında mekansal becerilerin önemli bir rol oynadığı düşünülmektedir (Casey vd., 2015).

Literatürdeki bulgular değerlendirildiğinde görsel mekansal becerilerin (mental rotasyon, mekansal görselleştirme gibi) matematik performansıyla yakından ilişkili olduğu belirtilmiştir (örn., Gunderson vd., 2012). Buna ek olarak, mekansal düşünme sadece bu beceriler ile sınırlı olmamaktadır. Mekansal düşünmenin bir başka boyutu da mekansal dil olarak karşımıza çıkmaktadır. Mekansal dil, nesnelerin konumlarını, nasıl ifade edildiklerini ve nesneler arasında yer-yön ilişkilerini kurabilmek olarak tanımlanmaktadır (Gilligan-Lee vd., 2021). Matematik ile mekansal dil arasındaki ilişkiye yönelik literatürde kısıtlı bir bulgu bulunmaktadır.

Bu çalışmanın amacı, okul öncesi dönemdeki çocukların farklı matematik becerilerinin (sembolik işlemler, sembolik olmayan karşılaştırmalar ve nesne sayma)

onların mental rotasyon ve mekansal dil becerileriyle ilişkili olup olmadığını araştırmaktır.

1.1. Sayı Gelişimi

Çocuklar sayı kelimelerini sırasıyla öğrenmektedirler ve yaklaşık 4 yaşında kardinallik ilkesini (söylenen son sayı kelimesinin bir nesne kümesine karşılık geldiğini anlayabilmek) kavramaktadırlar (Sarnecka vd., 2007). Okul öncesi dönem onların sayma gelişimi için çok önemlidir. Bu dönemde sayma aktivitesini günlük etkileşimlerde çok sık kullanırlar (Uyanır & Kandır, 2010). Önceki çalışmalar çocukları alt-küme bilen ve kardinalite bilen olarak ikiye ayırmıştır. 4 sayısına kadar bu sayıyı gösterebilen çocukların alt-küme bilen grubunda yer alırken 5 ve daha fazla sayıyı gösterebilen çocukların ise kardinalite bilen grubunda yer aldıkları belirtilmiştir (Sarnecka & Lee, 2009). Çocuklar her zaman sayı kelimelerinin anlamını bilmeseler dahi belirli bir obje kümesinin az ya da çok oluşunu tahmin edebilmektedirler. Bu yetenek ise Yaklaşık Sayı Sistemi (ANS) olarak tanımlanmaktadır ve çocukların sembolik olmayan sayı kümelerininin miktarını karşılaştırmaları ile ölçülmektedir (Izard vd., 2009). Çalışmalar erken yaşlardaki sembolik olmayan karşılaştırma becerisinin çocukların sayma prensipleri ve hesaplama becerilerine yardımcı olduğunu belirtmektedir (Libertus vd., 2011). Sembolik beceriler ise Arap rakamı ile yazılan sayılar ile işlem yapabilmek olarak tanımlanmaktadır. Çalışmalar erken dönemdeki sembolik ve sembolik olmayan becerilerin çocukların ilerleyen zamanlarda gösterdikleri matematik başarılarıyla ilişkili olduğunu belirtmektedir (Kolkman vd., 2013; Libertus vd., 2011).

1.2. Mekansal Beceriler ve Sayı Gelişimi

Mental rotasyon gibi mekansal becerilerin okul çağındaki çocukların matematik başarılarıyla ilişkili olduğu gösterilmiştir (Li & Geary, 2013). Linn ve Petersen (1985) üç adet mekansal beceri tanımlamıştır: mental rotasyon, mekansal görselleştirme ve mekansal algı. Birçok çalışma farklı mekansal becerilerin matematik performansları ile ilişkisini incelemiştir (örn., Geer vd., 2019). Bu çalışmalar erken dönemdeki mekansal görselleştirme ile mental rotasyon becerisinin çocukların ilerleyen yaşlardaki matematik performanslarını açıkladığını belirtirken mekansal algı yeteneğinin matematikte yaşanan bu değişiklik ile açıklandığını belirtmişlerdir. Sayı ile Mekan arasındaki yakın ilişkiyi gösteren bazı teori ve bulgular mevcuttur. SNARC etkisi sayı ile mekan arasındaki yakın ilişkiyi göstermektedir. SNARC etkisine göre zihinsel bir sayı doğrusuna sahip olduğumuz belirtilir ve sayıların zihinsel temsillerinin, tıpkı normal bir sayı doğrusunda olduğu gibi, soldan sağa doğru temsil edildiği belirtilmiştir (Dehaene vd., 1993). Yapılan bir çalışmada, katılımcılara bazı sayılar gösterilmiş ve sayıların tek mi çift mi olduğunu belirtmeleri istenmiştir. Sonuç olarak, katılımcıların gösterilen sayı küçük olduğunda sol ellerinin altındaki tuşa daha hızlı bastıkları ancak büyük sayılar gösterildiğinde sağ ellerinin altındaki tuşa daha hızlı bastıkları bulunmuştur. Diğer bir yandan ATOM (Walsh, 2003) ise zihinimizde bir büyüklük sistemine sahip olduğumuzu ve bu büyüklük sisteminde mekansal ve sayısal konseptlerin birlikte işlendiğini öne sürer. Bu konseptler uzunluk, hacim, ağırlık, çokluk gibi konseptlerdir. Bir objeyi kavramaya çalışırken hem o obje ile aramızdaki mesafe hem de objenin azlığı çokluğu bizim hareketimizi yönlendirmektedir. Bu bulgular sayıların mekan ile olan yakın ilişkisini açıkça göstermektedir.

1.3. Mekansal Dil ve Sayı Gelişimi

Mekansal dil, nesnelerin mekansal özelliklerini, konumlarını ve uygun ifadelerle nasıl adlandırıldıklarını yorumlamayı ifade etmektedir ve sayısal gelişimde önemli bir rol oynar. Mekansal kelimeleri anlama ve kullanma becerisi (örn., üstünde, altında, yanında gibi) sayısal beceriler ile yakından ilişkilidir (Georges vd., 2021). Çalışmalar okul öncesi çocukların dil becerilerinin ve kelime anlama ve üretme yeteneklerinin matematik bilgileri ile ilgili olduğunu göstermektedir (LeFevre vd., 2010). Özellikle bu dönemde bazı özel kelimeleri bilmenin (az, çok, üstünde, yanında gibi) çocukların kendilerine yöneltilen matematik problemlerini daha iyi anlamalarını ve daha iyi bir sonuç göstermelerini sağladığı gösterilmektedir (de Smedt & Turan, 2022). Ancak literatürde bu ilişkiyi araştıran çalışma sayısı oldukça az olarak gözlemlenmiştir. Okul öncesi çocuklarda mekansal dil ve matematik performansı arasındaki ilişkiyi doğrutdan inceleyen üç çalışma bulunmaktadır. Hawes ve arkadaşları (2017) 6 yaşındaki çocuklarda mekansal dil ile matematik performansı arasında anlamlı bir ilişki bulmuştur. Bu çalışmada mekansal dilin ölçümü şekil tanıma ve konumsal dile dayandığından, sonuçlar matematiğin özellikle mekansal ilişkilerin anlaşılmasıyla hangi derecede bağlantılı olduğunu değerlendirmek için yeterli değildir. Gilligan-Lee ve meslektaşları (2021) tarafından yürütülen başka bir çalışmada ise çocukların mekansal ilişkileri (örn., sol, sağ, alt,üst) anlama ve diğer bazı matematik performansları ölçülmüştür. Mekansal beceriler kontrol edildiğinde dahi mekansal dilin çocukların matematik performanslarını %15 oranında açıkladıklarını belirtmişlerdir. Son olarak ise Chan ve meslektaşları (2025) yaptıkları bir çalışmada mekansal dil ve sayı becerileri arasındaki çift yönlü ilişkiyi incelemiş ve okul öncesi çocukların erken dönemdeki sayı doğrusu bilgilerinin ilerleyen zamanlardaki mekansal dil becerilerini yordadığını belirtmişlerdir. Buna ek olarak daha yüksek

sayısal becerilere sahip çocukların yer-yön bilgilerinden günlük hayatlarında daha çok faydalandıkları da belirtilmiştir. Bu doğrultuda, mekansal dil ile sayısal gelişim arasında literatürde bulunan az çalışmada farklı sonuçlar belirtilmektedir. Bu nedenle matematik ile mekansal dil arasındaki ilişki daha detaylı bir şekilde incelenmelidir.

1.4. Güncel Çalışma

Önceki çalışmalar değerlendirildiğinde çocukların mekansal yetenekleri (mental rotasyon) ile matematik performansları arasında güçlü bir ilişki belirtilmiştir (bkz. Casey vd., 2015; Li ve Geary, 2013). Ancak bu çalışmalar, genellikleri okul çağındaki çocukları çalışmalarına dahil etmişlerdir ve çok çeşitli olmayan genellikle hafızadan sayma gibi matematiksel becerileri araştırmaya odaklanmışlardır. Bu çalışmalarda matematik gelişimi boylamsal olarak incelenmektedir. Erken dönem matematik becerilerinin daha sonraki beceriler için önemi düşünüldüğünde, ilk olarak, okul öncesi çocukların farklı matematiksel görevlerdeki başarılarının diğer becerilerle ne ölçüde eşzamanlı olarak ilişkili olduğunu belirlemek de önemlidir. İkinci olarak ise, nesnelerle aktif etkileşim ve sayı sözcüklerinin kavramsal olarak anlaşılmasını da gerektiren diğer sayma görevlerinin mekansal becerilerle ilişkili olup olmadığını araştırmak da önemlidir. Ayrıca, sayıların mekansal olarak kodlandığına dair sunulan güçlü kanıtlara rağmen (Dehaene vd., 1993), okul öncesi çocuklarda mekansal dil ile farklı matematik performansları arasındaki ilişki daha önce çalışılmamıştır. Önceki çalışmalar mekansal dilin sembolik becerileri yordadığını öne sürse de (bkz. Hawes vd., 2017), bu çalışmaların mekansal dil ölçme biçimlerindeki farklılıklar ve mekansal dil ile sayısal beceriler arasındaki ikili ilişkiler tartışmalı bulguları vurgulamaktadır. Literatürdeki bu boşlukları doldurabilmek ve daha farklı bir bakış açısı sunabilmek amacıyla çocukların farklı matematik performansları ile mekansal becerileri (mental

rotasyon ve mekansal dil üretimi ve anlama) ölçülmüştür. Bu doğrultuda okul öncesi çocuklarından (4-5 yaş) veri toplanmıştır.

1.5. Hipotezler

Literatürdeki bulgular değerlendirildiğinde okul öncesi çocukların mental rotasyon görevinde gösterdikleri performansın tüm matematiksel beceriler (sembolik, sembolik olmayan ve nesne sayma) ile ilişkili olması beklenmektedir. Buna ek olarak, mekansal dil becerilerinin çocukların sembolik ve nesne sayma becerileri ile anlamlı bir ilişkisinin olması beklenmektedir. Ancak literatürdeki farklı bulgular nedeniyle hangi matematik performansının mekansal beceriler ile daha yakından ilişkili olduğuna yönelik bir hipotezimiz bulunmamaktadır.

BÖLÜM 2

YÖNTEM

2.1. Katılımcılar

Çalışma, ODTÜ İnsan Araştırmaları Etik Kurulu'ndan (324-ODTUİAEK-2023) ve Milli Eğitim Bakanlığı'ndan (54850036-605.01-E.528) gerekli izinler alınarak yürütülmüştür. Örneklem, 3 yaş 10 ay ile 5 yaş 9 ay arasında değişen yaşlarda 60 çocuk (34 erkek) içermektedir.

2.2. Araştırmada Kullanılan Görevler

2.2.1. Ghost Görevi

Çocukların zihinsel döndürme becerilerini ölçebilmek amacıyla bu görev kullanılmıştır. Bu görev özellikle 3-5 yaş arasındaki çocuklar için geliştirilmiştir (Frick vd., 2013). Bu çalışma 6 adet pratik aşaması 21 adet ise test aşaması sorusu içermektedir. Pratik aşamasında çeşitli şeffaf ve fiziksel olarak dokunulabilir şekiller (anahtar, gemi vb.) içeren kağıtlar döndürülmektedir ve çocuklardan iki seçenek

arasından hangi şekil için daha uygun olduğunu bulmaları isenir. Daha sonrasında test aşamasında ise çocuklardan gördükleri resimleri zihinlerinde döndürmeleri ve verilen seçeneklerdeki şekillerden hangisine uygun olduğunu bulmaları istenmiştir. Ham puanlar, katılımcılar tarafından verilen cevapların toplam doğruluğuna göre hesaplanmıştır.

2.2.2. Mekansal Dil Bilgisi

Bu görev çocukların mekansal dil bilgisi becerilerini ölçebilmek amacıyla kullanılmıştır (Gilligan-Lee vd., 2021) Bu görevde mekansal dil üretme ve anlama aşamaları olarak iki aşama bulunmaktadır. Mekansal dil üretme aşamasında çocuklara çeşitli resimler gösterilmiştir. Resimlere bakarak çocukların uygun yer-yön bilgisini üretmeleri beklenmiştir. Örneğin, bir uçağın bulutun üstünde olduğunu gösteren bir resme baktıklarında çocuklara "Uçak bulutun neresinde?" şeklinde sorulmuştur. Çocukların resme bakarak bu soruyu yanıtlamaları beklenmiştir. Mekansal dil anlama aşamasında ise çocuklara çeşitli resimler gösterilmiştir ve sorulan soruya göre uygun olan resmi belirtmeleri istenmiştir. Örneğin, çocuklara "hangi resimde oyuncak dolabın üstünde?" şeklinde sorulmuştur ve çocuğun yanıtı kaydedilmiştir.

2.2.3. Sembolik Hesaplama Görevi

Bu görev çocukların sembolik sayıları ekleyip çıkartarak doğru yanıtı bulabilmeler için uygulanmıştır ve çocukların sembolik becerileri ölçülmüştür (Gilmore vd., 2007). Görevde bir kedi ve bir köpek resmi bulunmaktadır. Kedi ve köpeğin kutularında ise çeşitli sayıda topları vardır. Bu sayılar sembolik sayılar şeklinde yazılmıştır (Örn., 1,2 gibi). Bir sonraki aşamada köpek belirli sayıda bir top almaktadır ve son durumda ise kedinin mi yoksa köpeğin mi daha çok topu olduğu sorulmuştur. Bu aktivitede dört adet toplama ve dört adet çıkartma test sorusu bulunmaktadır. Test aşamasından önce pratik aşamasında çocuklara aktivite anlatılmış ve araştırmacı ile birlikte pratik

yapmalarına olanak tanınmıştır. Çocuklar aktivite esnasında bazen doğru seçeneği elleriyle göstererek yanıt verseler de, köpek veya kedi gibi doğru seçeneği yansıtan sözel yanıtlar vermeye motive edilmişlerdir. Araştırmacı yanıtların analizini sağlamak amacıyla aktivite esnasında notlar almıştır.

2.2.4. Sembolik Olmayan Sayısallık Karşılaştırması Görevi

Sembolik olmayan sayı karşılaştırma görevi, çocukların soyut sayı temsillerini ölçmek için geliştirilmiştir (Barth vd., 2006). Görev, her biri eşit büyüklükte olan mavi ve kırmızı noktalardan oluşan iki dizi içermektedir. Denemelerdeki nokta sayısı 6 ila 60 arasında değişmektedir. Katılımcılardan beş saniye boyunca ekrana bakarak daha fazla ya da daha az nokta olup olmadığını belirtmeleri istenmiştir. Çocuklara ilk olarak dizilerin ve noktaların tanıtıldığı pratik denemeleri yapılmıştır. Sonrasında ise sol tarafta bulunan mavi noktalı dizi gösterilmiştir. Ardından, bu dizinin üzeri gri bir diziyle kapatılmış ve hemen yan tarafında ise kırmızı noktalar içeren bir dizi gösterilmiştir. Son aşamada ise siyah bir ekran belirmiş ve çocuklardan hangi renk noktaların daha fazla/daha az olduğu sorusuna yanıt vermeleri beklenmiştir. Bu aktivitede 3 adet hangi rengin daha fazla olduğunu 3 adet ise hangi rengin daha az olduğunu soran toplam altı adet test sorusu sorulmuştur.

2.2.5 Nesne Sayma Görevi

Bu görev, çocukların sayma becerilerini ölçebilmek amacıyla kullanılmıştır (Gibson vd., 2018). Görevde bir kukla oyuncak, boncuklar, çubuklar ve farklı sayıda noktalar içeren kartlar kullanılmıştır. Kartlardaki nokta sayıları 1'den 9' a kadar olacak şekilde belirtilmiştir. Görevde, çocuklardan okula hazırlanmak için belirli sayıda boncuğa ihtiyaç duyan bu kukla oyuncağa yardım etmeleri istenmiştir. Çocuklardan karttaki nokta sayılarını sayarak bu nokta sayısı kadar çubuğa boncuk yerleştirmeleri istenmiştir. Çocuklara bu kartlar 5,8,3,6,9,4,1,7,2 olacak şekilde sabit bir sırayla

gösterilmiştir. Boncuklar çubuğa yerleştirildikten sonra araştırmacı çocuğun bitirdiğinden emin olmak için "Bitti mi?" şeklinde sormuştur ve çocuk "Bitirdim" diyene kadar saymalarına ve boncuk sayılarını değiştirmelerine izin verilmiştir. Sonrasında ise boncuklar alınmıştır ve bir sonraki kart gösterilmiştir. Çocukların yanıtları doğru/yanlış olacak şekilde sonraki analizler için kayıt altına alınmıştır.

2.3. Uygulama

Gerçekleştirilen tüm görevler ya ailelerin evinde ya da okul ortamında sessiz bir odada uygulanmıştır. Görevlerin uygulanma sırası her veri toplama aşaması için aynıdır. Tüm oturumlar ilerleyen aşamalardaki kodlama ve analiz süreçleri için ebeveyn onayları sonrasında kayda alınmıştır.

2.4. Bulgular

2.4.1. Ön Analizler

Bu araştırma okul öncesi çocukların farklı matematiksel görevlerdeki performanslarının onların mental rotasyon ve mekansal dil becerileri ile ilişkisini araştırmaktadır. Yapılan korelasyon analizi bulgularına göre mekansal dil ile sembolik ($r = 0.36$, $p < .01$) ve nesne sayma becerileri ($r = 0.60$, $p < .001$) arasında anlamlı bir ilişki bulunmuştur. Benzer şekilde, mental rotasyon becerisi ise sembolik ($r = 0.28$, $p < .05$) ve ve nesne sayma becerisi ($r = 0.31$, $p < .05$) ile anlamlı bir şekilde ilişkilidir. Özellikle mekansal dil üretimi hem sembolik ($r = 0.40$, $p < .01$) hem de nesne sayma becerileri ile anlamlı bir şekilde ilişkili bulunurken ($r = 0.56$, $p < .001$) mekansal dil anlama sadece nesne sayma becerileri ile anlamlı bir şekilde ilişkili bulunmuştur ($r = 0.49$, $p < .001$). Ancak ne mental rotasyon ne de mekansal konum bilgisi sembolik olmayan beceriler ile anlamlı bir ilişki göstermiştir (tüm p değerleri $> .05$).

2.4.2. Veri Analiz Planı

Genelleştirilmiş doğrusal karma model analiz yöntemi kullanılarak mental rotasyon ve mekansal dil becerilerinin farklı matematiksel becerileri yordayıp yordamadığı incelenmiştir. Çocukların mental rotasyon ve mekansal dil beceri skorları sabit etki olarak alınmıştır. Ayrıca, her bir denemeden ve katılımcıdan kaynaklanan sapmaların etkisini kontrol edebilmek amacıyla bu etkiler rastgele etki olarak modele eklenmiştir. Yapılan analizlere göre mental rotasyon ve mekansal dil arasındaki etkileşimin olduğu modelin diğer modellere göre analizi daha iyi açıkladığı bulunmuştur.

2.4.3. Temel Analiz

Sonuçlar, sembolik becerilerin hem mekansal dil (β = 0.33, SE = 0.11, p = 0.003) hem de mekansal dil ile mental rotasyon arasındaki etkileşim (β = 0.29, SE = 0.13, p = 0.027) tarafından yordandığını göstermektedir. Böylece mekansal dilin sembolik beceriler üzerindeki etkisinin artan zihinsel rotasyon becerileri ile açıklanabileceği bulunmuştur. Buna ek olarak, sembolik olmayan sayısallık karşılaştırma becerisini mental rotasyon ve/veya mekansal dil becerisi yordamamaktadır. Tüm p değerleri .05 değerinden küçüktür. Son olarak ise nesne sayma becerilerinin sadece mekansal dil tarafından yordandığı bulunmuştur (β = 1.4, SE = 0.32, p <.001). Mekansal dil üzerindeki bir birimlik artış nesne sayma becerisinde 1.4 birimlik artışa neden olmaktadır. Ancak mental rotasyonun nesne sayma becerileri üzerinde anlamlı bir yordayıcılığı gözlemlenmemiştir (β = 0.31, SE = 0.33, p = 0.34). Analizde mekansal dil becerilerinin sembolik ve nesne sayma becerileri üzerinden anlamlı etkisi gözlemlendikten sonra mekansal dil üretimi ve anlamanın etkileri de ayrıca incelenmiştir. Sonuçlar, mekansal dil üretiminin sembolik (β = 0.31, SE = 0.14, p = 0.023) ve nesne sayma becerilerini (β = 1.11, SE = 0.37, p = 0.003) anlamlı bir şekilde

açıkladığını göstermektedir ancak mekansal dil anlamanın bu beceriler üzerinde etkisine rastlanmamıştır.

BÖLÜM 3

TARTIŞMA

Bu çalışma farklı mekansal becerilerin okul öncesi çocukların matematik performansları üzerindeki etkisini araştırmaktadır. Çocukların matematik başarılarını yordayan faktörlerin belirlenebilmesi için bazı şekilleri zihinlerinde döndürmeleri ve bazı lokasyonları anlamaları ya da üretmeleri istenmiştir. Ayrıca çocuklar aritmetik hesaplama, nesne sayma ve büyüklük kıyaslaması gibi aktivitelerde gerçekleştirmiştir. Sonuçlar, mekansal dilin farklı matematik performansları üzerindeki etkisini açıkça göstermektedir. Mekansal dil (özellikle üretme görevi) çocukların sembolik ve nesne sayma performanslarını anlamlı bir şekilde açıklamaktadır.

Bu bulgular literatürdeki bulgular ile de uyumludur. Literatürde mekansal dil becerilerinin çocukların matematik performansları ile ilişkili olduğu belirtilmiştir (Gilligan-Lee vd., 2021; Hawes vd., 2017). Ancak bu görevler matematiksel performans olarak genellikle zihinsel sayı doğrusu görevi kullanmıştır. Bu çalışma, ilk defa mekansal dilin herhangi bir mekansal özellik içermeyen (zihinsel sayı doğrusu gibi) bir görevde de anlamlı bir etkisi olduğunu kanıtlaması bakımından önem arz etmektedir. Buna ek olarak, mekansal düşünmenin sadece zihinsel döndürme, ya da zihinsel görselleştirme gibi becerileri içermediğini aynı zamanda mekansal dil becerilerini içerdiğini de belirtmiştik. Araştırmamizdeki bulgular da mekansal dilin mekansal düşünme ile yakından ilişkili olduğunu destekler niteliktedir.

Önceki çalışmalar sayıların sembolik olmayan temsilleri ile mekansal beceriler arasındaki yakın ilişkiyi vurgulamaktadır (Dehaene vd., 1993; de Hevia & Spelke, 2010). Ancak bu araştırmada bu ilişkiyi kanıtlayan bir veriye rastlanmamıştır. Bu

bulgu çeşitli sebepler ile açıklanabilir. Matejko ve Ansari (2016) gerçekleştirdikleri bir çalışmada çocukların sembolik görevlerde kullanılan stratejileri sembolik olmayan görevlerdeki stratejilere göre daha kolay edinebildiklerini ve daha iyi bir performans ortaya koyabildiklerini belirtmiştir. Ancak bizim çalışmamızda çocukların %28'i sembolik olmayan becerilerde en yüksek skoru almıştır. Bu oran sembolik beceriler için sadece %5'dir. Bu nedenle çalışmamızın bulguları çocukların sembolik görevlerdeki stratejileri daha kolay öğrenebildikleri ile açıklanamamaktadır. Sembolik ve nesne sayma görevleri değerlendirildiğinde çocukların bu görevlerde özellikle bazı mekansal ilişkileri kodlayabilmeleri gerekmektedir. Örneğin, sembolik görevde sorulan soru şu şekildedir: Pamuk'un *kutusunda* iki tane topu vardır. Pamuk 1 tane topu *kutusundan çıkartıyor*. Mavişin *kutusunda* ise 5 tane topu vardır. Sence hangisinin *kutusunda* daha çok topu vardır? Nesne sayma görevinde ise sorulan soru şu şekildedir: *Buradaki* noktaları sayabilir misin ve saydığın kadar noktayı *bu* çubuğa yerleştirebilir misin? Bu görevlerden de anlaşılacağı üzere çocukların görevlerdeki yönergeleri anlayabilmeleri için yer-yön bilgilerini aktif bir şekilde kullanmaları gerekmektedir. Ancak sembolik olmayan karşılaştırma görevinde sadece ekrana bakmaları ve hangi noktanın daha çok/daha az olduğunu belirtmeleri istenmiştir. Bu görevde herhangi bir yer-yön bilgisini kullanmadan da doğru yanıt verebilmeleri beklenmektedir. Bu açıdan değerlendirildiğinde mekansal dilin sembolik olmayan becerilerde herhangi anlamlı bir etkisinin olmaması anlaşılabilir bir durumdur.

Mekansal dil anlama ile kıyaslandığında mekansal dil üretiminin sembolik ve nesne sayma becerilerini yordadığı gözlemlenmiştir. Mekansal dil üretiminin matematik görevlerinde gerekli olan mekansal ilişkileri kodlamaya yönelik sözel bir söylem sağladığı göz önüne alındığında üretmenin önemi ön plana çıkmaktadır. Buna ek olarak Farran ve Atkinson (2016), mekansal dil üretimi ile mekansal

kategorilendirme arasında anlamlı bir ilişki bulmuştur. Bu doğrultuda 4-7 yaş arasındaki çocukların mekansal kategorilendirme becerileri geliştikçe yer-yön üretme konusunda daha iyi performans gösterdikleri kanıtlanmıştır. Ancak yer-yön anlama ile mekansal kategorilendirme arasında anlamlı bir ilişkiye rastlanmamıştır. Bu nedenle yer-yön üretme becerisinin mekansal becerileri daha iyi bir şekilde yansıttığı sonucuna varılabilmektedir. Ayrıca, çalışmamızda 60 çocuktan 37'sinin mekansal dil anlama görevinde en yüksek skoru aldığı göz önünde bulundurulduğunda mekansal dil üretimindeki geniş sapmalarında matematiksel becerileri daha iyi açıklamasına olanak sağlaması öne sürülebilmektedir.

Sonuç olarak, sayı ve mekan arasında oldukça yakın bir ilişki bulunmaktadır. Bu ilişkiyi gösteren teori ve bulgular da mevcuttur (Örn., SNARC etkisi ya da ATOM) (Dehaene vd., 1993; Walsh, 2003). Benzer bir şekilde, çocukların mekansal terim bilgilerine sahip olmalarının ve onları uygun bir şekilde kullanabilmelerinin aritmetik ve sayma aktivitelerinde kendilerine yardımcı olduğu anlaşılmaktadır.

3.1. Sınırlamalar ve Gelecek Çalışma Önerileri

Çalışma mekansal dil ile matematik performansları arasındaki yakın ilişkiye dair kanıtlar sunsa dahi bazı sınırlamalar da içermektedir. Çocukların matematik başarıları sadece mekansal becerileri ile ilişkili değildir. Benzer şekilde içinde yaşadıkları çevresel özellikler (Örn., ebeveynlerin kullandıkları dilin zenginliği, sosyoekonomik statü ve anaokulundaki öğretmenleri ile ilişkileri) onların matematik performanslarını etkileyen faktörlerdendir (Gunderson & Levine, 2011; Shi & Yong Tan, 2021). Bu çalışma herhangi bir çevresel faktörü kontrol etmediğinden dolayı gelecek çalışmaların bu faktörleri de analizlerine dahil etmeleri önem arz etmektedir. Buna ek olarak, çalışma boyunca birçok aktivite yapılmış ve bunların her biri tek bir oturumda gerçekleşmiştir. Çocukların bu aktiviteler esnasında yorgunluk belirtileri

göstermemeleri ve dikkatlerini görevlere vermeleri önemsendiğinden dolayı soru sayısı azaltılmak durumunda kalınmıştır. İlerleyen zamanlarda yapılacak olan çalışmaların soru sayısı ve aktivite sayısı arasında bir denge yaratması ve bu bulguları test etmesi gerekmektedir.

Genel olarak bu çalışma matematiğin bir dil olduğunu belirten iç görüleri (örn., de Smedt & Turan, 2022) destekler niteliktedir. Özellikle niceliksel (az, çok gibi) ve mekansal (yanında, üstünde gibi) kelimelerin günlük hayatta doğru kullanımının matematiksel dilin gelişiminde de rol oynadığını ve çocukların matematik başarılarının sadece tek bir faktöre indirgenemeyeceğini, birçok farklı faktörün birlikte etkileşim içerisinde bu sürece katkı sağladığını vurgulamak gerekmektedir.

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TEZİN ADI / TITLE OF THE THESIS (**İngilizce** / English): Relationship between Spatial and Number Development: Spatial Location Knowledge Strongly Predicts Numerical Skills of Preschoolers than Mental Rotation

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