THE DISTANCE EFFECT ON MAGNITUDE PROCESSING OF FRACTIONS: THE EFFECT OF NON-SYMBOLIC PRIMING

EBRU BEKTÜRK

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EBRU BEKTÜRK

THESIS ADVISOR: ASSOC. PROF. DR. BURAK ERDENİZ

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ETHICAL DECLARATION

I hereby declare that I am the sole author of this thesis and that I have conducted my work in accordance with academic rules and ethical behaviour at every stage from the planning of the thesis to its defence. I confirm that I have cited all ideas, information and findings that are not specific to my study, as required by the code of ethical behaviour, and that all statements not cited are my own.

Name, Surname: Ebru Bektürk

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ABSTRACT

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BEKTÜRK, Ebru

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Advisor: Assoc. Prof. Dr. Burak ERDENİZ

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The distance effect, which is a widely studied effect in numerical processing, suggests that numbers that are numerically farther apart produce faster responses, while closer numbers are associated with longer reaction times. The aim of the present study is to test whether pie charts presented as non-symbolic stimuli can produce a cross-notational priming effect on symbolic fractions within the framework of the distance effect. For this purpose, reaction times obtained in the control condition, in which the symbolic fractions were presented with no prime, were compared with reaction times after priming with the pie chart. In line with this effect, we expected that numerically far fractions were responded faster than close fractions. The results showed that participants responded faster to the primed symbolic fractions compared to the control condition during the magnitude comparison task. In addition, the results showed that fractions that were far from each other in terms of whole magnitude produced faster reaction times, while when the difference between the numerators and denominators of the presented fraction pairs was equal to each other, the reaction times were prolonged. These results indicated that fractions without a common component may be processed with both componential and holistic processing. As a result, the significant priming effect found in this study may indicate that non-symbolic visualization can be an important facilitator for better understanding of fractions.

Keywords: Magnitude comparison, Fractions, Non-symbolic priming, Distance effect, Numerical cognition

ÖZET

KESİRLERİN BÜYÜKLÜKLERİNİN İŞLEMLENMESİNDE UZAKLIK ETKİSİ: SEMBOLİK OLMAYAN HAZIRLAMANIN ETKİSİ

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Sayısal işlemede yaygın olarak çalışılan bir etki olan uzaklık etkisi, sayısal olarak birbirinden uzak olan sayıların daha hızlı tepkiler ürettiğini, yakın olan sayıların ise daha uzun tepki süreleri ile ilişkili olduğunu öne sürmektedir. Bu çalışmanın amacı, sembolik olmayan uyaranlar olarak sunulan pasta grafiklerinin, uzaklık etkisi çerçevesinde sembolik kesirler üzerinde çapraz notasyonel hazırlama etkisi yaratıp yaratmadığını test etmektir. Bu amaçla, sembolik kesirlerin hazırlama etkisi olmadan sunulduğu kontrol koşulundan elde edilen tepki süreleri, pasta grafiği ile hazırlandıktan sonraki tepki süreleri ile karşılaştırılmıştır. Bu etki doğrultusunda, sayısal olarak uzak kesirlere yakın kesirlerden daha hızlı tepki verilmesi beklenmiştir. Sonuçlar, katılımcıların büyüklük karşılaştırma görevi sırasında kontrol koşuluna kıyasla hazırlama etkisi ile sunulan sembolik kesirlere daha hızlı tepki verdiğini gösterdi. Buna ek olarak, sayısal büyüklük açısından birbirinden uzak olan kesirlerin daha hızlı tepki süreleri ürettiğini, sunulan kesir çiftlerinin pay ve paydaları arasındaki

fark birbirine eşit olduğunda ise tepki sürelerinin uzadığını göstermiştir. Bu sonuçlar, ortak bileşeni olmayan kesirlerin hem bileşensel hem de bütünsel işleme ile işlenebileceğini gösterebilir. Sonuç olarak, bu çalışmada bulunan anlamlı hazırlama etkisi, sembolik olmayan görselleştirmenin kesirlerin daha iyi anlaşılması için önemli bir kolaylaştırıcı olabileceğini gösterebilir.

Anahtar Kelimeler: Büyüklük karşılaştırma, Kesirler, Sembolik olmayan hazırlama, Uzaklık etkisi, Sayısal biliş

Dedicated to my beloved family and to all women who have been deprived of the right to get educated

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CHAPTER 1: INTRODUCTION

Numerical cognition is one of the most widely studied areas in experimental psychology, and how numbers are represented and processed in the mind is considered as one of the most important questions. Studies conducted in the field of numerical cognition have shown that although humans and non-human animals share important common features (Feigenson, Dehaene and Spelke, 2004), such as the processing of approximate magnitudes and numerical information, the ability to create symbolic representations of exact quantities of natural numbers is unique to humans (Agrillo, 2015). Considering the majority of studies conducted on humans, it is known that prominent hypothesis and effects -such as mental number line hypothesis, distance and SNARC effect- found are related to single quantities (Galton, 1880; Moyer and Landauer, 1967; Dehaene et al., 1990, 1993). In these studies which included single quantities (such as 1, 2, 3…), a consensus has been reached that there is a relationship between number and space. This relationship was first described by Galton, who suggested that individuals have spatially organized number forms that are oriented from left to right (Galton, 1880). Later studies by Moyer and Landauer (1967) and Restle (1970) demonstrated that individuals have a mental number line (MNL). The MNL hypothesis suggests that individuals have a horizontal line, increasing from left to right, in which numbers are represented internally (Dehaene et al., 1993). Therefore, according to the MNL hypothesis, small numbers are represented on the left and large numbers on the right. The results of these studies provided first evidence for the presence of number space association.

One of the effects that results from the MNL hypothesis is called the symbolic or numerical distance effect (Moyer and Bayer, 1976; Dehaene et al., 1990). The distance effect suggests that numbers that are numerically closer are compared more slowly, while numbers that are numerically further apart are compared more quickly. The effect also shows that numerically close numbers are more prone to error when their magnitudes are compared (Moyer and Landauer, 1967; Restle, 1970). Following on from this evidence, Deheane et al. (1990, 1993) contributed new findings by conducting studies of number space association. In Deheane et al.'s (1993) study, participants were asked to judge the parity of numbers and it was found that the difference in reaction time between the left and right hand was significant. When the results were examined, left-hand responses were faster for relatively small numbers and right-hand responses were faster for relatively large numbers. Based on this study, Deheane et al. (1990, 1993) proposed a new effect that supports this association between numbers and space: The Spatial Numerical Association of Response Codes (SNARC) effect. Therefore, small numbers are associated with the left and large numbers are associated with the right, which drives the SNARC effect (Huber et al., 2016). The findings from these studies confirm that numbers and space have a relationship when considering single quantities.

In this context, while there are many studies on single quantities such as natural numbers or integers (1, 2, 3...), research on proportions is relatively limited. A proportion expresses the relationship between two quantities, and understanding proportions derived from single quantities is more complex than understanding these single quantities alone. The difficulty in understanding proportional information lies in its representation, which can take the form of symbolic (such as fractions and decimals) or non-symbolic notation (such as area models like pie charts or linear models using spatial information). This flexibility of proportional representations increases the complexity of understanding them by allowing them to adapt to the context (Hurst, 2017).

A review of recent research on proportional information through symbolic notation suggests that fractions stand out as significant numerical entities worthy of investigation. There's a growing interest in understanding the cognitive processes involved in processing and learning fractions (Wortha, Obersteiner and Dresler, 2022). Numerical quantities that indicate the relationship between two whole numbers and that is equivalent to a real number is called fraction. The simplest and quickest way to learn fractions is to develop mental representations of the whole numbers of the fractions, i.e. their real values. Access to these mental representations allows people to classify $\frac{1}{2}$ as greater than $\frac{1}{5}$ (Bonato et al., 2007). However, many studies have shown that children in particular have difficulty in learning fractions (Bright et al., 1988; Hartnett and Gelman, 1998; Smith, Solomon and Carey, 2005). In these studies with children, the reason for the difficulty in learning is related to the fact that the components called numerator and denominator within the concept of fractions make it difficult to make inferences about the real values of the fraction (Stafylidou and

Vosniadou, 2004). It is also widely agreed that one of the reasons for this difficulty is the notion that prior knowledge of numbers, known as whole number bias, can interfere with the structuring of the concept of fraction. In other words, particularly in the representation of fractions known as the bipartite format ($\frac{a}{b}$), children may tend to evaluate the numerator and denominator as two whole numbers, but this format represents a coherent unit (Ni and Zhou, 2005). One of the most compelling demonstrations of this bias is observed in the tendency of individuals to engage in biased reasoning when deciding which of two fractions is larger (Wortha, Obersteiner and Dresler, 2022). For example, the fraction $\frac{1}{6}$ may be perceived as greater than $\frac{1}{5}$ because the number 6 is greater than the number 5.

On the other hand, difficulties in understanding fractions have been found not only in studies with children but also in studies with adults (Gigerenzer and Hoffrage, 1999). While the precise mechanisms behind how adults process fractions remain unclear, two different approaches to these mechanisms have been identified: the holistic approach and the componential approach (Bonato et al., 2007; Meert et al., 2009). The holistic approach is defined by the numerical magnitude obtained by dividing the numerators and denominators of fractions, e.g. the numerical magnitude or real value of the fraction $\frac{1}{2}$ is 0.5. Conversely, the componential approach involves evaluating the numerator and denominator of the fractions separately without accessing the actual value of the fraction (Gabriel et al., 2013).

In studies focusing on the mental representation of fractions, the investigation of the distance effect is noteworthy, but the results regarding the processing of fractions are contradictory. In a study investigating the distance effect and the SNARC effect of fractions (Bonato et al., 2007), participants were asked to compare target fractions presented in 4 different experiments with 3 different fixed standard values ($\frac{1}{5}$, 0.2, 1) using a magnitude comparison task. In the experiment where target fractions were compared to $\frac{1}{5}$, the numerator of the targets was 1 and the denominators varied between 1 and 9. The distance effect found in this experiment was between the denominator of the reference fraction and the denominator of the target fraction. This was also found to be valid for the other two reference values (0.2, 1). This means that the participants converted the fixed reference values into fractions ($\frac{1}{5}$, $\frac{5}{5}$) directly to compare the components of the fractions. In addition, when the SNARC effect was investigated, the interaction between hand and magnitude was found to be significant and a situation called reversed SNARC occurred. In other words, an interaction was observed that is the opposite of the classic SNARC effect, participants responded more quickly with the left hand to large fractions, and faster with the right hand for fractions smaller than the reference. These results provided strong evidence that adults can use componential strategies and that participants did not access the magnitude of whole fractions. In addition, Bonato et al. (2007) found in this study that componential strategies in the processing of fractions were compatible with the whole number bias observed in children. They interpreted this finding as being due to the fact that fractions are represented in the mind as discrete rather than continuous quantities.

On the other hand, Meert et al. (2009) showed in their study that people can use both componential and holistic representations when mentally representing fractions. In this study, participants were asked to compare two different fractions presented on the right and left halves of the screen in terms of numerical magnitude. However, this time the fractions presented to the participants were divided into the common denominator ($\frac{3}{5}$ vs. $\frac{4}{5}$) or the common numerator ($\frac{2}{5}$ vs $\frac{2}{7}$). According to the results, a distance effect was found for both fraction comparisons. In the case of common denominators, the distance effect found was between the numerators, whereas in the case of fractions with common numerators, the distance effect found was between the whole magnitudes of the fractions. With this result, numerical magnitude representations of fractions can be evaluated not only componentially but also holistically. That is, the magnitude representation can be described as hybrid.

Another study by Schneider and Siegler (2010), with similar findings, showed that fractions can be processed holistically. In this study, Schneider and Siegler diversified the types of fractions presented to the participants and added the concept of non-unit fractions to the study. In other words, this time participants were presented not only with pairs of fractions with common components, but also with pairs of fractions with different components. For example, participants were asked to compare both pairs of unit fractions (such as $\frac{1}{4}$ and $\frac{1}{6}$), and pairs that do not contain common components (such as $\frac{3}{5}$ and $\frac{1}{4}$), in terms of numerical magnitude. The results showed that the distance effect found in both comparison types was between the whole magnitudes of fractions. This result has been interpreted that participants benefit from holistic representations when comparing the magnitudes of fractions that do not contain common components.

Another similar study (Meert et al., 2010) examined how adults compare the magnitude of fractions that do not contain common components. They proposed a hybrid model of magnitude representation, arguing that the approach to processing fractions differs depending on the type of fraction. They presented participants with two different sets of fractions in four different conditions. Both types of fractions do not contain common components, and the distance effect found was between the whole magnitudes of the fractions for both. However, it was found that pairs of fractions prepared by manipulating the relationship between the numerator and the denominator had an effect on participants' performance. This manipulation showed that the difference between the numerator and denominator, named as the intra-fraction distance, of the fraction pairs presented to the participants also affected performance. For example, the fraction pair presented to participants was $\frac{1}{5}$ vs $\frac{3}{8}$. While the intra-fraction distance value of the fraction $\frac{1}{5}$ is 4 (5-1=4), that of the fraction $\frac{3}{8}$ is 5 (8-3=5). It was concluded that when the presented pairs of fractions' intra-fraction distance were equal, participants' reaction times were prolonged. As the distance between the numerator and denominator increased, the reaction time decreased. This was interpreted as participants being able to process not only holistic but also componential information when comparing the magnitudes of fractions and supported the existence of the hybrid model. Additionally, these studies (Schneider and Siegler, 2010; Meert et al., 2010) in the literature show that accessing holistic or whole magnitudes of fractions is not an automatic response and that holistic values can be achieved in cases where componential strategies do not work in the fractions presented.

On the other hand, since these studies presented tasks requiring intentional numerical processing, Size Congruity Effect (SiCE) provided a different perspective to test whether fractions are processed automatically. To test this effect, Henik and Tzelgov (1982) varied the physical and numerical size of integers from 1 to 9 and asked participants to choose the physically larger or smaller number, ignoring the numerical magnitude of the numbers. For example, when the numbers 4 and 6 were presented together, the condition in which the number 4 was physically larger was called incongruent, whereas the condition in which the number 6 was physically larger was called congruent. According to the results, since the reaction time in the congruent condition was faster than in the incongruent condition, it was found that the numerical magnitude of integers was processed unintentionally. Moreover, in a study (Kallai and Tzelgov, 2009) testing whether SiCE exists in the fraction context, participants were presented with fraction pairs and fraction-natural number pairs. SiCE was found in the part of the study where unit fractions ($\frac{1}{x}$) were compared; however, it was observed that this effect occurred between the numbers in the denominator, not between fractions' whole magnitudes. Since the fraction's whole magnitude decreases as the denominator increases in unit fractions, the SiCE found was reversed, similar to reversed SNARC effect (Bonato et. al, 2007). This provided evidence for the presence of componential processing. In addition, when fraction and natural numbers were compared, a SiCE was found that increased with the magnitude of the natural numbers, but was not affected by the fraction's whole magnitude. This was interpreted as the fraction having a primitive representation that exists as "smaller than one", because comparing unit fractions to 1 elicited faster reaction times than comparing them to 0 (Kallai and Tzelgov, 2009). Since it is argued that this primitive representation was derived from the general structure of fractions (a ratio of two natural numbers), this entity was called as "generalized fraction" (Tzelgov et al., 2015). In addition to the SiCE found between natural numbers and unit fractions, according to a study (Ganor-Stern, 2012) that compared unit fractions to positive numbers and negative numbers, a distance effect was found when comparing positive numbers and unit fractions. As a result of this study, it was interpreted that generalized fractions were represented on the MNL with positive numbers.

In line with the study by Kallai and Tzelgov (2009), they carried out a similar study in the period that followed. In this study (Kallai and Tzelgov, 2012), participants were given a training procedure to map unit fractions with unfamiliar figures. The stimuli presented throughout the study were based on magnitude comparisons between fractions and unfamiliar figures. When the results were analyzed, it was observed that the distance effect was not between components but between holistic values, which was interpreted as the numerical magnitudes of the fractions assigned to the figures. This raises the possibility that the numerical values assigned to the figures may come from participants' background knowledge and that at least unit fractions may be represented in long-term memory (LTM) as unique units prior to the training procedure (Tzelgov et al., 2015). The fact that a fraction has a primitive representation in the LTM means that its meaning can be retrieved from the LTM without the need for intentional processing. Since it is claimed that unit fractions are represented in the MNL in a similar way to natural numbers, these findings raise the question of whether non-unit fractions also have a representation in long-term memory.

Besides these studies, there are several studies investigating which part of the brain is involved in how numbers are processed (Nieder, 2005; Piazza et al., 2007; Pinel et al., 2001; Deheane et al., 2003). According to these studies, the intraparietal sulcus (IPS) plays an important role in the processing of numerical magnitude. Results from Arsalidou and Taylor (2011)'s study shows that the distance effect, which occurs in magnitude comparison tasks where natural numbers are compared, is negatively associated with activation in the IPS. In line with this information, Ischebek et al. (2009) and Jacob and Nieder (2009) found that in adult fMRI studies, whole magnitude fractions elicited activation in the IPS. This has been interpreted as adults may have a similar representation of the magnitude of whole fractions and of whole or natural numbers. This has strengthened the idea that fractions can exist in the mind with the magnitude of the whole rather than the numerical magnitude of the numerator and denominator.

1.1 Non-symbolic Representations of Proportional Information

The study of proportions in non-symbolic representations is considered important alongside the study of proportions represented in symbolic forms. Some studies (Denison and Xu, 2010; McCrink and Wynn, 2007) have shown that infants are able to perceive non-symbolic proportions. This ability to compare non-symbolic objects with each other and convey them without the learning of number words has been attributed to the Approximate Number System (ANS; Halberda et al., 2008). The Integrated Theory of Numerical Development proposes that the Approximate Number System (ANS) initiates numerical understanding by extending the basic knowledge of numbers acquired in infancy and thus shapes numerical cognition from early childhood to adulthood. According to this theory, MNL is organized from non-symbolic numbers and progresses to small, positive, symbolic integers. This progression continues to larger integers on the right side and negative integers on the left side of the mental representation. Subsequently, the MNL expands to include symbolic fractions and decimals in between these established markers (Siegler and Lortie-Forgues, 2014). When this theory is considered from a broad perspective, individuals can first make more precise inferences about the non-symbolic magnitudes. They then develop representations of integers by combining these non-symbolic numerical magnitudes with their symbolic representations, gradually expanding the space between these distinct markers. Finally, by integrating fractions, decimals and negative numbers into these spaces, they eventually achieve the ability to represent numerical magnitudes.

Given that each individual has a non-symbolic representation prior to the symbolic representation of numerical quantities, how non-symbolic proportions are also represented can be considered an important question. Visual representations of proportional information can take various forms, including pie charts or number lines. These models are effective in visually illustrating proportional relationships. Moreover, according to some studies (Cramer et al., 1997; Cramer et al., 2002), area models such as pie charts are effective tools for illustrating the part-whole relationship. The part-whole relationship is based on the comparison of the shaded part with the whole unit (Cramer and Wyberg, 2009). The bipartite format ($\frac{a}{b}$) of fraction notation has also been found to be better at conveying discrete part-whole information (DeWolf et al., 2014, 2015; Rapp et al., 2015). Interpreting these findings, it is suggested that the mental representations of proportional information, such as fraction in bipartite format, and area models such as pie charts, may be similar.

Pie charts can also be presented in different ways. They can be continuous or discrete. Continuous pie charts allow you to compare the numerator and denominator across the entire area. On the other hand, discrete pie chart representations allow access to the numerical magnitude of the numerator and denominator (Hurst, 2017). For example, a continuous pie chart with two different colored areas, e.g. green and yellow, can be approximated by comparing the relative amount of the green area with the relative amount of the yellow area. Nevertheless, it is very difficult to make a precise inference about the symbolic equivalence of the numerator and denominator of this pie chart. On the other hand, if the pie chart is presented in a discrete representation, it is possible to make certain inferences about the symbolic numbers of the numerator and denominator of the pie chart. In accordance with this information, studies with children (Boyer et al., 2008; Jeong et al., 2007) found that children performed worse on pie charts presented with the discrete area model when asked to compare the relative amounts of two proportions. The reason for this is that the numerical information provided by discrete pie charts causes numerical interference (Boyer et al., 2008). The mechanisms responsible for this numerical interference still remain a mystery, and it is an important question why adults and children prefer to process numerical information when evaluating proportional magnitude. However, since number knowledge and whole numbers learned at an early age are seen as the cornerstone of mathematics learning, the tendency to focus on numerical features instead of proportional information during proportional magnitude evaluation may be increased (Hurst, 2017).

There is another way of looking at non-symbolic proportions, which can be divided into continuous and discrete proportions. According to one study (Jeong et al., 2007), 4-year-old children can successfully evaluate continuous non-symbolic proportions, whereas even 10-year-old children have difficulty in evaluating discrete non-symbolic proportions. However, the difference in this study was that the discrete representation was divided into two different conditions. The first condition was called discrete adjacent, and all hatched parts were shown side by side. In the second condition, the hatched parts were placed in different parts of the whole and was called the discrete mixed condition. It has been argued that this may cause perceptual difficulties in children and may lead to difficulties in strategies such as counting. In this context, we wonder whether adults, like children, would have difficulty in processing numerator and denominator information in discrete mixed pie charts, and whether the numerical information processed in the magnitude comparison task would differ significantly from symbolic fractions containing the same information.

Moreover, the neural correlations created by symbolic and non-symbolic representations in the brain, and the regions they activate, can provide important clues about the similarities and differences between these representations. According to studies (Piazza et al., 2004; Venkatraman et al., 2005; Ansari et al., 2005), the processing of overall magnitude—both in symbolic fractions and non-symbolic proportions—elicits similar neural activity within the intraparietal sulcus. However, more recent studies have shown that symbolic and non-symbolic numerical magnitudes are processed by both similar and distinct neural systems (Piazza et al., 2007; Sokolowski et al., 2017). In particular, non-symbolic magnitudes have been found to activate the visual cortex more than symbolic magnitudes because they require more visual demands (Holloway et al., 2010). There are also some studies that have used the distance effect to understand whether there is a difference between non-symbolic and symbolic magnitudes (Mock et al., 2018, 2019). In line with the results of other studies, fMRI results of Mock et al. (2018) showed activation in the intraparietal sulcus regardless of whether the numerical magnitude is symbolic or non-symbolic, and it was concluded that different brain regions were also active depending on the presentation format. In addition, Mock et al. (2019) investigated whether there is a common brain region or neural correlate other than the IPS in the processing of proportional magnitude, and also how part-whole relations are processed. In the study, which tested four different presentation formats consisting of fractions, decimals, pie charts and dot patterns, it was shown that fractions, pie charts and dot patterns share common neural correlates that represent the bipartite part-whole relationship, while decimals differ from them. The interpretation of these results is that fractions, pie charts and dot patterns produce similar neural correlations and can lead to results that support each other.

It is curious how the magnitude information obtained from both non-symbolic and symbolic representations of proportions is integrated and processed together. According to a study (Gabriel et al., 2012), pairing symbolic and non-symbolic representations side by side is a strategy used to activate proportional relationships, which is particularly useful in the learning process of understanding the concept of fractions. In addition, neural studies have shown that the processing of symbolic and non-symbolic representations overlaps in similar regions of the brain. FMRI studies have also supported this finding by showing that habituation to either symbolic or non-symbolic representations leads to habituation in the processing of the other form (Piazza et al., 2007). In this context, the presentation of non-symbolic proportions alongside their corresponding symbolic fractions is likely to improve judgments of the magnitude of symbolic fractions. This simultaneous presentation aids in reinforcing the understanding and evaluation of the relative magnitudes represented by symbolic fractions. For example, one study has found that spatial representations of proportions such as pie charts are widely used in teaching fractions in the United States (Hurst, Relander and Cordes, 2016). Similarly, in a study involving the Turkish population, it was discovered that among area, set, and linear models used in mathematics courses, teachers most frequently used models with pie charts to illustrate fractions (Doğan, 2018). Taken together, these findings suggest that adults learn fractions by associating them with pie charts in primary school and that non-symbolic representations of fractions may exist in long-term memory. These findings raise the possibility that non-symbolic versions of fractions may contribute to long-term memory traces.

1.2 Priming Paradigm in Number Processing

One of the paradigms used in the field of numerical cognition to test how numbers are represented in humans is the priming paradigm. This paradigm consists of presenting the first stimulus, called as the prime stimulus, and the second stimulus, called the target or probe, in short successive intervals and analyzing the response time of the probe stimulus as a function of the prime stimulus (Reynvoet, Smedt, and Van den Bussche, 2009). In Koechlin et al.'s study (1999), participants first compared the numbers presented as both prime and probe stimuli with the number 5. In the second experiment, the prime stimulus was presented for a very short time (66 ms) and then the probe stimulus had to be compared to 5 again. The numbers presented as prime and probe were given in Arabic digits, verbal notation or random dot patterns. An effect called priming distance effect was found between prime and probe presented in the same notations (Reynvoet, Brysbaert, and Fias, 2002) This effect claims that when the numbers presented as prime and probe are close (e.g., prime:3, probe:4), reaction time decreases during the task, and when they are numerically far (e.g., prime:1, probe:8), reaction time increases. However, this effect did not occur when prime and probe were presented in different notations. This has led to the idea that there may be notation-specific subsystems.

However, there are studies that provide evidence against this study. According to a study (Roggeman, Verguts and Fias, 2007), it was found that different notations can perform semantic facilitation during the naming task in which both digits and dot patterns were presented to the participants as prime and probe. In the priming condition with digits, a place coding was found, which was called a V-shaped function, whereas in the priming condition with dot patterns, a summation coding was found representing a step-like function. During summation coding, all smaller numbers are activated to reach the larger number of non-symbolically presented dot patterns, whereas during place coding, each number activates only the neurons of the two closest numbers (Verguts and Fias, 2008). The priming study mentioned above confirmed the study of Verguts and Fias (2004) and showed that symbolic and non-symbolic numerosities are represented in the same cognitive system, but their coding types are different.

In another similar study (Herrera and Macizo, 2008), the effect of cross-notational semantic priming was investigated. In the first experiment of this study, Arabic digits and canonical dot patterns were presented as both prime and probe, and both stimulus types were asked to be compared to 5 in magnitude comparison task. While a semantic priming effect was observed in conditions where the primes and probes were presented in the same notation, this effect was not observed in different notations. In the second experiment, random dot patterns were used instead of canonical dot patterns as non-symbolic stimuli. According to the results of this experiment, a cross-notational priming effect was observed in the condition where digits were primed with random dots. However, digits did not produce a priming effect for dot patterns. This is an important finding that non-symbolic numerical knowledge can produce a priming effect on symbolic numerical knowledge.

In addition to natural numbers, this paradigm includes various studies with fractions, particularly in the context of negative priming (Meert et al., 2009; Rossi et al., 2019). Meert et al. (2009) used the priming paradigm to test whether the numerator and denominator were also processed when the whole numbers of the fractions were accessed. In this study, when natural numbers were primed with fractions, if the pair of fractions presented as the prime stimulus consisted of a common numerator and the numbers in the denominator were then presented as probes (e.g., prime comparison: $\frac{2}{5}$ vs. $\frac{2}{7}$ and probe comparison: 5 vs. 7), the participants' responses slowed down and error rates increased. On the other hand, if the fraction pairs presented were different from the numbers in the natural number comparison (e.g., prime comparison: $\frac{11}{16}$ vs. $\frac{11}{13}$ and probe comparison: 5 vs. 7), participants' response time was shortened. It was concluded that participant’s reaction times were affected during the selection of the larger natural number if it consisted of the same numbers with the fraction's components, which was named as negative priming effect.

Also another study (Rossi et al., 2019) investigated whether the inhibitory control abilities of children and adults play a role when comparing different fraction pairs consisting of a common numerator and denominator. In the control condition of the study, as a prime stimulus, pairs of fractions with common numerators were presented to participants and they were asked to choose the fraction whose denominator was greater than the numerator. As a probe stimulus, pairs of common denominators were presented and participants were expected to choose which of the fractions was larger. In the experimental condition, a pair of common numerators was again presented as the prime stimulus, but this time the task was to select which of the fractions was larger. The probe task was identical. Participants responded slower in the experimental condition than in the control condition. The reason for this situation was interpreted as participants having more difficulty while inhibiting the task in the test condition. Because the task which was presented as prime caused a negative priming effect by selecting the larger fraction that did not consist of a larger number (such as $\frac{2}{5}$ is larger than $\frac{2}{7}$, but whole number bias can lead to misinterpretation because 7 is larger than 5). This misinterpretation stemmed from whole number bias.

In addition to the priming studies with symbolic fraction pairs, another research question was whether the cross-notational priming effect found for natural numbers also exists for symbolic (fractions) and non-symbolic (pie charts, number lines) proportions. Cross-notational priming involves presenting the prime and probe stimuli in different notations (such as symbolic and non-symbolic) and if these different notations share the same semantic code, semantic facilitation is expected (Herrera and Macizo, 2008). In this context, a study of symbolic and non-symbolic proportions was conducted by Hurst, Relander and Cordes (2016). According to the results, adults were more accurate at mapping between fractions and pie charts in bipartite format than between fractions and number lines. This finding is consistent with DeWolf et al. (2014) and Rapp et al. (2015). In addition, a study (Hurst et al., 2020) that tested children and adults together investigated whether it was beneficial to think about rational numbers using a number line or a pie chart. In the first experiment with adults, it was a matter of curiosity how symbolic fractions were visualized. According to the results, adults rarely visualize fractions along a number line. In the other two experiments of this study, after children were primed with a pie chart or number line, they were asked to compare symbolic fractions in a magnitude comparison task. These subsequent experiments showed that mapping rational numbers with a number line does not provide an improvement effect compared to mapping them with a pie chart. The interpretation of these results raises the question of whether using a pie chart as a prime stimulus in an experiment with adults in a priming paradigm would improve magnitude comparison performance in the symbolic fractions presented afterwards.

1.3 The Present Study

Although there are a number of studies with a broad perspective on children, studies on adults' processing of fractions are quite limited when the studies on fractions are examined in the literature. Therefore, this study aims to provide important clues about how adults process and represent fractions in their minds.

In this study, we aimed to investigate a) whether symbolic fractions would elicit faster reaction times when those were primed with pie charts (presented as non-symbolic proportions) than in the control condition in which there were no priming b) whether symbolic fractions and pie charts would produce faster reaction times when pairs were presented in accordance with the mental number line hypothesis, as seen in natural numbers (Moyer and Landauer, 1967; Dehaene et al., 1990) c) whether symbolic fractions and pie charts that do not consist of common components would show distance effect d) whether the numerical distance between the numerator and denominator, which is also known as intra-fraction distance effect, of both symbolic fractions and pie charts would have an effect on participant’s reaction time in magnitude comparison task e) whether the stimuli presented as both symbolic fractions and pie charts made a difference on participants’ reaction times in terms of stimulus type.

In this context, two different conditions and stimulus types were created. For the symbolic notation, fractions without a common component were used, while for the non-symbolic notation, pie charts that were prepared as a discrete mixed representation were used. In the control condition, only symbolic fractions were presented as compatible and incompatible with MNL and a magnitude comparison task was applied. In the experimental condition, the non-symbolic counterparts of the symbolic fractions presented in the control condition were presented as prime stimuli and a magnitude comparison task was performed for both stimulus types. Given the expected priming effect of the non-symbolic proportions, it was expected that reaction times to the symbolic fractions would be significantly faster in the experimental condition than in the control condition. In addition, both stimulus types were manipulated as compatible and incompatible with MNL, and as a result of this manipulation, it was expected that the pairs compatible with MNL would be responded faster. Moreover, again in line with the literature (Bonato et al., 2007; Mock et al., 2019), within the scope of the numerical distance effect for both stimulus types, numerically far proportions were expected to be responded faster than close ones. Additionally, the intra-fraction distance effect was expected to occur in both symbolic and non-symbolic stimulus types, and when the difference between the numerator and denominator of the two presented fractions was the same, it was expected to cause a slower response than the pairs in which the difference was different. In addition to the main effects, we expected an interaction between the distance and intra-fraction distance effects, due to the componential and holistic processing mentioned in the hybrid model (Meert et al., 2010). Thus, when the intra-fraction distance of fractions were equal in close-distance fraction pairs, reaction times were likely to be much longer. Another interaction effect can be expected between MNL compatibility and intra-fraction distance. When symbolic fraction pairs were presented as compatible and the difference between numerators and denominators was different, participants were expected to produce faster responses.

Finally, whether stimulus type would make a difference in the magnitude comparison task was also investigated. According to Mock et al.'s (2018) study, the reaction times obtained from pie charts in the magnitude comparison task were shorter than those obtained from symbolic fractions. However, they used continuous pie chart representation as non-symbolic proportions. The current study aimed to investigate whether this finding was valid in case of discrete mixed representation of pie charts as non-symbolic proportions. To test this, reaction times obtained from pie charts in discrete mixed representation and reaction times obtained from symbolic fractions were compared.

CHAPTER 2: METHOD

2.1. Participants

All participants included in this study were undergraduate or graduate students at Izmir University of Economics, and a total of 52 participants participated voluntarily. During the experiment one participant wanted to withdraw from the study and the data of this participant could not be included, so all analyses were conducted with fifty-one participants. Of these 51 participants', 41 females and 10 males, mean age was 20.9 (*SD*= 2.27) and the range of age was 18-32.

To determine the sample size required for this study, a power analysis was performed using the pwr package in R programming (Champely et al, 2020). According to the analysis, this experiment required 39 participants with a power > .80 and a medium effect size.

Before conducting this experiment, three different exclusion criteria were identified. Having dyslexia, dyscalculia or spatial neglect were the exclusion criteria determined before the experiment was conducted, and according to the completed participant forms, none of the participants violated these criteria.

2.2. Participant Forms, Stimuli and Apparatus

2.2.1. Participant Consent Form, Participant Information Form and Edinburgh's Handedness Inventory

Participants completed the Participant Consent Form (Appendix A), which informed them of the purpose of the study and their rights. This consent form included information such as that participants could ask the researcher questions about the study or withdraw from the study if they wished. Participants were also informed that the data collected would only be used for this study and that their personal information would remain anonymous. On the other hand, the Participant Information Form (Appendix B) was prepared to obtain information about the participants' current disorders and their neurological and psychological states in their past lives. Participants were asked whether they had a neurological or psychological diagnosis, whether they were currently taking medication or had taken medication in the past, whether they had a history of head trauma, and whether they had a history of visual impairment. Participants were also screened for dyslexia, dyscalculia and specific neglect. If they had these diagnoses, they were excluded from the study. Finally, the Edinburgh Handedness Inventory (Appendix C) was used to learn about the participant's hand preferences for actions such as writing, throwing, using scissors, brushing teeth, using a knife and spoon, lighting a match, and using a mouse. Each item was rated on a 5-point Likert scale from “always right” to “always left”. Scores on this scale were obtained by subtracting the “always right” responses from the “always left” responses, then dividing by the total number of responses and multiplying by 100. If the score obtained was negative, the individual's hand preference was "left"; if it was positive, the individual's hand preference was "right" (Oldfield, 1971).

2.2.2. Stimuli

Two types of stimuli were used in this study: symbolic fractions and pie charts. The symbolic fractions presented in this study consisted of single-digit numbers (1-8). They were presented in Arial font, size 48, and in pairs (Figure 1). These pairs were presented in the middle of the right and left halves of the screen, and all fraction pairs were presented in black ink on a white background. The components of the fractions were presented with one component on top of the other and separated by a fraction bar. The height of each fraction was set at 3.5 cm and the width at 2.5 cm. The numbers in the numerator and denominator were positioned 0.5 cm above and below the fraction bar. The distance between the two fractions was set to 15 cm.

To ensure that the numerical magnitudes of the fractions were less than 1, the denominator was chosen to be greater than the numerator in all pairs of fractions used in the study. All pairs of fractions were presented in a way that could not be simplified in order to avoid the application of strategies in the participants' evaluation of the fractions, i.e. the denominator was never a multiple of the numerator. The symbolic fraction pairs presented were taken from Meert et al. (2010) and were limited to 30 fraction pairs. The distances between the numerical magnitudes of the presented fraction pairs range from 0.05 to 0.42. When these 30 pairs of fractions were examined in terms of numerical magnitudes, a cut-off point of 0.19 was determined, and 16 pairs of fractions constituted the close-distance pairs, while 14 of them constituted the far-distance pairs in terms of the numerical distance effect (NDE) (closeness of the fraction compared to the other fraction of the pair). These pairs of fractions were categorized as: (1) close distance (0.05 - 0.18), (2) far distance (0.19 - 0.42). On the other hand, the intra-fractional component distances, i.e., the numerical distance between the numerator and denominator of a fraction, of 15 of these fraction pairs are the same, the other 15 are different. These fraction pairs were also categorized as: (1) positive-same distance (the distance of the numerator and denominator of the fraction is equal to the other fraction), (2) negative-different distance (the distance of the numerator and denominator of the fraction is not equal to the other fraction).

The other type of stimulus used in the study was the pair of pie charts. These stimuli, presented as non-symbolic proportions, were arranged as the non-symbolic equivalent of the symbolic fraction pairs used. The numerator parts were presented with a black fill color, and the remaining white parts and the sum of the numerator parts filled with black represented the denominator (Figure 1). The black parts representing the numerator were randomly positioned. As the discrete mixed representation can lead to a counting strategy, random positioning was used (Jeong et al., 2007). With this representation, it was intended to allow participants to understand that the symbolic fractions and pie charts were numerically conjugate, even though no information was given to them to provide priming effect with the pie charts. Pie charts, like symbolic fractions, were positioned in the middle of the right and left halves of the screen, with a radius of 3.4 cm (Hurst, Relander and Cordes, 2016). The distance between the centers of the pie charts was 18 cm.

2.2.3. Task

In the present study, a magnitude comparison task was used. Participants were asked to evaluate the magnitude of both symbolic fractions and pie charts. Participants were asked to press the button for the numerically larger fraction presented as pairs from the center of the right and left halves of the screen. For example, if the fractions $\frac{1}{2}$ and $\frac{2}{3}$ appear on the left and right of the screen respectively, the right key (“i”) on the keyboard should be pressed. If the same pair of fractions appeared in reverse, it was expected from the participants to press the left key (which is "a").

2.2.4. Apparatus and Material

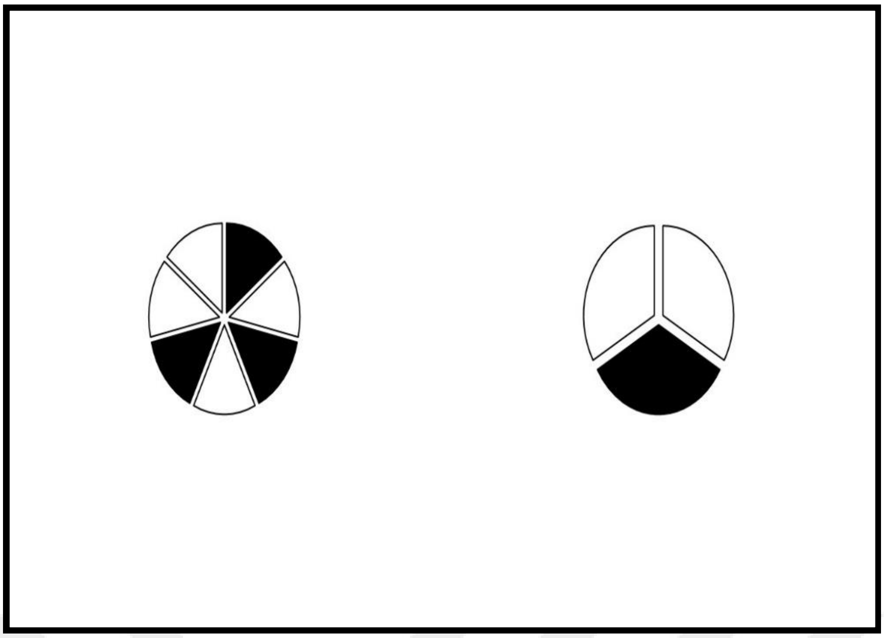
All stimuli were presented on a desktop computer (TECHNO PC 750GB HDD/ 4GB RAM/ AMD FX-6100 3.3Ghz/ 1GB VGA) with a 19" LCD monitor, 1600 x 900 resolution, 60 Hz refresh rate, and white background using the experimental program Superlab 4.0 (Cedrus Corporation, San Pedro, California). Participants were also provided with a Turkish QWERTY keyboard to respond by pressing the “a” and “i” keys.

2.2.5. Stimulus Presentation Program

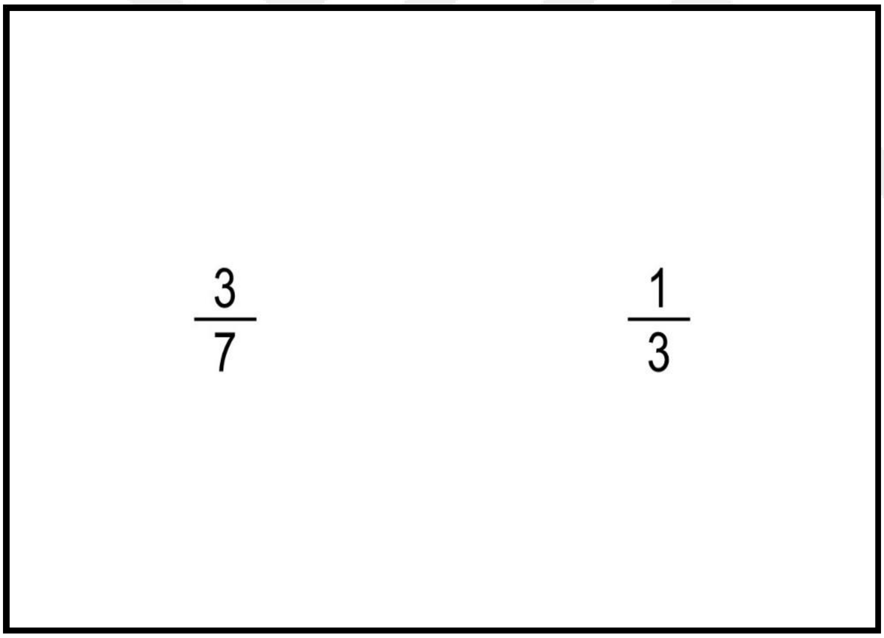
In this study, a magnitude comparison task was used for control and experimental conditions. The control condition included 2 different trials, which were referred to as compatible and incompatible. The compatible trial, which included two different fractions, was formed by placing the larger fraction on the right side of the screen. If the larger fraction was presented on the left side of the screen, the trial was called an incompatible trial. These trials were randomly presented to the participants. On the other hand, the experimental condition consisted of 4 different trials that could be classified as compatible prime- compatible fraction pairs, compatible prime-incompatible fraction pairs, incompatible prime-compatible fraction pairs, and incompatible prime-incompatible fraction pairs. These trials were randomly presented to the participants. All participants completed both conditions.

In the control condition, participants were asked to evaluate the magnitude of symbolic fractions. If the stimulus was a compatible fraction pair, participants were asked to press the “i” key because the larger fraction was on the right side of the screen. If the stimulus was presented as an incompatible fraction pair, participants were asked to press the “a” key because the larger fraction was on the left side of the screen. This condition, which consisted of two trials, contained a total of 60 fraction pairs.

In the experimental condition, participants were asked to judge the magnitude of both symbolic fractions and pie charts. First, participants were asked to evaluate the numerical magnitude of a pair of pie charts. Participants were then presented with a pair of symbolic fractions corresponding to the pie chart to perform the magnitude comparison task again (Figure 1). These presentations were classified in terms of stimulus compatibility. If the pie chart and symbolic fraction pair were compatible with the MNL, the larger pie chart and fraction took place on the right side of the screen; this trial was referred to as a compatible prime-compatible fraction pair. The other trial, formed by placing the larger prime stimulus on the left side of the screen and the larger symbolic fraction on the right side of the screen, was called incompatible prime-compatible fraction pairs. On the other hand, when the larger pie chart and the symbolic fraction were presented on the left side of the screen, this constituted an incompatible prime-incompatible fraction pairs trial. Finally, when the larger pie chart was presented on the left side of the screen, but the larger symbolic fraction was presented in reverse, this trial was identified as a compatible prime-incompatible fraction pairs trial. As in the control condition, both of these stimulus types were to be responded to with the "i" key when the larger part of the pair was presented on the right side of the screen and with the “a” key when the larger part of the stimuli was presented on the left side of the screen.



a) An example of pie chart pair



b) An example of symbolic fraction pair

Figure 1. The examples of presented stimuli. The “a” and “b” were designed to be numerically conjugate. The position of the pie chart and symbolic fraction can be changed based on the mental number line hypothesis.

2.3. Procedure

At the beginning of the study, each participant was invited into the experimental room. They were seated in a comfortable chair and asked to turn off their mobile phones and put away their belongings so as not to distract them. After making sure that the participant was comfortable, the Participant Consent Form (see Appendix A), Participant Information Form (see Appendix B), and Edinburgh's Handedness Inventory (see Appendix C) were given to the participant to read and complete carefully. Once the participant had completed all the forms, these were reviewed to determine whether or not the participant was suitable for this study. The participant who met the eligibility criteria was verbally informed about the study.

After receiving the participant’s verbal confirmation that those were ready for the study, the first SuperLab experimental programme was initiated. First, the practice trial of the control condition was started so that the participant would understand the requirements of the main experiment of the control condition. Once the programme was started, participants were presented with the instructions for the control condition on the screen. Participants were asked to read these instructions carefully and then to compare the magnitudes of the symbolic fractions to be presented, which were given in the middle of the right and left halves of the screen. Participants were first presented with a fixation cross (+) in the center of the screen for 500 ms. Symbolic fractions were then presented in the right and left halves of the screen. The pair of fractions remained on the screen for 5000 milliseconds (ms) or until the participant responded. Participants had to press the "a" or "i" key to respond. Participants were expected to press “i” with their right index finger when the right fraction was larger and “a” with their left index finger when the left fraction was larger. The interstimulus interval (ISI) was 2000 ms. The practice trial consisted of 10 trials in which 5 right and 5 left keys had to be pressed.

After the practice trial was completed, the main experiment of the control condition was started by following the same procedure and then the researcher left the experimental chamber. In this part, participants were shown the same pair of fractions 2 times and were expected to see a total of 60 stimuli. These 60 stimuli were presented pseudo-randomly to the participants and they were expected to press the right and left keys 30 times for the stimuli. After the participant had completed the control condition of the experiment, the researcher entered the experimental chamber.

One step later, the practice trial of the experimental condition was initiated, and participants were allowed to read the instructions presented on the screen. Once the participant had finished reading the instructions, the researcher informed them about the experimental condition verbally. Firstly, the pie charts were presented as compatible and incompatible as prime stimuli. Participants were asked to judge which of the two pie charts presented in the middle of the right and left halves of the screen was numerically larger. If the pie chart on the right was numerically larger than the one on the left, they were asked to press the “i” key, whereas if the left was larger than the right, they were asked to press the “a” key. They were then asked to respond to the symbolic version of the same fractions. While the numerically large fraction in the pie chart is on the right, its equivalent symbolic fraction can be on the right or left. Therefore, participants evaluated both pie charts and symbolic fractions.

In this step, participants were first presented with a 500 ms fixation cross followed by pie charts as a prime stimulus which was presented on the screen for either 5000 ms or until the participant responded. This was followed by a 500 ms blank screen followed by a 500 ms fixation cross. Participants were then presented with the symbolic equivalents of the fractions on the pie chart. The stimulus disappeared from the screen after the participant responded or remained on the screen for a maximum of 5000 ms. Participants were also asked to compare the numerical magnitudes of the symbolic fractions presented on the right and left halves of the screen. If the fraction on the right was large, the “i” key had to be pressed; if the fraction on the left was large, the “a” key had to be pressed. Following the participant's response or the disappearance of the stimuli from the screen, 2000 ms was presented as the ISI (inter-stimulus interval).

In the practice trial, 16 non-symbolic and 16 symbolic pairs of fractions were evaluated. 8 of the 16 pie charts had to be responded with "a" and 8 of them with "i". Similarly, 8 of the 16 symbolic fractions had to be responded with “a” and 8 were with “i”. After the participant successfully completed the practice trial, the main trial was opened, the instruction was repeated both verbally and visually, and the researcher left the experimental room. Notably, the trial numbers of the control and experimental conditions are different from each other. Since we used the same fraction pairs in both conditions, we wanted to minimize the occurrence of the practice effect. In the experimental condition, participants were presented with a total of 120 pie charts and 120 pairs of symbolic fractions. For both pie charts and symbolic fractions, participants were instructed to press the “i” key 60 times and the “a” key 60 times, taking into account MNL compatibility. A total of 240 responses were expected to be obtained. At the end of the experiment, the researcher entered the experimental room and finalized the experiment.

a) Compatible trial

b) Incompatible trial

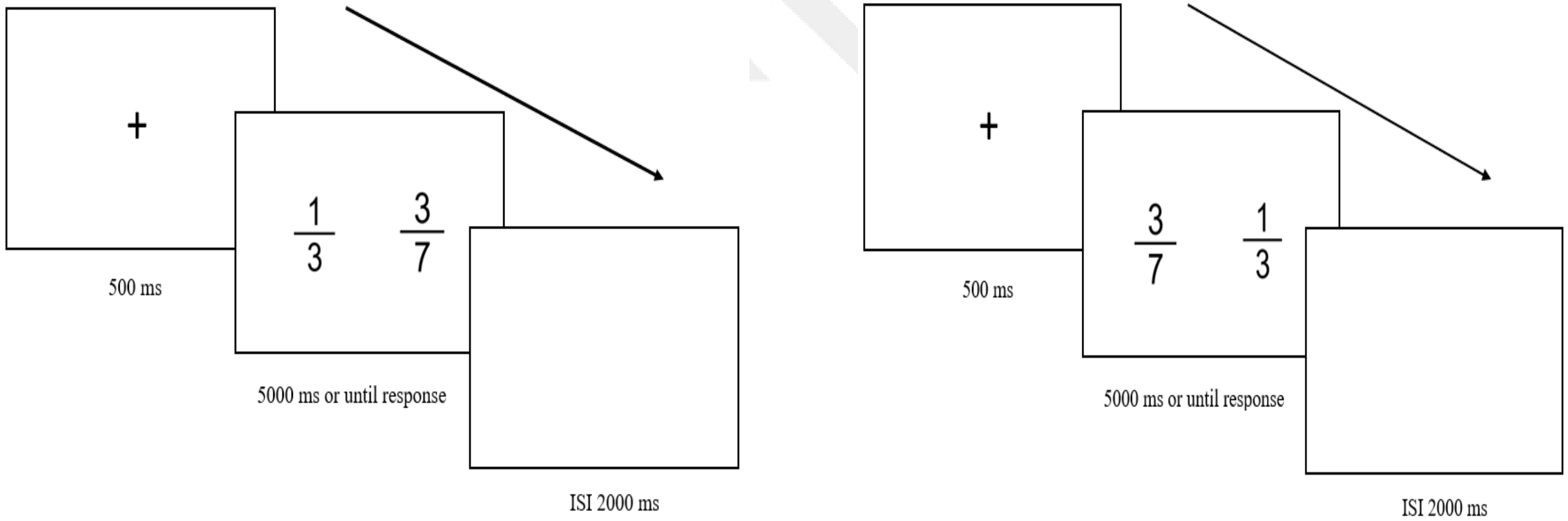


Figure 2. Control condition including compatible and incompatible trials. a) Compatible trials in the control condition: symbolic fractions presented in the middle of the left and right halves of the screen were expected to be responded with the "i" response key. b) Incompatible trials in the control condition: symbolic fractions presented in the middle of the left and right halves of the screen were expected to be responded with the "a" response key.

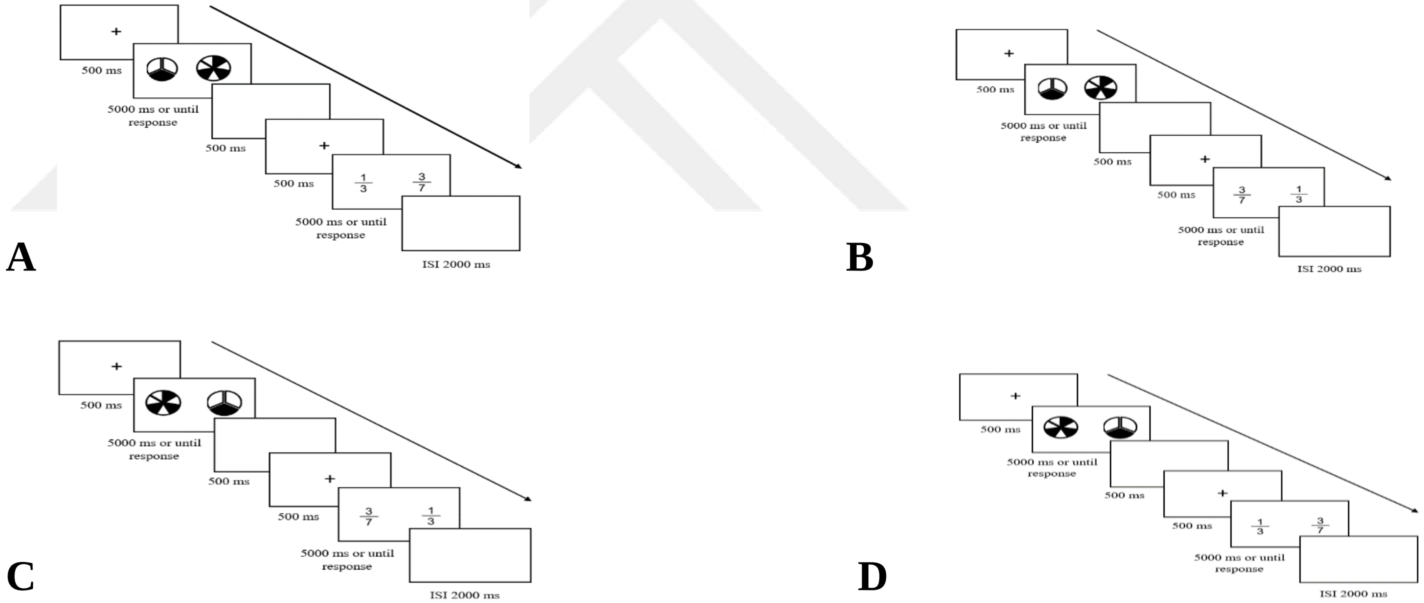


Figure 3. Experimental condition including 4 different trials. A) Compatible prime-compatible fraction pairs: The “i” key was expected to be pressed for both the pie chart and symbolic fraction presented in the center of the right and left halves of the screen. B) Compatible prime - incompatible fraction pairs: In this trial, the “i” key was expected to be pressed in the numerical magnitude evaluation of the pie chart pair, while the “a” key was expected to be pressed in the symbolic fraction pair. C) Incompatible prime-incompatible fraction pairs: The “a” key was expected to be pressed for both the pie chart and symbolic fraction presented in the center of the right and left halves of the screen. D) Incompatible prime-compatible fraction pairs: The “a” key was expected to be pressed for the pie chart, while the “i” key for symbolic fraction.

CHAPTER 3: RESULTS

The scores of the 51 participants included in the study were checked for accuracy before analysis. Considering the error rate in the study by Meert et al (2010), 3 participants who made 35% or more errors in both stimulus types in both the control and experimental conditions were excluded from the experiment. Then, when the reaction times of 48 participants were examined, 1 participant was excluded from the study because the participant gave extreme values in the control condition. Normality was tested for the three analyses performed. The data were found to be normally distributed. The analyses to be used were determined as repeated measures ANOVA and were performed at a significance level of 0.05.

The research design which was determined for this study was 3(priming: no priming/ compatible prime/ incompatible prime) X 2(distance: close/ far) X 2(MNL compatibility: compatible/ incompatible) X 2(intra-fraction distance: positive/ negative) within factors. This research design was analyzed using repeated measures ANOVA to reveal the effect of priming. This analysis was performed on reaction times obtained from symbolic fractions only. This analysis showed that there was a significant main effect of priming, $F(1,46) = 32.366$, $p < .000$, $\eta p^2 = .41$, indicating that the reaction times of the experimental conditions were significantly faster than the control condition (Figure 4). Furthermore, these results revealed a significant main effect of distance, $F(1,46) = 58.084$, $p < .000$, $\eta p^2 = .55$, which means that the symbolic fractions that were numerically far from each other were significantly responded faster than the fractions that were close to each other (Figure 5). In addition to these main effects, the third main effect of intra-fraction distance was significant, $F(1,46) = 10.254$, $p = .002$, $\eta p^2 = .182$, which means that the symbolic fraction pairs consisting of the same difference (positive) between numerator and denominator were responded significantly slower than the negative ones (Figure 6). On the other hand, there was no significant main effect of MNL compatibility, $F(1,46) = 4.933$, $p = .36$.

In addition to the main effects, the interaction effect between compatibility and intra-fraction distance effects was also significant, $F(1,46) = 4.933$, $p < .05$, $\eta p^2 = .09$. Significant interaction effects were examined by using simple effects analysis. Looking at the significance values for each simple effect, there was a significant difference between positive and negative intra-fraction distance in MNL compatible symbolic fractions, which means that the compatible symbolic fraction pairs were responded slower when they consisted of the same difference (positive) between numerator and denominator (*M* = 1294.81, *SE* = 10.25) in contrast to negative difference (*M* = 1236.19, *SE* = 10.56). However, there was no significant difference between positive and negative intra-fraction distance in MNL incompatible symbolic fractions (Figure 7).

There was also a significant interaction effect between the distance effect and the intra-fraction distance, $F(1, 46) = 24.228$, $p < .000$, $\eta p^2 = .34$. Significant interaction effects were examined by using simple effects analysis. According to the results, there was a significant difference between distance levels of close and far in positive intra-fraction distance pairs, which means that the symbolic fraction pairs which consisted of the same difference between numerator and denominator were responded slower when these fractions were taken from close-distance fraction pairs (*M* = 1387.97, *SE* = 12.54), in contrast to far-distance fraction pairs (*M* = 1188.02, *SE* = 8.83). However, there was no significant difference when the fraction pairs' intra-fraction distance were different (Figure 8). In contrast to these findings, the other interaction effects were not significant (all ps > .05).

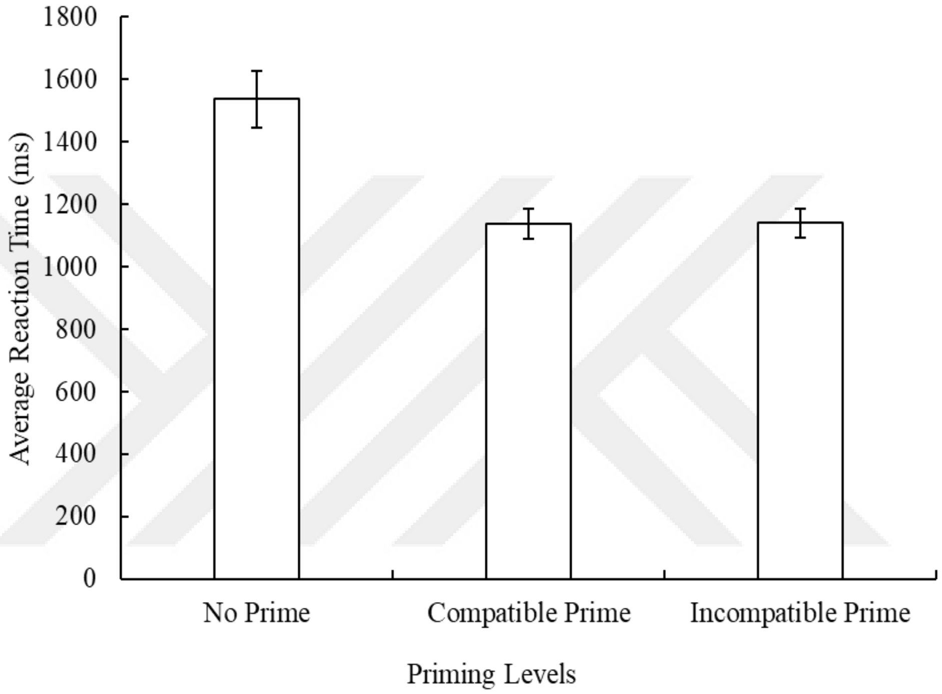


Figure 4. Mean reaction time for three different priming levels (Error bars indicate %95 adjusted Confidence Interval).

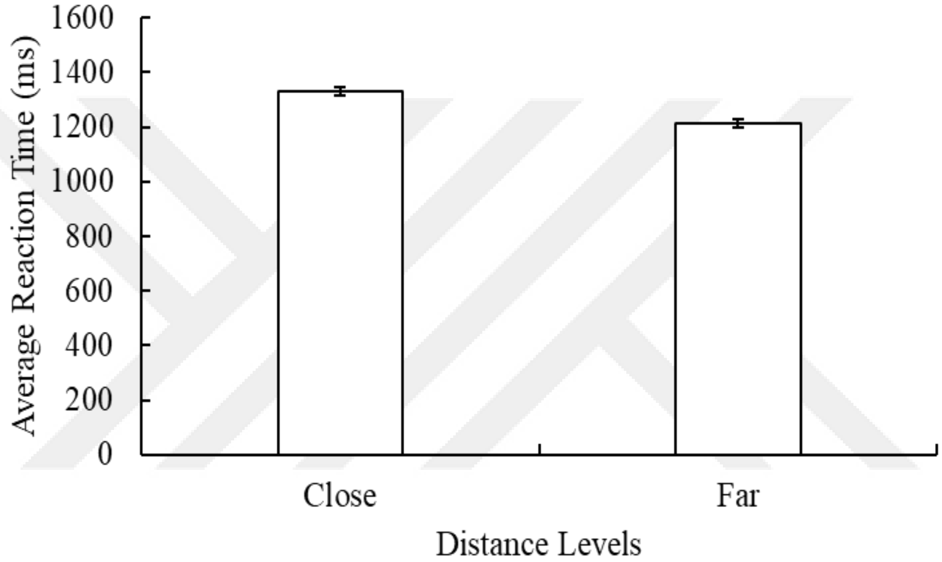


Figure 5. Mean reaction time for each distance level (Error bars indicate %95 adjusted Confidence Intervals).

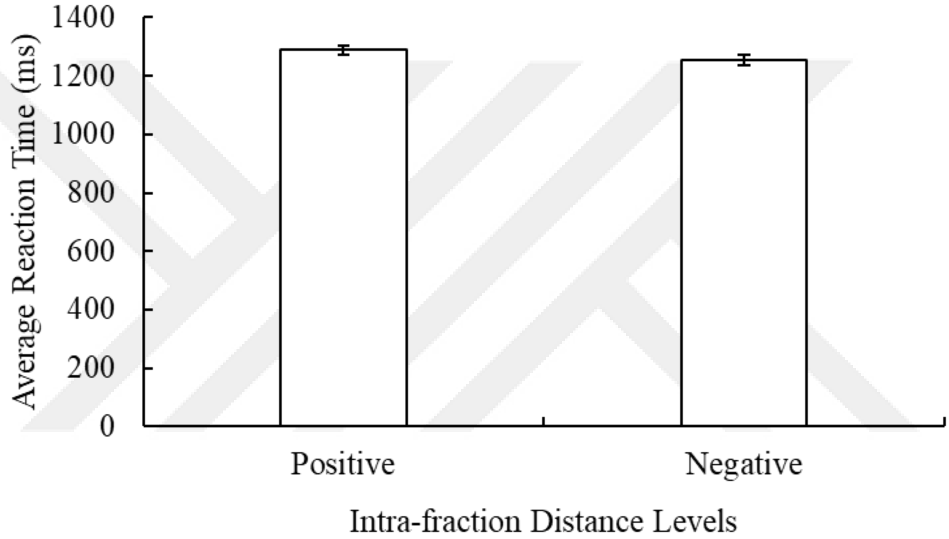


Figure 6. Mean reaction time for intra-fraction distance levels (Error bars indicate %95 adjusted Confidence Intervals).

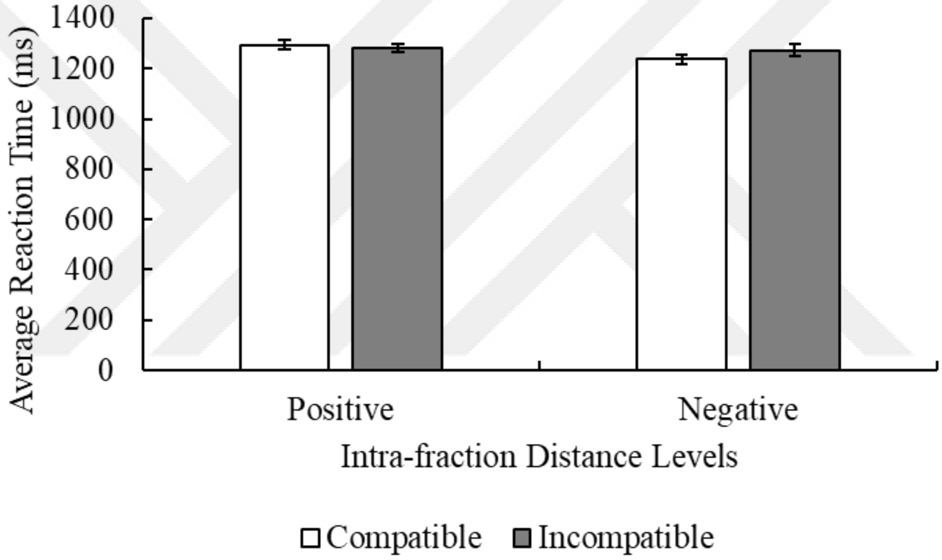


Figure 7. Mean reaction time in magnitude comparison task of each intra-fraction distance levels for MNL compatible symbolic fractions and MNL incompatible symbolic fractions (Error bars indicate %95 adjusted Confidence Intervals).

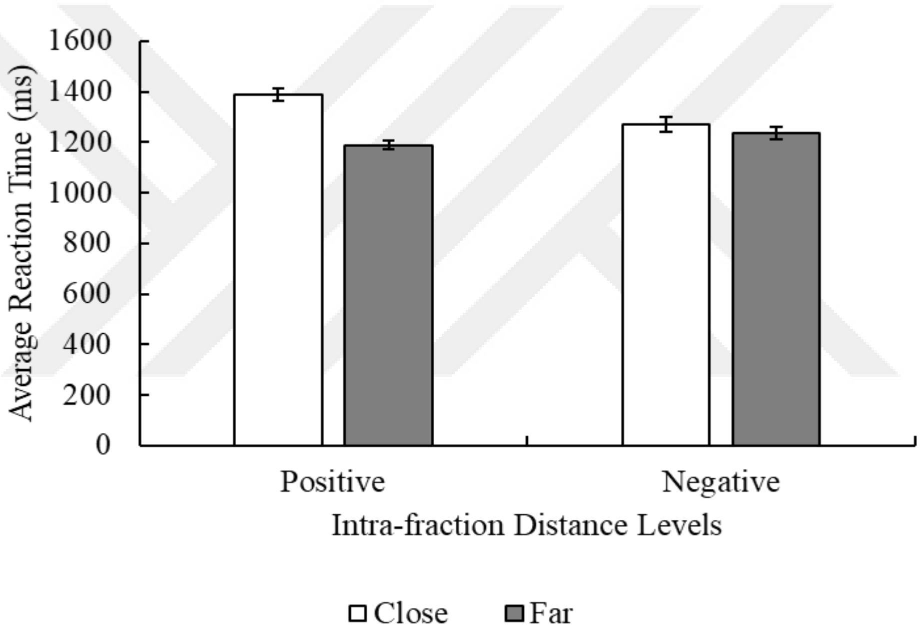


Figure 8. Mean reaction time in magnitude comparison task of positive (same difference) and negative (different difference) intra-fraction levels for close distance symbolic fraction pairs and far distance symbolic fraction pairs (Error bars indicate %95 adjusted Confidence Intervals).

In addition, reaction times obtained from non-symbolic proportions (pie charts) presented as prime stimuli were analyzed to understand whether or not the distance effect, intra-fraction distance effect and MNL compatibility were present. For this purpose, another factorial repeated measures ANOVA was performed. According to the analysis, only the main effect of distance was found significant, $F(1, 46) = 54.678$, $p < .000$, $\eta p^2 = .54$, indicating that the non-symbolic proportions which was far from each other numerically were responded faster than the close proportions in comparing the magnitudes of the proportions (Figure 9). The remaining main and interaction effects were not significant. (All ps > .05).

Finally, whether stimulus type made a difference in the magnitude comparison task was also investigated. For this purpose, reaction times obtained from symbolic fractions and non-symbolic proportions which were pie charts, symbolic fractions in control condition, symbolic fractions primed with compatible pie charts and symbolic fractions primed with incompatible pie charts in experimental condition were compared. A one-way repeated ANOVA was conducted to test whether two different types of stimuli could be distinguished from each other. According to the results, there was a significant main effect of the variable of stimulus type, $F(3, 138) = 23.270$, $p < .000$, $\eta p^2 = .33$, which means that the reaction times obtained from non-symbolic proportions and symbolic fractions are significantly different from each other (Figure 10). According to Helmert contrast analysis, the reaction times given to the non-symbolic proportions were significantly faster than the mean reaction time to symbolic fractions in the control and experimental conditions, $F(1, 46) = 12.698$, $p < .01$, $\eta p^2 = .22$. In addition, as evidence of the priming effect, the reaction time to symbolic fractions in the control condition was significantly slower than the mean reaction time in the experimental conditions, $F(1, 46) = 32.917$, $p < .000$, $\eta p^2 = .42$.

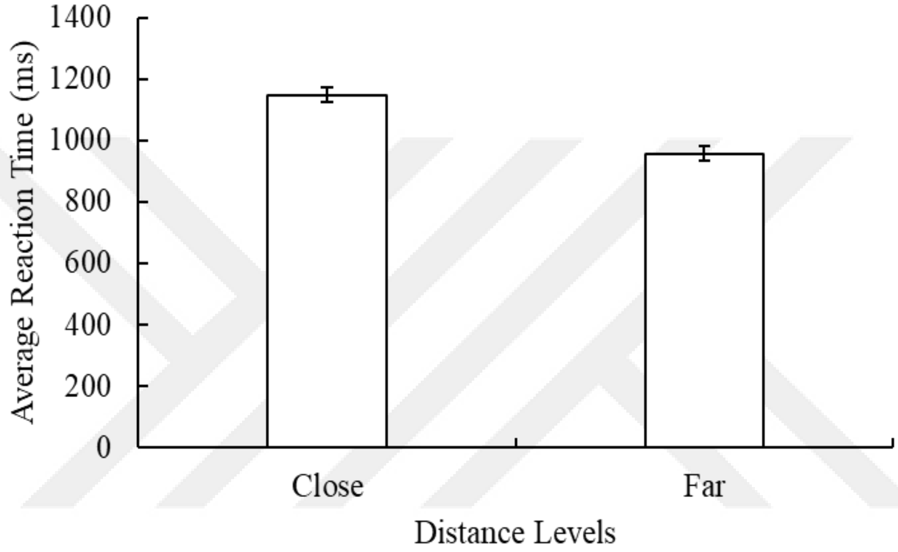


Figure 9. Mean reaction time for each distance levels on non-symbolic proportions (Error bars indicate %95 adjusted Confidence Intervals).

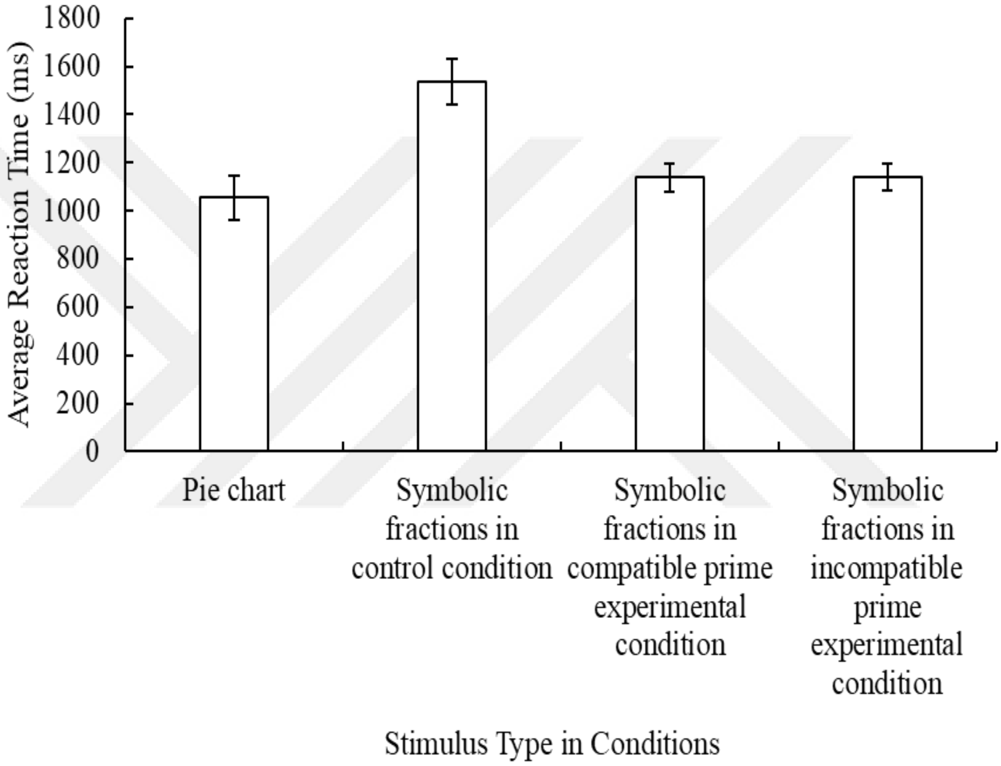


Figure 10. Mean reaction time for symbolic fractions and non-symbolic (pie chart) proportions (Error bars indicate %95 adjusted Confidence Intervals).

CHAPTER 4: DISCUSSION

The main aim of this study was to examine whether the priming effect of pie charts presented as non-symbolic proportions had an effect on the symbolic fractions' reaction times in a magnitude comparison task within the framework of the distance effect. In this context, it was tested whether there was a significant difference between the reaction times obtained from the symbolic fractions presented with no prime in the control condition compared to those primed with pie charts in the experimental condition. Besides that, based on the MNL hypothesis (Moyer and Landauer, 1967; Dehaene et al., 1990), the presented symbolic fraction and pie chart pairs were manipulated. Our expectation was faster reaction times for both MNL compatible symbolic fractions and pie chart pairs in contrast to MNL incompatible. Also, we wanted to see the presence of the distance effect in two stimulus types and, in line with the literature (Meert et al., 2010; Schneider and Siegler, 2010), we expected that pairs that were numerically far from each other would produce faster reaction times than close-distance ones. In addition to the distance effect, we wondered whether the intra-fraction distance effect would cause an effect in this study. To test this, we separated the symbolic fraction and pie chart pairs according to the difference between the fraction's numerator and denominator. We claimed that if the pair consisted of the same difference between numerator and denominator, these pairs were responded slower when the difference was different in the magnitude comparison task. Finally, we wondered whether the responses to pie charts representing non-symbolic notation and fractions representing symbolic notation would differ from each other. To test this, we compared the reaction times obtained from pie charts, symbolic fractions in the control condition and symbolic fractions in the two experimental conditions. In this context, we expected pie charts to produce faster reaction times than symbolic fractions in line with Mock et al. (2018) even though discrete mixed representation was used.

According to the results of the study, we found that the symbolic fractions primed with pie charts in the experimental condition produced faster responses than the symbolic fractions presented with no prime in the control condition. This suggests that the cross-notational priming effect occurred even though the participants were not informed that pie charts and symbolic fractions were conjugates of each other. This suggests that semantic information can be mapped between pie charts presented as prime stimuli and symbolic fractions presented as probe stimuli. Our result seems to be compatible with Herrera and Macizo's (2008) study with natural numbers, in which the non-symbolic prime stimulus produced semantic facilitation on the symbolic probe stimulus and showed a cross-notational priming effect. In addition, the result seems to support the conclusion of Hurst, Massaro and Cordes (2020) that 64% of the adults in the study preferred the visual area model (such as pie chart) as a result of the questionnaire on how they visualize symbolic fractions. In another study (Gabriel et al., 2013), it was mentioned that presenting symbolic and non-symbolic representations side by side activates the knowledge of proportional relationship and makes the concept of fraction more understandable. In addition to this study, another fMRI study (Piazza et al., 2007) found that representing a symbolic or non-symbolic stimulus leads to habituation of the other form. It can be said that the cross-notational priming effect found in this study confirmed these findings.

However, when the two levels of compatibility conditions were examined, no significant difference was found between compatible prime with symbolic fractions and incompatible prime with symbolic fractions. The experimental conditions consisting of compatible and incompatible pie charts could not affect the participant’s reaction times on symbolic fractions. There was no effect of MNL compatibility on the responses given to the pie charts presented as non-symbolic proportion. This may be due to the fact that although first comparisons of non-symbolic proportions can be made even in infancy (Halberda et al., 2008), symbolic notations learned at school age take precedence over non-symbolic notations. This may prevent the non-symbolic proportions from adapting to the mental number line on which the natural numbers are represented, and so the MNL compatibility effect may not occur. However, the MNL compatibility effect tested in symbolic fractions was found to be non-significant, suggesting that this effect may remain weak in symbolic fractions as well, since fractions are the last numerical quantities included in the mental number line (Siegler and Lortie-Forgues, 2014). Despite the information that generalized fractions and positive numbers were represented along the mental number line (Ganor-Stern, 2012), it is puzzling that the MNL compatibility effect does not appear for fractions. However, this result may be due to the magnitude comparison task used in our study, which requires intentional processing (Tzelgov et al., 2015). Even if non-unit fractions have primitive representations like whole numbers, this task may not be suitable for retrieving information from long term memory.

The other variables tested for both symbolic and non-symbolic proportions were distance and intra-fraction distance effect. When the distance effect, which was obtained during the magnitude comparison task, was evaluated as evidence of magnitude processing (Deheane et al., 1990), a significant distance effect was found for both stimulus types. In line with the literature (Schneider and Siegler, 2010; Meert et al., 2010; Mock et al., 2018), both symbolic fractions and pie charts that were numerically far from each other produced faster reaction times than those that were close. This is consistent with the idea that the processing of fractions may be holistic. Also, the main effect of intra-fraction distance was significant for symbolic fractions. In line with Meert et al.'s study (2010), participants responded slower when the numerical difference between the numerator and denominator of fractions presented as pairs was the same. However, this effect was not significant for pie charts. This situation suggests that the participants did not have clear numerical information about the numerators and denominators of the pie charts. The fact that the significant distance effect was found in the context of whole magnitudes, but the main effect of intra-fraction distance was non-significant leads us to question whether the participants applied different strategies in pie charts while making this evaluation. In the other analysis comparing the response times of symbolic fractions and pie charts, we found that pie charts produced faster responses than symbolic fractions. Despite the possibility that pie charts in the discrete mixed representation used in this study may cause numerical interference, we found faster responses than symbolic fractions, just like in Mock et al. (2018). The fact that the discrete mixed representation in this study provides similar comparison results to the continuous representation strengthens the possibility that the non-significant intra-fraction distance effect in pie charts is due to the participants' use of different strategies during the magnitude comparison task.

In addition to the main effects, we found a significant interaction between distance and intra-fraction distance in symbolic fractions, which provides evidence for the existence of a hybrid model of fraction processing. Within this model, symbolic fractions are processed both componentially and holistically (Meert et al., 2010). In other words, both numerator and denominator numerical information and holistic values can be reached. According to the results, it was seen that if the fraction pair was a close distance fraction pair, the participants produced significantly slower reaction times when the intra-fraction distance values in this fraction pair were equal. Also, participants responded faster when the close distance fraction pair consisted of different intra-fraction distance values. This finding is consistent with the main effects of distance and intra-fraction distance in symbolic fractions and can be interpreted as meaning that even when participants were presented with fractions that do not consist of common components, information about the components provides an important strategy, even though componential strategies were attempted to be prevented. However, this interaction was not significant for pie charts. This supports the possibility that a different strategy was used during the magnitude comparison task in pie charts as distinct from symbolic fractions.

Another interaction found was between the effect of compatibility and intra-fraction distance in symbolic fractions. When participants were presented with MNL compatible fraction pairs, the condition where the intra-fraction distance was the same for both fractions elicited slower responses than the condition where the intra-fraction distance was different. The fact that this effect was not found when fraction pairs were presented as incompatible can be attributed to the unit decade compatibility effect. According to Nuerk et al. (2001), when comparing two-digit numbers, if the comparison in the tens and units was compatible with each other (42-89, $4<8$ and $2<9$), it was called a compatible pair. However, if the magnitude comparison in tens and units of the numbers in this pair was not compatible (49-85, $4<8$ and $9>5$), it was called an incompatible trial. The results show that incompatible pairs produce slower responses than compatible pairs. If we consider the numerator and denominator values in the fraction pairs we use as multi-digit processing, this effect can be explained by the fact that it is observed in compatible pairs because the comparison of the components is compatible with the whole magnitude when the larger fraction is presented on the right. When the presented fraction pair is incompatible, the components and the whole magnitude are incompatible. This may explain why the intra-fraction distance in the incompatible pair makes no difference.

However, as mentioned in the method section, the so-called congruent fraction pairs used in Meert et al. (2010) were used in this study. The characteristic of the fractions in these pairs is that when the denominator is larger, the whole magnitude of the fraction is larger. In this context, the lack of precise information about whether or not participants realized this situation prevents precise inferences about the strategies used. For this reason, a different set of fractions may be used in future studies.

4.1 Conclusion

The main aim of this study was to investigate whether the priming of symbolic fractions with pie charts presented as non-symbolic proportions makes a difference compared to the condition with no prime. According to the results, a significant cross-notational priming effect was found between the stimuli. In this case, it seems that the similar cross-notational priming effect found for natural numbers (Herrera and Macizo, 2008) is also present for symbolic fractions. It was also observed that the distance effect shown by both pie charts and symbolic fractions was between whole magnitudes. However, the presence of a significant intra-fraction distance effect found in symbolic fractions seems to confirm the presence of both holistic and componential processing for this stimulus type. Overall, the significant priming effect shows that we benefit from visual representations especially when processing fractions. The effect of this semantic facilitation on symbolic fractions shows that visual support can improve the process.

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APPENDICES

APPENDIX A- Participant Consent Form

Katılımcı no: ……..

Katılımcı İzin Formu

Bu çalışma kesirli sayıların büyüklük uzam ilişkisi kapsamında incelenmesi amacıyla yapılmaktadır.

Çalışma sırasında bilgisayar ekranında sunulan görsel uyarıcılara bilgisayar klavyesinin tuşları aracılığıyla tepki vermeniz beklenmektedir. Çalışma boyunca ekrandan sunulan yönergeleri dikkatlice okumanız ve sizden istenenleri olabildiğince doğru bir biçimde yerine getirmeniz gerekmektedir.

Çalışma kapsamında katılımcılardan elde edilen veriler isim kullanılmaksızın analizlere dahil edilecektir. Katılımınız araştırma hipotezinin test edilmesi ve yukarıda açıklanan amaçlar doğrultusunda literatüre sağlayacağı katkılar bakımından oldukça önemlidir. Ayrıca katılımınızın psikoloji alanının gelişmesi açısından da pek çok faydası bulunmaktadır.

Çalışmaya katılımınız tamamen kendi isteğinize bağlıdır. Katılımı reddetme ya da çalışma sürecinde herhangi bir zaman diliminde devam etmeme hakkına sahipsiniz. Eğer görüşme esnasında katılımınıza ilişkin herhangi bir sorunuz olursa araştırmacıyla iletişime geçebilirsiniz. Eğer deney sonrasında aklınıza takılan bir soru olursa aşağıdaki e-mail adresine yazabilirsiniz.

Araştırmacının e-mail adresi:

Okudum, kabul ediyorum.

Katılımcının imzası: ……………………

Katılımcı no: ……..

Çalışmanın amacını ve içeriğini ….. numaralı katılımcıya açıklamış bulunmaktayım. Çalışma kapsamında yapılacak işlemler hakkında katılımcının herhangi bir sorusu olup olmadığını sordum ve katılımcı tarafından yöneltilen bütün soruları yanıtladım.

Tarih ....……………………… Araştırmacının imzası ……………………….

Çalışmanın amacı ve içeriği hakkında açıklamaların yer aldığı "Katılımcı İzin Formu"nu okudum. Araştırmacı çalışma kapsamındaki haklarımı ve sorumluluklarımı açıkladı ve kendisine yönelttiğim bütün soruları açık bir şekilde yanıtladı. Sonuç olarak, uygulama esnasında şahsımdan toplanan verilerin bilimsel amaçlarla kullanılmasına izin verdiğimi ve çalışmaya gönüllü olarak katıldığımı beyan ederim.

Tarih ………………………. Katılımcının imzası ……………………….

APPENDIX B- Participant Information Form

Katılımcı no: ……….

Katılımcı Bilgi Formu

Yaş: ………….

Cinsiyet: ………………

Bölüm: ………………………

Yazışma adresi (telefon numarası ya da e-posta adresi): ………………………………….

1. İki dilli misiniz?

☐ Evet ☐ Hayır

Yanıtınız Hayır ise lütfen ana dilinizi belirtiniz…………………….

2. Düzeltilmemiş bir görme bozukluğunuz var mı?

☐ Evet ☐ Hayır

3. Daha önce psikiyatrik/psikolojik bir rahatsızlık tanısı aldınız mı?

☐ Evet ☐ Hayır

Yanıtınız Evet ise lütfen konulan tanıyı belirtiniz…………………….

4. Daha önce nörolojik bir rahatsızlık tanısı aldınız mı?

☐ Evet ☐ Hayır

Yanıtınız Evet ise lütfen konulan tanıyı belirtiniz…………………….

5. Herhangi bir ilaç kullanıyor musunuz?

☐ Evet ☐ Hayır

Yanıtınız Evet ise lütfen ilacın adını belirtiniz…………………….

6. Daha önce kafa travması geçirdiniz mi?

☐ Evet ☐ Hayır

7. Aşağıda belirtilen bozukluklardan herhangi birine dair tanı aldıysanız lütfen işaretleyiniz (Birden fazla işaretleme yapabilirsiniz).

☐ Disleksi ☐ Diskalkuli ☐ Uzamsal İhmal

8. Daha önce laboratuvarda yürütülmüş bir psikoloji deneyine katıldınız mı?

☐ Evet ☐ Hayır

Yanıtınız Evet ise deneyin ne ile ilgili olduğunu kısaca belirtiniz.

………………………………………………………………………………

APPENDIX C- Edinburgh Handedness Inventory

Edinburgh El Tercihi Envanteri

Lütfen aşağıdaki tabloda ilk sütunda sıralanmış olan aktiviteleri yaparken veya söz konusu aletleri kullanırken hangi elinizi tercih ettiğinizi ilgili sütundan işaretleyiniz.

	Her zaman sol	Genelde sol	Tercihim yok	Genelde sağ	Her zaman sağ
Yazma					
Fırlatma					
Makas					
Diş fırçası					
Bıçak					
Kaşık					
Kibrit					
Mouse					