ACHIEVEMENT IN ARITHMETIC WORD PROBLEMS IN ADULTS: THE ROLE OF WORKING MEMORY

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ACHIVEMENT IN ARITHMETIC WORD PROBLEMS IN ADULTS: THE ROLE OF WORKING MEMORY

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this wok.

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ABSTRACT

ACHIEVEMENT IN ARITHMETIC WORD PROBLEMS IN ADULTS:
THE ROLE OF WORKING MEMORY

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Arithmetic word problems include various scenarios, some of them corresponding to real life situations. It is expected from the human problem solver to devise methods to solve those problems. Solving an arithmetic word problem requires using arithmetic abilities, reading comprehension, and spatial, verbal and numeric abilities that are related to Working Memory capacities. In particular, verbal and spatial working memories are assumed to be employed during the course of arithmetic word problem solving. Arithmetic word problem texts also exhibit different characteristics than plain texts. Therefore, the investigation of arithmetic word problem solving goes beyond reading comprehension. The study includes two phases; (i) to investigate the relationship between the putative Working Memory components and arithmetic word problem solving characteristics, and (ii) to investigate the differences between standard written language through a corpus and arithmetic problem texts. Our analyses revealed that there was a statistically significant relation between the digit span task scores and the accuracy of solutions. The study also showed that arithmetic word problem texts are different than plain texts in terms of their syntactic categories.

Keywords: Working Memory, arithmetic word problem, verbal, visuospatial, linguistic

ÖZ

YETİŞKİNLERDE ARİTMETİK KELİME PROBLEMLERİ BAŞARISI: KISA SÜRELİ BELLEĞİN ROLÜ

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Aritmetik problemler, bir kısmı gerçek hayattaki durumlarla eşleşen çeşitli senaryolar içermektedir. Problemleri çözen kişilerden, bu türlerdeki soruları çözmeleri için çeşitli yöntemler tasarlamaları beklenmektedir. Matematiksel bir problemi çözmek; aritmetik becerilerin; okuduğunu anlama becerisinin, İşler Bellek yeterliği ile bağlantılı olan uzamsal, sözel ve numerik becerilerin kullanımını gerektirmektedir. Özellikle sözel ve uzamsal işler belleklerin aritmetik sözcük problemlerinin çözüm süreçlerinde kullanıldıkları varsayılmaktadır. Yanı sıra, aritmetik problemlerin metinleri yazı dili derlemlerinin tasarlanması için kullanılan salt metinlerden birçok açıdan farklılaşmaktadırlar. Bu nedenle aritmetik kelime sorularını çözebilme araştırması okuduğunu anlamanın ötesine geçmektedir. Bu çalışmanın esas hedefleri, (i) varsayımsal İşler Bellek bileşenleri ile aritmetik sözcük problemi çözme etkinliğinin karakteristikleri arasındaki ilişkiyi ve (ii) standart yazılı derlem ile aritmetik problem metni arasındaki farkları araştırmaktır. Çalışmanın sonuçları göstermiştir ki yapılmış olan deneysel çalışmadan elde edilen bulgular, sayı dizisi testi skorları ile deneklerin cevaplarının doğruluk oranı arasında istatistiksel olarak kayda değer bir ilişki olduğunu göstermiştir. Ayrıca, aritmetik kelime sorularının metinleri, kanonik derlem içeriğinden, bileşenlerin sözdizim kategorileri bakımından farklılaşmaktadır.

Anahtar Sözcükler: İşler Bellek, aritmetik kelime soruları, dilsel, görsel-uzamsal, dilbilimsel

DEDICATION

To My Grandfather

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LIST OF ABBREVIATIONS

ADHD	Attention Deficit Hyperactivity Disorder
AVWM	Auditory Verbal Working Memory
CE	Central Executive
MD	Math Difficulty
METU	Middle East Technical University
NLP	Natural Language Processing
PoS	Part Of Speech
PVWM	Phonological Verbal Working Memory
TOMA	Test of Math Ability
VSWM	VisuoSpatial Working Memory
WAIS	Wechsler Adult Intelligence Scale
WISC-VI	Wechsler Intelligence Scale for Children-Fifth Edition
WISC-III-PI	Wechsler Intelligence Scale for Children-Third Edition
WJ-III	Woodcock–Johnson Tests of Cognitive Abilities
WM	Working Memory
WMC	Working Memory Capacity

CHAPTER 1

CHAPTER

INTRODUCTION

Sample Question:

"There are 90 passengers in a three carriage train. Firstly, seven passengers move from first wagon to the second one. Then, thirteen passengers move from second carriage to the third carriage. At last, the number of passengers in each wagon is equal. According to the information given above, how many passengers were there in the second carriage at the beginning?"[1]

Solving an arithmetic word problem is in need of various cognitive activities (Swanson, 2016). Consider the example above; the problem solver needs to store the numeric knowledge for a short time in mind, comprehend the written texts in relation to identified entities or digits, figure out the appropriate solving arithmetic strategy, draw diagrams (if needed by the problem solver), and then solve the problem.

Arithmetic problems, geometry problems and word problems are main sorts of mathematical problems (Kyttala & Lehto, 2008). Word problems include both abstract and concrete concepts and they are longer than other types of mathematical problems. Relevant components are e.g. proper names, numbers, and time located in the texts. Reasoning, mathematical problem solving abilities and Working Memory need to be used simultaneously in the problem solving process. In fact, Geary (2004) indicated that mathematical abilities consist of both conceptual and procedural competencies.

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[1] This question was derived from Academic Graduate Exams – Retired Questions Corpus. The question was asked in 2007 Academic Graduate Exam – Quantitative part. Question index is 25 in this leaflet. To see the original question, please visit the osym.gov.tr retired question corpus web page. It was selected accordance with included spatial factors, numerical knowledge, proper names and relational concepts. It was also used in the experiment part for this thesis. It will be also used in some other certain written sections of this paper as an example.

The role of Working Memory in academic achievement was investigated in previous researches. Studies showed the significance of Working Memory on academic success, particularly in the field of mathematics (as cited in Kyttala & Lehto, 2008).

Working Memory was described as an executive function that stores the temporary knowledge for a short time (e.g., Baddeley, 2012; Engle, Tuholski, Laughlin & Conway, 1999; Swanson, 2016; Unsworth, 2010). Baddeley (1986) called it Working Memory (WM), rather than short-term memory because he indicated that WM does not only store raw information for a short time. Baddeley (1986, 1997, 2003) divided WM into three fundamental components; namely, visuospatial Working Memory (VSWM), central executive (CE), and phonological verbal Working Memory (PVWM).

Grerofsky (1996) studied word problems in terms of linguistic and narrative aspects. She remarked that previous studies focused on mathematical word problems with regard to their "*readability*", which is the linguistic factors that make them easier or harder to comprehend. She proposed that linguistic features of a word problem specify its difficulty in the process of translating them from "*normal language*" to "*mathematical symbolism*".

Word problems are composed of many words as in the example question presented at the beginning of this chapter. Researchers call them "Story-Problems"; not because of including words but because of containing real-life stories. Morton and Qu (2013) focused on text comprehension in words problems. They highlighted that not only children but also adults experience challenges while solving word problems, not because of their mathematical skills but because of text comprehension deficits. Therefore, in this thesis before investigating cognitive skills such as WM capacity, arithmetic word problem texts are investigated from a corpus analytic perspective. Word problem texts are compared with a plain-text corpus (METU Turkish Corpus Project, Say, et al., 2002) in terms of the frequencies of parts of speech. The method and analyses will be discussed in the Chapter 3.

1.1. Research Questions

Word problems can be elaborated with regard to text comprehension, mathematical background and logical reasoning. Morton and Qu (2013) divided word problem solving processes into three fundamental parts: [1] interpretation of a word problem, [2] building data relationship, [3] applying the correct operation to compute a word problem.

We approach arithmetic word problems in two dimensions: linguistic properties of problem texts and cognitive properties of the problem solver. In particular, to study cognitive aspects, WM components (through The Digit and Corsi Span Tasks) were investigated. The Digit Span Task (Swanson, 1992, 2013) is related to Verbal Working Memory and the Corsi Span Task (Milner, 1971) is related to Visuospatial Working Memory (VSWM). For linguistic analyses of the problem texts, NLP tools were used to specify Parts of Speech (PoS) of the texts. Then, these analyses were compared with another set of words selected from METU Turkish Corpus. In relation to these subcomponents, four essential research questions were asked.

Research Question 1: What is the difference between an ordinary text and word problem text in terms of their syntactic properties? METU Turkish Corpus are composed of various genres, e.g. fiction (novel and story), news, bibliography, etc. On the other hand, word problems are a different genre, comprised of sentences, questions containing numbers, names of persons, etc. These two types of corpora may be different at the syntactic level, especially in terms of the frequencies of word types. In this thesis, the differences are investigated at PoS level.

Research Question 2: Is there a correlation between arithmetic achievement and Working Memory span characteristics? Problem solvers use their verbal and spatial WM components to store digits, proper names and their logical relations (through the digit and corsi span tasks). Problem solvers also use their VSWM to process visual and spatial elements. Therefore, it was investigated whether there is a significant relationship between Working Memory and arithmetic achievement in word problems. How do Working Memory components influence arithmetic word problem achievement of problem solvers?

Research Question 3: This question included two sub-questions. One of them was about the relationship between WM and the solution time, and the other is about the relationship of the correct answers and the solution time. Is there a significant relationship between the solution time and Working Memory capacity (WMC)? How does Working Memory (WM components) affect the time spent on solving the problem? Second, is there a significant relationship between solution time and arithmetic word problem achievement? It is expected that there will be a relationship between the total solution time and the total correct number of answers. If the problem solver has a short total solution time, it is expected to have a high number of total correct answers.

Research Question 4: The last research question is about the diagrams drawn during solving the problems. The problem solver uses them as a facilitator in the process of arithmetic word problem solving. Is there a relationship between the number of diagrams drawn and Working Memory components? Also, the correct number of answers will be examined in relation to the diagram sketching. How does the number of diagrams influence achievement in word problem solving?

In addition to these research questions, the role of age in arithmetic achievement will be investigated.

1.2. Outline of the Thesis

Chapter 2 covers the previous studies about the arithmetic abilities and WM, and Working Memory itself. The studies which investigated the relationship between arithmetic achievement and WM will be presented in this part, as well. Moreover, studies on linguistic features of word problems (namely, the parts of speech in word problem texts) will be presented in the second chapter. Chapter 3 addresses the experimental study that was conducted for this thesis. The experimental design and details about the experiment will be presented. Chapter 4 presents the results of the experiment analyses. Chapter 5 presents the discussion of the results and possible further studies. Lastly, Chapter 6 provides a summary of the thesis.

CHAPTER 2

LITERATURE REVIEW

2.1. Working Memory, Mathematics and Academic Achievement

The Concise Oxford Dictionary (1995) describes a problem as "*A doubtful or difficult matter requiring a solution*". People need certain skills to solve mathematical problems. Specifically, to solve word problems, the solver should have the ability to interpret the problem text, to figure out the appropriate solving arithmetic strategy and apply the correct operations to compute the problem (Morton & Qu, 2013). Studies in the literature; Kintsch and Greeno (1985), Mayer (1992), O'Connell (1993, 1999), O'Connell and Carter (1993), Reusser (1996) separated the process of problem solving into sequential stages, which are (as cited in Corter & Zahner, 2007).

a. Initial problem understanding (text comprehension),
b. Formulating the mathematical problem,
c. Finding a solution method or schema,
d. Computing the answer.

In the process of problem solving, certain cognitive domains are activated. In particular, mathematical productivity is influenced by these cognitive abilities such as attention, previous domain-specific knowledge, motivation, storage capacity and so on. Working Memory concept appeared for the first time in the book titled *Plans and Structure of Behavior* written by Miller, Galenter and Pribram in 1960. A part from this book is presented below:

> "*The parts of a Plan that is being executed have special access to consciousness and special ways of being remembered that are necessary for coordinating parts of different Plans and for coordinating with the Plans of other people. When we have decided to execute some particular Plan, it is probably put into some special state or place where it can be remembered while it is being executed. Particularly if it is a transient, temporary kind of Plan that will be used today and never again, we need some special place to store it. The special place may be on a sheet of paper. Or (who knows?) it may be somewhere in the frontal lobes of the brain. Without committing ourselves to any specific machinery, therefore, we should like to speak of the memory we use for the execution of our Plans as a kind of quick-access, Working Memory.*" (p. 65)

Then, the concept of Working Memory was defined as a restricted cognitive capacity to store information temporarily (Baddeley, 2003). Baddeley and Hitch (1974) proposed the three-component model for WM. Baddeley (2003) argued that WM involves the central executive that is the control system for attentional capacity and two other storages; which are phonological loop and visuospatial sketchpad. Phonological loop executes an articulatory rehearsal process to hold set of numbers or unconnected words. Baddeley (2003) indicated that Working Memory has a restricted span, since articulation occurs in real time. The second storage component of Working Memory is visuospatial WM. Visual serial tasks such as the corsi span task and matrix pattern are commonly used to measure Visuospatial Working Memory. The objects' place and orientation in space and their appearance are visual and spatial elements. Working Memory components were used in the process of mathematical problem solving. Anderson, Reder and Lebiere (1996), LeBlanc and Weber-Russell (1996), Logie, Gilhooly and Wynn (1994), Swanson, Cooney and Brock (1993) indicated that mathematical solving of arithmetic word problems depend on Working Memory (as cited in Swanson & Sachse-Lee, 2001). Other studies highlighted the correlation between WM capacity and performance on cognitive tasks (as cited in Kyttala & Lehto, 2008). Some studies are presented below.

Kyttala and Lehto (2008) investigated the relation between visuospatial Working Memory and mathematical performance among high school students. Participants were 128 students who were 15 and 16 years old. Researchers separated VSWM into two parts: active and passive VSWM. The mental rotation task was applied to observe active VSWM and, the corsi block test and the matrix pattern task were conducted to observe passive VSWM. Participants were from a Finnish high school. They were examined within groups: with a number of subjects ranging between 11 and 24. The experiment had three parts: the WM phase, the non-verbal fluid intelligence part and the mathematical problem solving part that was composed of mental arithmetic tests, geometry tests and word problem tests (Kyttala & Lehto, 2008). The mathematical task is developed to measure mathematical success at varied grades in Finland. The test includes a mental arithmetic task and paper and pencil tests. The tests are composed of orally presented word problems and paper-and-pencil word problems. Their results showed that the passive sequential WM result correlated significantly with the mathematical word problems, but passive and active VSWM were linked with all math sub-scores. They revealed that VSWM and nonverbal fluid intelligence has a role in mathematical performance. They found that if a participant got high scores from passive VSWM (the corsi block-tapping task and the matrix pattern task), their word problem achievement increases associatively (Kyttala & Lehto, 2008).

Hitch (1978) investigated the role of Working Memory on mental arithmetic. They conducted four experiments to explore WM effects on achievement in mental arithmetic. Experiment 1 assessed auditorily presented basic mental arithmetic questions such as, 325 + 46. Experiment 2 and 3 investigated the effects of delaying in remembering numbers, and the last experiment showed that when mental load increases, the rate of forgetting the initial knowledge increases. Thirty participants solved four mental arithmetic problems for Experiment 1. Then the participants verbally explained the process in which they had dealt with in the problems. They clarified their strategies and style of writing answers on the paper verbally. The results showed that there was a correlation between strategy and time. The second experiment was about the storing digits in mind. The hypothesis was that the interim result was stored then forgotten in short-term memory thus there was expected to be more mistakes. It was expected from participants to write their answers in the right and the adverse order. They found that the writing sequence did not significantly influence the accuracy of the hundreds of the figures but did influenced mistakes in the tens and the units (Hitch, 1978). In Experiment 3 the subjects were expected to learn either the adverse or normal written strategy for calculating the hundreds and the tens. Their results showed that the normal written sequence resulted in reduced hundreds mistakes and increased unit mistakes when contrasted with the reverse order. In the fourth experiment, they thought that the written page helps the external working storage. The researchers also changed the amount of written information during the calculation process. The results showed that the errors tended to decrease as the amount of typed information increased. All in all, this study showed that the error arises because first information and interim information are stored in the working memory (Hitch, 1978).

Another study was conducted with adolescents to understand inattention, WM and academic achievement referred by Attention Deficit Hyperactivity Disorder (ADHD) (Rogers et al., 2011). The age of participants ranged between 13 and 18. Path analyses were conducted to examine whether verbal and visuospatial WM would be related with inattention symptoms and achievement results. Verbal WM is associated with reading and mathematics, whereas VSWM is related to achievement in mathematics. They proposed that WM is a risk element for academic fault for teenagers who have attentional problems. The experiment was conducted with 145 adolescents. They used clinical interviews, teacher interviews, rating scales, the digit span task, WISC-IV (cf. Rogers et al., 2011; Wechsler, 2003), the corsi block task, WISC-III-PI (Kaplan et al, 1999) and WJ-III (cf. Rogers et al., 2011; Woodcock, 2001) for academic achievement. Their results indicated that there was a statistically significant relation between WM and academic achievement. They indicated that Working Memory is a risk element for teenagers who have attentional problems in academic failure (Rogers et al., 2011).

Another study investigated relations among Working Memory, executive functioning and mathematical achievement at the age of seven (Bull et al., 2008). It was predicted that the academic achievement of children at the age of seven would be related to their WM scores in the past. Thus their hypothesis was that Working Memory, and executive functioning scores in preschool students could estimate academic achievement in the following years. The researchers collected cognitive measures, mathematical outcomes and did reading tasks on children for three times (in the process of entrance to elementary school and at the end of the third and first year of the elementary school). Their results showed that better executive function and the digit span task skills facilitate reading and math abilities among these children. The Visuospatial Working Memory span was found to be a factor of mathematical ability. The analyses showed that although executive function skills were related to general learning, VSWM was directly related to math achievement in this age range (Bull et al., 2008).

Swanson (2016) investigated the relationship between math difficulties (MD), word problem solving and Working Memory. Their target sample included 433 third grade students. Children who had math difficulties solved word problems.. They were selected from students whose score were lower than the 35^{th} percentage on norm-referenced arithmetic word problem solution math test (Test of Math Ability, TOMA, Brown, Cronin & McEntire, 1994). They were chosen from grade three because word problems are added to the curriculum in this grade for the first time. The conceptual span task and the digit span task were employed as WM measures. Swanson indicates two ways of presenting word problems; in the first one, the experimenter read the question to the subject, and then asked them to read it again. After this reading processes, the participants solved the questions by paper and pencil. In the second method, while reading the word problems, the experimenter also showed a picture illustrating the problem. Then it was expected from the participants to verbalize the answer (Swanson, 2014, 2016). Children's WMC scores were specified as low and high. He found that children focused on the irrelevant information, thus leading to attentional deficits.

In the light of these studies, we decided to investigate whether the relationship between working memory and academic achievement could be valid for the adult participants. Thus, we examined the relationship between academic achievement, Working Memory and the solution time of adults in the present study.

Although the central executive, Visuosopatial Working Memory and the phonological verbal Working Memory have an important role in academic achievement in math, Titz and Karbach (2013) indicated that achievement depends on the task employed and the participants' ages. Agostino, Johnson and Pascual-Leona (2010) investigated multiplication word problems and executive functioning. They called WM aspects as "*M-capacity*". They changed the level of difficulty of the problems in some cases and they revealed that problem type matters in the *M- capacity*. Another study showed that although seven-year-old WM capacity predicts math performance, eight-year-old WM capacity and math performance were not correlated (Alloway & Passolunghi, 2011). DeStefsano and LeFevre (2004) indicated that WM components are used collectively in the mental arithmetic problem solving process. Krajewski and Schneider (2009) found that phonological mindfulness has no effect on quantity-number competencies.

The above mentioned studies indicate that there was no correlation between WM and academic achievement in children. In our own study on adults, there are similar findings. The related literature will be discussed in comparison with our own results in the Discussion section.

2.2. Arithmetic Word Problems and Linguistics

Comprehending problem text requires linguistic and cognitive abilities. According to Morton and Qu (2013) students are most challenged in the process of word problem solving not because of only their arithmetic abilities but because of text understanding.

Lewis and Mayer (1987) suggested a model of the comparison process about comparison problems, because they detected that students had more difficulties when the associational term in the comparison problem was incoherent with the required mathematical operation in an eye-tracker study. Hegarty, Mayer and Monk (1995) providing supportive evidence for the findings obtained by Lewis and Mayer. They compared the reading comprehension process of solvers who made mistakes on incoherent problems. They found that accomplished problem solvers began by sampling to construct a cognitive model of the situation that was defined in the problem text. Students planned the solution of this model. They called that model Problem Model Strategy. Participants used two methods to understand the arithmetic problems. In the first approach; that is, the short-cut approach, the problem solver attempted to pick the digits in the problem text and key relational premises like "more" and "less than"; and then developed a solution. In the second approach, the problem solver translated the problem statements into a cognitive model of the circumstance defined in the problem text (cf. Hegarty et al., 1992).

As indicated, arithmetic word problems do not only lead to models in the mind of problem solver. Arithmetic word problems also help to understand the real life scenarios and make the connections between incidents. After deciding to work with word problems, types of word problems were investigated in the mathematical phase in the present study. Our analyses revealed that the major types are number problems, age problems, percentage problems, distance problems, work-pool problems and mixture problems were primary types of arithmetic word problems (e.g., Verschaffel et al., 2000).

Another aspect that has a major role in arithmetic problem solving is the linguistic and nonlinguistic constituent in problem text. According to the Puchalska and Semadeni (1987) there was one numeric answer for verbal arithmetic problems. They indicated this answer number was calculated by using information that was supplied in the question text. If a problem solver wanted to solve these types of questions, pupil had to read the problem text rigorously and judicially before attempting to solve the part before constructing arithmetic relations deduced by problem texts (Puchalska & Semadeni, 1987). Decorte and Verschaffel (1985) found that high amount of students have difficulty in solving word problems because of not analyzing relations of problem situation.

Another study about comprehending linguistics factors in arithmetic word problems was conducted by Lean, Clements and Campo (1990). 2493 children aged from 5 to 15 were asked to solve the same 22 questions. They designated problem difficulty with using semantic factors. They found that children' solution approach differed among groups. They also found that achievement level differed in terms of English language competence.

Gerofsky (1996) remarked that word problems included pragmatic and discourse features, as well. She identified "readability" term, linguistics factors, which indicate whether, the word problems are harder or easier to understand and solve.

Wolff-Micheal Roth (1996) investigated discourse analysis to look at the math learning in the real-life scenarios question texts. He indicated that when a question's contextual level increases, students' engagement is integrated in a higher rate of meaning practices. He revealed that word problems did not become more contextual when students were familiar with the story circumstance in the problem.

In the light of these studies, linguistics aspects of word problems were decided to be analyzed in the lexical types frequency level. Then it was compared with another corpus.

According to the literature (eg., Chall et al., 1995; Coleman et al., 1975) complexity of a text was influenced by its syntactic and grammatical features.

Tokens types, lexical types and their frequencies analyzed at the linguistics level in the comprehending text level which was the first step to solve an arithmetic problem as indicated by Carter and Zahner (2010).

Another aspect was about visual facilitator that was depicted by problem solver in the period of problem solving. Using external visual representations in the period of arithmetic problem solving enhance problem-solving skills. Carter and Zahner (2007) indicated that students spontaneously use self-generated external visual aids in the period of problem solving. These representations were helpful in reaching the right answer. Another finding about the problem text is that if they are forced to think abstractly, students tend to draw more diagrammatic representations (Carter et. al., 2007). Participants are able to tend to apply external visual aids more frequently when they think a problem is complicated and difficult (cf. Carter & Zahner, 2007; Hegarty & Kozhevnikov, 1999; Lowrie & Kay, 2001).

According to the studies with the schoolchildren (e.g., Corter & Zahner, 2007; Lehrer & Schauble, 1998; Penner, Giles, Lehrer, & Schauble, 1996) high school and college students (e.g., Corter & Zahner, 2007; Hall, Bailey, & Tillman, 1997; Hegarty & Just, 1993; Kaufmann, 1990; Mayer, 1989; Mayer & Anderson, 1991, 1992; Mayer &Gallini, 1990; Mayer, Mautone, & Prothero, 2002; Molitor, Ballstaedt, &Mandl, 1989; Santos-Trigo, 1996; B. Tversky, 2001) used the external visual representations in the period of arithmetic problem solving to aid the scientific problem solving.

CHAPTER 3

METHODOLOGY

Computer-based materials and paper-based materials were covered; demographic background of subjects, properties of questions and pilot and experimental methods and the procedures were presented in this chapter. Firstly, a pilot study was discussed. Then main experimental setup and analyses were discussed in this chapter. Lastly, linguistic analyses were presented in the last part of this chapter.

To understand the nature of the arithmetic word problems and their solutions, a pilot study was conducted before the main study. The goal of the pilot study was to investigate diagram depictions, as well as bringing the experimental design to its final stage. In the pilot study, Working Memory components were not studied. Instead visual representations were examined since the most well-known method to store pre-knowledge in mind is taking some short notes in the real-life. Similarly, people tend to draw some visual representations, while solving arithmetic word problems (Carter & Zahner, 2007). Because of all these reasons, visual aids were investigated in the pilot study instead of Working Memory.

3.1. Pilot Study

Hypothesis of this pilot study was that there is a relationship between problem texts and the types of the visual representations drawn in the process of the problem solving. It was decided to find the reasons why some problems need some representational diagrams to be drawn throughout solving arithmetic word problems. Arithmetic word problems included more components than simple symbolic mathematical problems. This pushes problem solvers to take some notes and diagrams as hints on the paper.

Arithmetic word problem texts were chosen from Academic Graduate Exams corpus from 2006 to 2010. Some questions were taken from Emrehan Halıcı’s Brain Games book. 19 questions were chosen for this study. There were two types of questions asked in the exam: one of them includes one problem text and one question, and the other type includes one problem text and two or three questions stemming from this particular question text. Thus the total count of problem texts was 12. Types of questions were exemplified in Figure 3.4, Figure 3.5 and Figure 3.6.

It was decided to look at question texts because it was thought that there has to be some syntactic structures for these types of diagrammatical representation. It was decided that problem texts had to be analyzed deeply. Tokens types, lexical types and utterances were analyzed at the linguistic level in the text comprehending part, which is the first step to solve an arithmetic word problem.

We have analyzed arithmetic word problem texts in the natural language programs (NLP). They were analyzed with ITU toolkit for parsing and part of speech tagging was done. Frequencies for each syntactic class were calculated. They were distinguished as nouns, verbs, and propositions and so on with the help of also Haşim Sak Perceptron 2.0 Software, as well.

An experimental study was carried out with two participants to understand whether these twelve questions trigger visual representations for human subjects. Participants tried to solve chosen arithmetic problems. Their visual drawings and symbols have been collected and classified into two groups: diagram included or excluded. This experimental study was done to decide problem text's visual representations result. According to human subject results, 6 of the questions included visual representations and 6 of them did not include visual representations in the process of solving. In the light of this small study, it was expected to find which level is suitable for investigating the comprehension of problem texts. The most crucial question was that how problem text would be analyzed to observe the similarities between the drawn visual representations and text. Their visual drawings and symbols have been collected and classified according to the Carter and Zahner's (2010) types of the visual aids, which are reorganization of the supplied information, pictures, novel schematic representations, trees, outcome listings, contingency tables, and Venn diagrams.

No significant tendencies were observed in diagram generation. Therefore, we tended to center upon the role of Working Memory components on various aspects of problem solving.

3.2. The Experiment: Participants

The experimental study was conducted with 24 adults (13 males and 11 females). All of these people volunteered to complete this study. Their ages ranged from 21 years to 53 years. The distributions of ages are shown in Figure 3.1 (M= 31.71, SD= 8.277, N=21). All the subjects had corrected to normal vision and normal hearing. All participants had undergraduate degree. Ten of them were graduate students in universities. 14 participants were graduated from quantitative based departments such as engineering. 10 participants were graduated from equally weighted departments such as law school. They were from variety of professions; three of them were research assistants, two of them were lawyers, four of them were civil servants. There was an architect among the participants and nine of them were engineers and the remaining participants were from private sector.

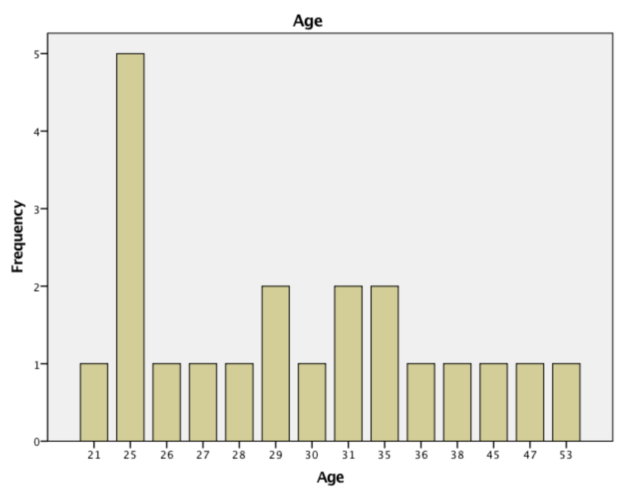

Figure 3.1 Age Distributions of Subjects

Participants provided written permission (see Appendix D) to indicate voluntary participation. In addition, METU Ethical Committee approved the permission.

3.3. Materials

Experiment was composed of two parts. The first part was computer-based. The second part was conducted with the aid of paper and pencil. Features of materials used in each phase were described in this part. In the first phase, with the help of a computer, the digit span test for verbal Working Memory and the Corsi span test for Visuospatial Working Memory were conducted. For the second phase of the experiment, 12 leaflets were prepared. Each leaflet had 20 arithmetic word problems as detailed below. Before starting the experiment, experimental instruction form was presented. It was attached at Appendix E.

3.3.1. Materials for Computer-Based Tests

Python programming language was used to develop the computer-based tool. There were two separate tools: for the digit span task (Swanson, 1992, 2013) and for the corsi span (Milner, 1971) task. Both of them had an integrated database in it. Experimental data were stored in this database. Before the experiment started each time, a pop-up box was seen in the screen and the name or number of the subject was asked. It was preferred to use a subject code to keep the names of the participants confidential. The code included 7 characters. This subject code started with the sequential number like “01”. After number, date information was located such as “1407”. The first two digits represented the date and the second two digits represented the month information. The last character of code was the first letter of the subject’s name. Thus codes were in the form “011407a”. This code was used during all experiments and analyses.

The digit span task started with instruction part. An instruction page was presented before the experiment started. It was defined what is expected from participant. After reading this instruction, the participant did two samples to enhance the understanding of task’s nature. After two trials, the main experiment continued. Some digits from 1-9 were seen in the screen. Then it was expected from participant to write the numbers that they have seen in the right order. Then they were required to use “-“ sign instead of forgotten digits as described in the Figure 3.2.

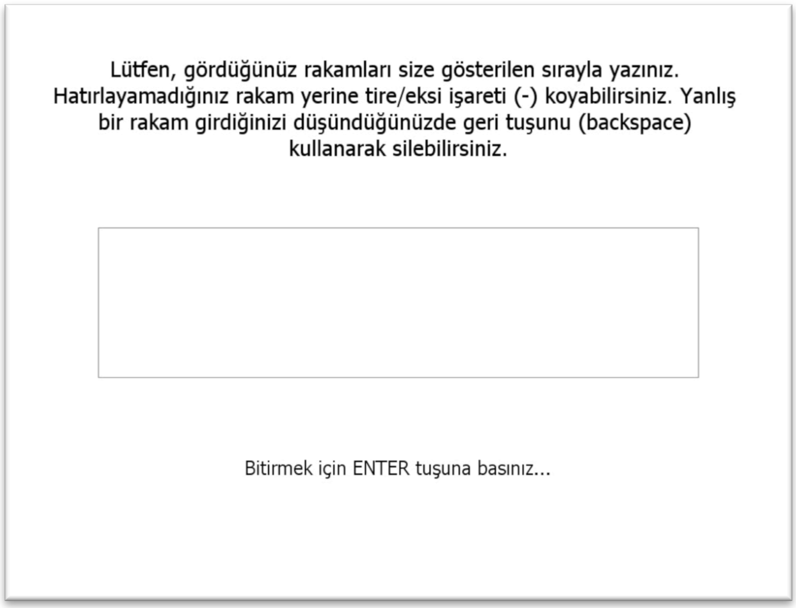

Figure 3.2 A Screenshot from the Digit Span Working Memory Part

Corsi Span Visuospatial Working Memory Task started with the instruction part. An instruction was presented before the experiment started. It was explained what is expected from participants. After reading this instruction, the participants did two samples to enhance the understanding of task. After two trials, the main experiment continued. There were a total of 12 boxes in the screen. Some of them blinked in an order. After showing blinked boxes, there was one second for a blackout. Then mouse cursor appeared. It was expected from participants to click the boxes that had blinked in the right order. Please look at Figure 3.3 too see the VSWM experiment.

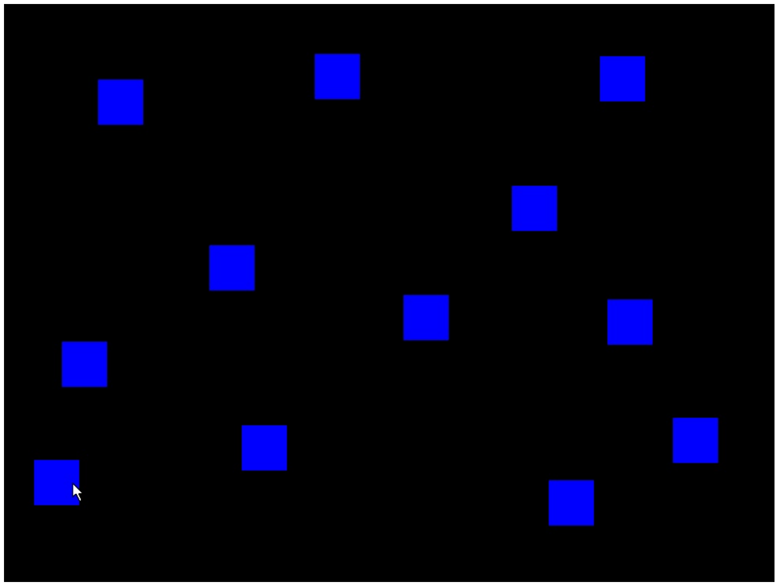

Figure 3.3 A Screenshot from Corsi Span Visuospatial Working Memory Part

3.3.2. Materials for The Problem Solving Phase

Test booklet and demographic data form were distributed to each participant. There were ten pages for the test booklet. Two problems were located in one page. There was one page for the demographic knowledge and one page for the time form. Please look at Appendix C and F to see time record form and demographic data form. Twelve leaflets were created randomly. They were named as A, B, C, D, E, F, G, I H, I, J, K, L, M. Each leaflet had 20 questions. To see the distribution of questions in each leaflet, please see the Appendix A.

3.4. Arithmetic Word Problems in the Experiment

Sixty questions were used in this study. Some representative sample questions were presented in this part. Each participant solved mixed representative questions consisting of 20 questions. Please look at the Figure 3.4, to see a representative question.[2]

Question 1: A number different from zero is multiplied with three and the result is divided to the initial number. What is the division?

Figure 3.4 An Example Question

An example of another question was indicated in Figure 3.5. They included one main narration statement part and more than one questions related with this main task.

Question 2: Eight children sequenced around a circular table from 1 to 8 numbers in the clockwise direction. These kids are playing a counting game. Any child starts to count saying “1” and the others follow counting in an order. The child who says 3 leaves the game. The next child starts counting again starting with 1 and the child who says 3 leaves the game. Counting continues clockwise and game ends when only two children remain.

Question (2.1): If child number 5 starts the counting, which numbered child will remain at the end of the game?

Question (2.2): To keep the children numbered 5 and 8 at the end of the game, which child should start to count?

Figure 3.5 An Example Problem Tex

[2] The questions in the boxes were excerpted from sample Academic Graduate Exams (ALES), conducted by "Measuring, Selection and Placement Center" (ÖSYM) in Turkey. A language expert translated question texts from Turkish to English. The texts from 20 example questions are presented in Appendix B.

Question 3: There are 180 animals in a zoo. Number of herbivorous or carnivorous animals are 9 times of omnivore animals and 3 times of herbivorous animals.

Accordingly, what is the number of carnivorous animals in this zoo?

Figure 3.6 An Example Problem Text

An example question text was presented in Figure 3.6. They included one main narration statement part and one question. A leaflet sample was attached to the Appendix B part.

Participants solved a representative questions, which were composed of three types of questions. There are equal numbers of questions of the same type within solved problems.

Each participant was not able to solve 60 questions because this number was high. Then it was decided to apply standardization and configuration. Therefore, questions were separated into 12 sub sets. Each subset included 20 questions. Leaflets were named as A, B, C, D, E, F, G, I H, I, J, K, L, M. Two subjects solved each leaflet. Thus 8 persons solved each question. The distribution of questions was showed in Appendix A.

3.5. Procedure

3.5.1. Working Memory Tests

The experiment was comprised of two parts. The first phase was consisted of Working Memory tests. This part of the study was conducted in the computer environment. An interface was used to record the digit and the corsi span tasks values as described in the previous section. The digit and thr corsi span tests were conducted in a way that each participant had finished those tests right before solving the word problems.

In the digit span task, each participant saw the numbers in the screen. Then these numbers disappeared. It was expected to write the number seen to the empty field in the screen (Figure 4.2). Seen numbers were between 1 and 9. In the first time, two digits were shown. Each participant had two that have an equal number of digits per trials. Thus each number of digits was seen two times. If at least one of these trials was written correctly, subject was allowed to see the next trial. Otherwise, experiment was finished. Then, number of digits increased up to eight. The maximum number was eight. Each number of digits was seen two times. In the corsi block test, there were 12 boxes in the different parts of the screen (Figure 4.3). They appeared in the screen then disappeared. It was expected from participants to click the shown square boxes after disappearance in turn. Their color changed, thus subjects detected and marked them. The number of blinks in each trial increased by one. Each participant had two trials that have an equal number of blinking boxes per trial similar to the digit span task. The maximum number for the corsi block task was six. Therefore, each participant was able to see a maximum of 6 square boxes blinking, if they did all the blocks correctly.

For both experiments, if subject succeeded in the one of them or two of them, participants were allowed to pass to the next trials of numbers or blocks. Also for both experiments, there were test and main parts.

3.5.2. Arithmetic Word Problem Solving Experiment

After Working Memory experiments, participants were asked to solve 20 questions. Voluntary participation form and demographic data forms were filled by participants (Appendix C and D). The experimenter wrote subject code to the leaflet. Leaflets were distributed randomly. Instruction form distributed firstly and the experimenter would answer questions, if participant asked something before the solving process. Instruction text was added to the Appendix C part. After experiment started, it was not allowed to ask questions during solving process because of the time keeping procedure. Between questions, subjects were allowed to ask questions to the experimenter. There was no time limit for the question solving but elapsed time was recorded for each question. Time record sheet was used for this purpose. Time form was attached to Appendix F.

An experimenter kept a record of the elapsed time by using a chronometer with the help of a cellphone. Experimenter was far away from the participant in order not to disturb the process. Participants were instructed to solve each question without turning back again to the same question. If a participant did not solve a question, time for the giving up was recorded to the time record sheet. They were asked to cover their papers after solving. Therefore, subjects were not able to compare questions with the previously solved ones during problem solving processes. They were asked to say two commands to the experimenter to keep time for each question. They gave "Start" command when they started to solve a question. Then subject gave "Stop" command when they finished solving question. After solving or giving up all questions, the answer key was shown, if subject wondered the answers of the questions.

3.6. Outlier Analysis

According to the collected data, three of the subjects were outliers because two of them had the lowest Working Memory scores. Outliers were calculated according to the outlier's calculation method. Firstly, we ranged the data from the lowest to the highest. Then we calculated the median, lower and upper quartiles. The distance from the lower quartile to the upper quartile was calculated by subtracting lower from upper quartile. Then inner fences and outer fences were calculated. Data lying outside fences were remarked as outliers and omitted from data.

When participants were asked why did not handle the WM task, one of them indicated that his attention was distracted and the other said she was very exhausted and she did not feel self-motivated toward the task but then both of them solved the questions and took a high score from the second part of the experiment but because of their low Working Memory scores, their scores were not used for the analyses. Third outlier's total solution time was very low.

Therefore, he was also eliminated from data. He also indicated his self motivation was low during problem solving process.

3.7. Linguistic Analyses

Arithmetic word problems were composed of many words, thus, had linguistic characteristics. Word problem texts were compared with a plain texts corpus. We selected problem text corpora from Academic Graduate exam corpus. There were a total of sixty questions containing 2255 words. Then, a plain text corpus was selected from METU Turkish Corpus Project. This project corpus included 2 million words in Turkish. It had been continuing from 2002 to 2007. This project was funded by METU-BAP and TUBITAK. We used a very small part out of this corpus. 2255 words were selected. Please look at Figure 3.7 to see an example text.

Driver whipped the horses for not to stuck in the muddle unmercifully. He was going quickly although range of vision was close to zero because of the heavy snow. At last he entered the pits.

Figure 3.7 An Example Text from METU Corpus

To compare two corpora, METU corpus (Say et al., 2002) texts sizes were adjusted according to the question text size. NLP parser tools were used for these analyses. Problem texts and METU Corpus texts were analyzed with the help of computational linguistics parsers. Çağrı Çöltekin's (2014) TRmorph was used ad then an expert checked the data manually. There were twelve word classes which, were noun, verb, adverb, adjective, determiner, pronoun, postposition, punctuation, number, question word, and alpha. Alpha refers to letter that was used for indicating a component in the question texts.

For example, a driver goes A to B. A and B was tagged as alpha type. After parser tagged whole words, a linguistic expert checked and corrected both corpora. Frequencies for each type were calculated for each corpus. Please look at frequency Table 3.1. Results of the analysis were mentioned in the Results chapter.

Table 3.1 Frequencies of Word Classes

PoS TYPE	**METU CORPUS**	**WORD PROBLEMS**
ADJ	245	258
ADV	189	56
CONJ	93	54
DET	137	130
NOUN	977	998
VERB	423	209
NUM	9	307
POSTP	59	98
PRON	111	31
PUNC	1	23
QUES	9	64
ALPHA	0	27

CHAPTER 4

RESULTS

The aim of this study was to explore whether Working Memory has a significant role in the process of arithmetic word problem solving. Another aim of this study was to investigate linguistics components of these types of questions. To analyze these topics four fundamental research questions were asked. Please see table 4.1 to see whole research questions.

Table 4.1 Research Questions for this Thesis

Index	Research Questions
(1)	What is the difference between a usual text and word problem text in terms of syntactic properties?
(2)	Is there a correlation between Working Memory and arithmetic word problem achievement?
(3)	Is there a significant relationship between solution time, Working Memory scores and academic achievement?
(4)	Is there a significant relationship between drawn diagram count, Working Memory scores and academic achievement?

To answer the first question, frequency analyses were applied for both corpora. Their part of speech patterns were expected to be different in terms of frequency. When we look at Table 3.1, it was detected that these two corpora differed with regard to adverb, conjunction, verb, number, pronoun, question word and alpha frequencies. Numbers, punctuations (%), alpha and question word components count were higher in the problem text since problem texts were composed of mathematical items. The postposition type was higher in the problem texts because the mathematical structure requires postpositions such as: “according to” (olduğuna göre). The last difference was in verb frequencies. The verb counts in METU corpus (Say et al., 2002) were higher than the question texts because the question texts often involved question-words “How many” (kaç … vardır) instead a content verb.

Two-way ANOVA was applied to investigate the effects of conditions for the second, third and fourth questions. A comparison was used for the first research question.

4.1. Descriptive Statistics

The digit span task results for each participant, the Corsi Block Span task results, correct answer of each participant, diagram counts drawn by participant during problem solving, total solution time for each participant, gender, age and educational level was recorded during experiments. Comparing these data collection with each other, results were constructed. This part revealed the descriptive statistical information for the analyzed data.

Table 4.2 Mean Table for Variables

Variables	N	Minimum	Maximum	Mean	SD
Correct Number of Answers	21	9	18	14.57	2.420
Digit Span	21	6	8	7.29	.845
Corsi Span	21	5	6	5.67	.483
Diagram Count	21	2	10	6.10	1.841
Solution Time	21	0:16:01	1:32:15	0:42:01	0:17:20
Age	21	21	53	31.71	8.277

Table 4.3 Mean Values for the Corsi Working Memory Test

Corsi	Mean	Frequency
5	13.5	7
6	14.26	14

Table 4.4 Mean Values for the Digit Working Memory Test

Digit	Mean	Frequency
6	11.87	5
7	13.91	5
8	15.85	11

The digit span test started with two digits. Then it increased up to 8 digits. Maximum shown digit was 8. As shown Table 4.4, all the participants took 6, 7, and 8 scores from this task. The corsi block test was started with two blocks. Maximum shown numbers of boxes was 6. As shown in the Table 4.3, participants took 5 and 6 scores from the corsi span task.

4.2. Working Memory and Academic Achievement Relation

A two-way ANOVA was conducted to evaluate the effect of three-value digit and two-value corsi span Working Memory task results on correct numbers of answers. The means and standard deviations for correct numbers as a function of the two factors are presented in Table 4.4. ANOVA determined no significant relation between digit span verbal Working Memory values and the corsi span visuospatial Working Memory task, $F(2,15)=0.30$, $p=0.74$, partial $\eta^2 = .40$. On the other hand, there was statistically significant main effects for the digit span values, $F(2,15)= 4.42$, $p<.05$, partial $\eta^2 = .37$ on WM. It can be shown that, if subjects have high digit Working Memory task capacity, their correct number score can be higher than the one who has limited digit Working Memory task capacity. It was revealed that there was no statistically significant relation between correct number of answers and the corsi Working Memory span, $F(1,15)= .45$, $p=.51$, partial $\eta^2 = .37$. This means that Visuospatial Working Memory has limited effects on arithmetic problem achievement. In addition to the two-way ANOVA, stepwise multiple regression analyses were done. Results showed the same effect. Linear combination of the digit span task results significantly predict the academic achievement of participant, $R^2 = .361$, $F(1, 20) = 10.72$, $p < .05$.

Table 4.4 Means and Standard Deviation for the Correct Count of Answers

Corsi	Digit	Mean	*SD*
5	6	11.0	2.2
	7	13.5	1.5
	8	16.0	1.1
6	6	12.8	1.1
	7	14.3	1.3
	8	15.7	1.0

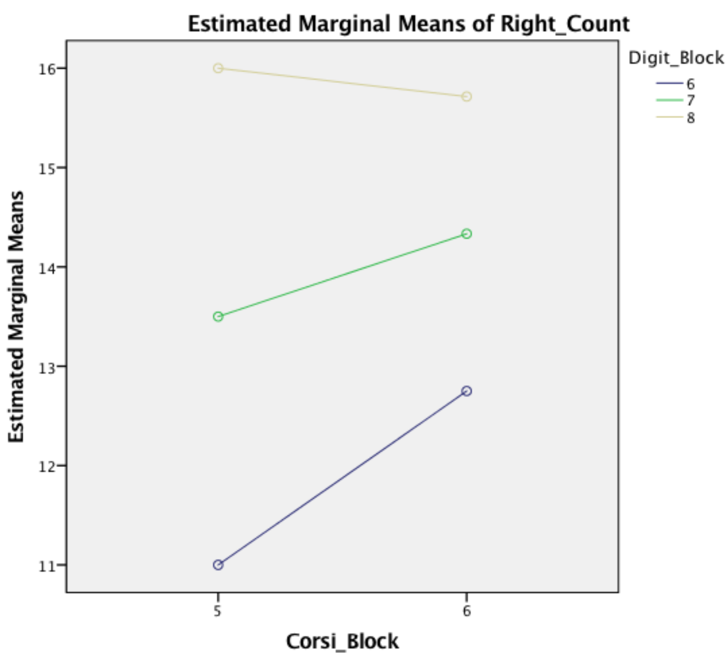

Figure 4.1 Estimated Marginal Means

4.3. Working Memory, Solution Time and Correct Answer Relation

A two-way ANOVA was conducted to evaluate the effect of three-value and two-value corsi Working Memory task results on solution time. The means and standard deviations for solution duration as a function of the two factors are presented in Table 4.5. ANOVA indicated no significant interaction between the digit span verbal Working Memory task values and the corsi span visuospatial Working Memory task, $F(2,15)=0.30$, $p=0.74$, partial $\eta^2 = .32$. There was no statistically significant main effects for the digit span task values, $F(2,15)= 1.47$, $p=.26$, partial $\eta^2 = .160$ on WM. It can be shown that, there was limited effect the digit Working Memory capacity on solution time. It was also revealed that there was no statistically significant relation between solution time and the corsi Working Memory span task, $F(1,15)= .37$, $p=.54$, partial $\eta^2 = .02$. This means that Visuospatial Working Memory has limited effects on solution time.

Table 4.5 Means and Standard Deviation for the Solution Time

Corsi	Digit	Mean	*SD*
5	6	34.87	10.9
	7	32.32	7.7
	8	20.41	5.5
6	6	27.42	5.5
	7	27.10	6.3
	8	22.49	4.1

This analyses was done with the total solution time which includes the time spent both correct and incorrect answers. Then, we did a second analysis just for the total time spent for correct answers. There was no statistically significant main effects for the digit span task values, $F(2,15)= 0.24$, $p=.78$, partial $\eta^2 = .32$ on WM. It was also revealed that there was no statistically significant relation between solution time and the corsi Working Memory span task, $F(1,15)= .53$, $p=.47$, partial $\eta^2 = .34$.

A Pearson product-moment correlation coefficient was used to compute the relationship between solution time and correct answers. There was correlation between these two variables, $r= -.602$, n=21, p=0.004. This means that when solution time increases, right answer decreases. To see the distribution, please look at Figure 4.2.

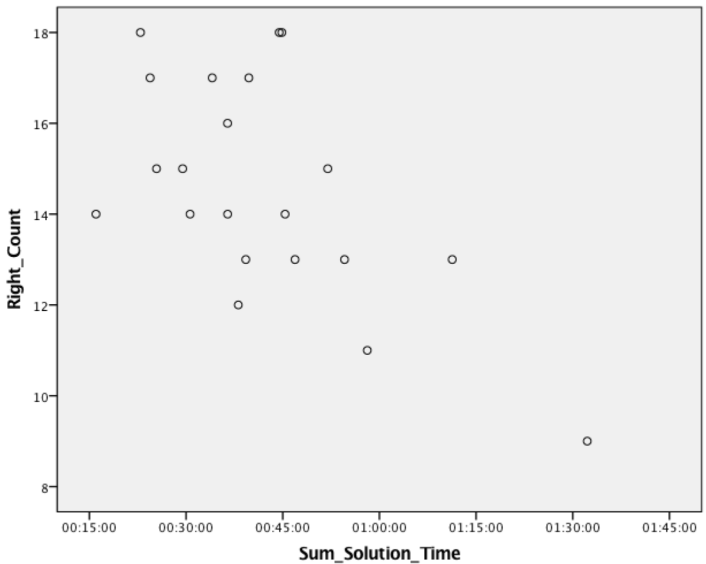

Figure 4.2 Scatterplot for Correct Answer X Solution Time

4.4. Working Memory, Diagram Count and Correct Answer Relation

Drawing diagrams as hint are complex patterns. Some participant tended to draw some visual representations whereas others did not depict any visual aids.

A two-way ANOVA was conducted to evaluate the effect of three-value digit and two-value corsi Working Memory task results on drawn diagram counts. The means and standard deviations for drawn diagram count as a function of the two factors are presented in Table 4.5. It was found that there was no significant interaction between the digit span verbal Working Memory task values and the corsi span visuospatial Working Memory task, $F(2,15)=0.16$, $p=0.85$, partial $\eta^2 = .21$. There was no statistically significant main effects for the digit span task values, $F(2,15)= 0.94$, $p=.41$, partial $\eta^2 = .11$. It can be shown that, there was limited effect the digit Working Memory capacity on diagram count. It was also revealed that there was no statistically significant relation between diagram count and the corsi Working Memory span task, $F(1,15)= .002$, $p=.96$, partial $\eta^2 = .00$. This means that Visuospatial Working Memory has limited effects on drawn diagram count.

Table 4.6 Means and Standard Deviation for the Diagram Count

Corsi	Digit	Mean	*SD*
5	6	4.7	1.1
	7	6.1	0.9
	8	6.5	0.7
6	6	4.8	0.8
	7	6.2	0.9
	8	6.7	0.6

A Pearson product-moment correlation coefficient was computed to assess the relationship between diagram count and correct answers. There was no correlation between these two variables, $r= .332$, n=21, p=0.223. To see the distribution, please look at Figure 4.3.

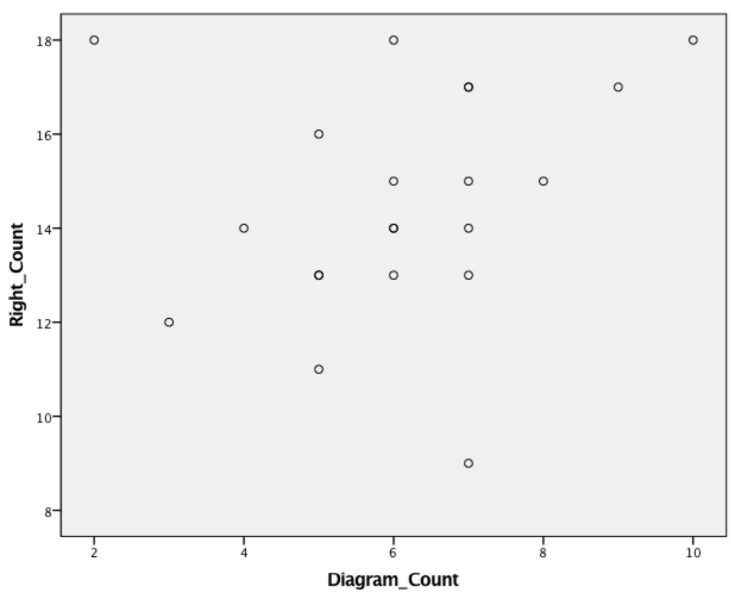

Figure 4.3 Scatterplot for Diagram Count X Correct Answer

4.5. Arithmetic Achievement and Age Effect

Distribution of ages was between 21 and 53. There was one subject in the age 21, 26, 27, 28, 30, 36, 38, 45, 47 and 53. Two subjects' ages were 29-years old, 31-years old, 35-years old. Lastly, there were five subjects whose age were 25 years old.

A Pearson product-moment correlation coefficient was computed to assess the relationship between age and answers. There was no correlation between correct count and age variables, $r = -.286$, $n=21$, $p=.209$.

Table 4.7 Mean Table for Gender

Gender	Mean	Number
Male	13.92	13
Female	15.55	11

A one-way analysis of covariance (ANCOVA) was conducted to investigate the relation between age and the correct answers. Dependent variable was the correct answers and independent variable was age. ANCOVA was not significant about relationship between age and the correct answers, $F(13,7)=2.58$, $MSE=2.88$, $p=0.10$, partial $\eta^2 = .82$.

4.6. Summary of Results

ANOVA determined no significant relation between the digit span verbal Working Memory task values and the corsi span visuospatial Working Memory task, $F(2,15)=0.30$, $p=0.74$, partial $\eta^2 = .40$. There was statistically significant main effects for the digit span task values, $F(2,15)= 4.42$, $p<.05$, partial $\eta^2 = .37$ on WM. It can be shown that, if subjects have high the digit Working Memory task capacity, their correct number score can be higher than the one who have limited the digit Working Memory task capacity. It was revealed that there was no statistically significant relation between correct number of answers and the corsi Working Memory span task, $F(1,15)= .45$, $p=.51$, partial $\eta^2 = .37$. This means that Visuospatial Working Memory had limited effects on arithmetic problem achievement.

It was also found that there was no statistically significant relation between solution time and the corsi Working Memory span task, $F(1,15)= .37$, $p=.54$, partial $\eta^2 = .02$. This means that Visuospatial Working Memory has limited effects on solution time.

There was no statistically significant main effects for the digit span task values on the number of diagrams drawn by the participant, $F(2,15)= 0.94$, $p=.41$, partial $\eta^2 = .11$. It can be shown that, there was limited effect the digit Working Memory task capacity on diagram count. It was also revealed that there was no statistically significant relation between diagram count and the corsi Working Memory span task, $F(1,15)= .002$, $p=.96$, partial $\eta^2 = .00$. This means that Visuospatial Working Memory has limited effects on drawn diagram count.

Lastly, there was no correlation between correct count of answers and age variables, $r= -.286$, n=21, p=.209.

CHAPTER 5

DISCUSSION

The main aim of this thesis was to investigate the relationship between Working Memory and arithmetic word problem achievement. We tried to research how Working Memory components such as Verbal Working Memory and Visuospatial Working Memory affect academic achievement especially in arithmetic word problems. Mainly, four research questions were asked.

The first question was about linguistic properties of problem texts. To deeply understand the ability of word problem solving, question texts were also focused on the linguistic sense, because arithmetic word problems contain many words that are verbs, nouns, numbers, adjectives, adverbs and so on. Another plain text corpus was selected from METU Corpus (Say et al., 2002). Then, these two corpora were compared. It was aimed to reveal the differences between these two corpora. Naturally, syntactic features of arithmetic word problems were different from a plain text corpus contained in novels, and stories. Linguistic aspects of word problems were investigated, because there were some studies in literature about linguistic properties of word problems such as semantic constituents.

Studies showed that pupils are challenged to comprehend the texts of questions in word problem solving processes (Morton & Qu, 2013). During problem solving processes of word problems, pupil has to read the problem text heedfully and critically and should not to attempt to solution part before constructing arithmetic relations deduced from problem texts (Puchalska & Semadeni, 1987). Decorte and Verschaffel (1985) revealed that a high number of students have difficulty solving word problems because of not analyzing relations of the problem setting. There was no specific study comparing word problem corpus with another corpus. Because of that, we thought that investigating lexical frequencies of problem texts, and comparing them with another text could be a milestone, since problem texts includes real-life scenarios, but they differed from a plain text in terms of adverb, conjunctions, verbs, numbers, pronouns, question words and alpha frequencies. Semantic and discourse analyses can be added in the further studies, but we focused WM instead linguistics analyses in this thesis work.

The second research question was about the connection between Working Memory and academic competence in the word problem solution. Working Memory was separated into three components; which are central executive (CE), visuospatial Working Memory, phonological Working Memory (Baddeley, 1986, 1997, 2003). We have investigated two domains, which are phonological verbal Working Memory and visuospatial Working Memory.

There were statistically significant main effects for the digit span task values on correct numbers of answers. It means that subjects with high verbal Working Memory capacity had high arithmetic word problem achievement records. This showed the role of phonological verbal Working Memory on academic performance. This result was consistent with some previous studies that Anderson, Reder and Lebiere (1996), LeBlanc and Weber-Russell (1996), Logie, Gilhooly and Wynn (1994), Swanson, Cooney and Brock (1993) indicated mathematical word problems achievement was dependent on Working Memor (as cited in Swanson & Sachse-Lee, 2001). Study conducted with adolescent also revealed the impact of verbal WM on academic competence (Rogers et al., 2011).

On the other hand, it was found that there was no statistically significant relation between the correct number of answers and the corsi Working Memory span task. This means that Visuospatial Working Memory has limited effects on arithmetic problem achievement. This result was not consistent with the literature completely, but as indicated in Chapter 2, there were also studies arguing the role of WM in academic achievement. Titz and Karbach (2013) indicated that the relation between Working Memory and academic achievement could change according to the task employed and ages of participants. Agostino, Johnson and Pascual-Leona (2010) showed that problem type or complexity matters. Moreover, Alloway and Passolunghi (2011) stated that age matters.

The third research question was about solution duration. There was no relation between solution duration and WM, but there was a correlation between solution time and correct answers. This means that when solution time increases, number of correctly answered questions decreases.

The last research question investigated relationship between drawn diagram count, Working Memory scores and academic achievement. There were studies about visual representations and mathematics. Carter and Zahner (2007) indicated that students automatically use self-generated external visual representations when solving problems. These representations are helpful to reach the right answer. We did not find statistically significant results for the relation between achievement and drawn diagram counts. Many studies were conducted with children, but ages of participants in our target group ranged between 21 and 53. Perhaps, this contrast rose from this difference because adults are more inclined to solve questions quickly.

It was detected that Working Memory and academic achievement studies were conducted with children in most studies. Our target group was different. Their education level, ages, graduated departments were different. Possibly this comes from the fact that we could not find the same results with previous studies since they used the same age-level in their experiments.

5.1. Limitations

The thesis had several limitations. Firstly, the sample size of the study (24 participants) was not adequately high. Any unclear results we obtained might have resulted from the low sample size.

Secondly, to the best of our knowledge, there are no studies about the adults' WM and academic achievements. We assume, as age increases, individual differences between adults also increase. We were unable to control such differences. We considered Working Memory as an independent variable that does not change in years, but among other things, the adult participants' background and mathematical enthusiasm are varied.

Thirdly, to the best of our knowledge, the literature is limited in terms of the linguistic analysis for word problems. To fill this gap, we analyzed all the question texts (word problems) in terms of their POS frequencies. However, it was not an easy task to combine the results with the Working Memory data. Moreover, we chose a random portion of METU Corpus (2250 words) for analysis but we cannot claim that this was a representative portion of the corpus. Thus, its comparison with word problems could not be done reliably. In addition to this, the word problems cover various types, which are much broader than the ones covered by present study.

Fourth, according to the results, participants were successful in the corsi span Working Memory task with very high scores. All our participants scored 5 or 6 points (the maximum) from this task. Hence, the participants' achievement in this test was not a useful variable for our analyses. It might be due to this that we were not able to find a correlation between the corsi span Working Memory test and other types of data in the study. The maximum score for the Visuospatial Working Memory could have been higher. Thus, this was a limitation for seeking relationships between Visuospatial Working Memory and arithmetic word problems achievement.

Finally, neurological and Working Memory studies mostly focus on basic arithmetic abilities, such as subtraction and addition. We chose more complex questions for the current study, and this brought further problems; we were confronted with a range of factors (e.g. low motivation, variations in reading comprehension abilities) that had to be considered as the source of difficulties during participants' problem solving. An additional limitation was that setting the same level of difficulty for all questions was impossible.

5.2. Future Work

Considering the limitations above, a future study can be conducted on adult participants who are from the same educational level or within the same age range. In our study, some participants reported that, due to their age, they forgot how to solve the types of problems in focus. On the other hand, participants whose ages are 21-26 reported that they are familiar with these types of questions. Most participants of this age range still continue to take exams involving word problems. Thus, being familiar with such problems affected the results. In the future, a homogenous group of participants (e.g. graduate-level university students) can be chosen.

In our study, the participants were (i) expected to comprehend the mathematical meaning of entities in word problems (*sıfırdan farklı bir sayı* 'a number that is not 0" in the question *Sıfırdan farklı bir sayının üç katı alınır ve sonuç başlangıçtaki sayıya bölünürse bölüm kaç olur*?); (ii) how the entities are related with each other (e.g. *sıfırdan farklı bir sayı* 'a number that is not 0" and *başlangıçtaki sayı* "the initial number"), (iii) they were expected to remember the semantic relation between the entities so that they can solve the question. Such issues are likely to concern the Central Executive (the supervisory system controlling the VisuoSpatial WM and Verbal Working Memory). Further studies can focus on the Central Executive.

We analyzed the problem texts on the POS level but the level of linguistic analyses should be improved and varied. For example, the word problems could be analyzed in terms of the abstractness/concreteness of the lexical items and categorized as more or less abstract problems. The effect of abstractness may be sought on level of difficulty.

Since there is no arithmetic word problems corpus in Turkish, we had to compared arithmetic problem texts with METU Turkish Corpus, whose genres are not compatible. This suggests that a corpus of word problems is needed. In the future, the problem texts can be compared with such a corpus.

Methodologically, further experimental methods can be added to the study, for example, in the process of data collection. Participants' solutions can be video-recorded for further analysis of the participants notes, drawings, etc. or steps of solutions. These can help understand the overall word problem solving process. An eye-tracker component can be added to this setting to capture various phases (e.g. text comprehension, problem solving) that the participants go through during problem solving.

Lastly, Working Memory is limited. No one can store too many digits after reading them just once. This suggests that WM capacity is a physiological issue. An FMRI study can be carried out to understand the memory region of the brain that is active during such problem solving processes.

CHAPTER 6

CONCLUSION

Solving an arithmetic word problem requires many mental faculties (Swanson, 2016). Word problems are composed of more abstract and concrete concepts than other types of arithmetic questions, and they are longer. Terms identifying duration, the entities of the problems (proper names), and digits are located in the texts. Reasoning abilities, mathematical problem solving abilities, text comprehension and the components of Working Memory have to be used simultaneously in the solving procedure of these types of problems. Baddeley (1986) indicates that Working Memory stores executive relational knowledge simultaneously with each other. Geary (2004) argues that mathematical abilities consist of both conceptional and procedural competencies.

Baddeley (1986) divides WM into three fundamental components; central executive (CE), visuospatial Working Memory (VSWM) and phonological Working Memory (Baddeley, 1986, 1997, 2003). According to Baddeley (1986), Working Memory is a cognitive perfection. Working Memory's role in academic achievement was investigated in previous research. A considerable amount of studies showed its importance in academic success, particularly in the field of mathematics (as cited in Corter & Zahner, 2007).

The main aim of this study was to investigate the role of Visuospatial Working Memory and Verbal Working Memory on arithmetical word problem competence. An experimental study was conducted to investigate the role of WM on the academic achievement of word problems. 24 adult participants participated in two phases of the study; WM tasks (the digit span and the corsi span tasks) and a problem-solving task.

The findings showed that there was a statistically significant main effect between the digit span task values and academic word problem achievement, $F(2,15) = 4.42$, $p < .05$, partial $\eta^2 = .37$. It was revealed that when the participant has higher the digit Working Memory task capacity, their word problem achievement was higher than that of those who have lower the digit Working Memory task capacity and vice versa.

A secondary aim of this thesis was to reveal the differences between a plain corpus and the problem texts corpus. Texts of both corpora were compared in terms of parts of speech and their frequencies. Their part of speech patterns were expected to be different in terms of frequency. The results showed that these two corpora differed with regard to the use of adverbs, conjunctions, verbs, numbers, pronouns, question words and alpha frequencies.

In conclusion, the main finding of the study was that Phonological Verbal Working Memory had an effect on academic achievement in the field of mathematical word problems solving. Secondly, the frequencies of lexical types in word problems texts were different from an ordinary corpus that was selected from METU Corpus (Say et al., 2002).

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APPENDICES

APPENDIX A

Distribution of Questions

INDEX	A	B	C	D	E	F	G	H	I	K	L	M
(1)	1	2	3	4	5	6	7	8	9	10	11	12
(2)	1	2	3	4	5	6	7	8	9	10	11	12
(3)	13	14	15	16	17	18	19	20	21	22	23	24
(4)	13	14	15	16	17	18	19	20	21	22	23	24
(5)	25	26	27	28	29	30	1	2	3	4	5	6
(6)	25	26	27	28	29	30	1	2	3	4	5	6
(7)	7	8	9	10	11	12	13	14	15	16	17	18
(8)	7	8	9	10	11	12	13	14	15	16	17	18
(9)	19	20	21	22	23	24	25	26	27	28	29	30
(10)	19	20	21	22	23	24	25	26	27	28	29	30
(11)	12	11	10	9	8	7	6	5	4	3	2	1
(12)	12	11	10	9	8	7	6	5	4	3	2	1
(13)	24	23	22	21	20	19	18	17	16	15	14	13
(14)	24	23	22	21	20	19	18	17	16	15	14	13
(15)	6	5	4	3	2	1	30	29	28	27	26	25
(16)	6	5	4	3	2	1	30	29	28	27	26	25
(17)	18	17	16	15	14	13	12	11	10	9	8	7
(18)	18	17	16	15	14	13	12	11	10	9	8	7
(19)	30	29	28	27	26	25	24	23	22	21	20	19
(20)	30	29	28	27	26	25	24	23	22	21	20	19

APPENDIX B

A Sample Questions Leaflet – Type A

SORULAR - A KİTAPÇIĞI

No:

1) Sıfırdan farklı bir sayının üç katı alınır ve sonuç başlangıçtaki sayıya bölünürse bölüm kaç olur?

2) 40 kişilik bir sınıftaki öğrencilerin 20'si esmer, kalanı sarışın, 21'i gözlüksüz kalanı da gözlüklüdür. Bu sınıfta 12 gözlüklü sarışın öğrenci olduğuna göre esmer öğrencilerin kaçı gözlüksüzdür?

3) 4 kişilik bir ailenin yaşları toplamı 82'dir. 3 yıl sonraki yaşları toplamı kaç olur?

4) Kısa kenarı a cm uzun kenarı b cm olan dikdörtgen biçimindeki bir levha ısıtılıyor. Isıtıldıktan sonra levhanın her bir kenar uzunluğunun % 10 arttığı gözlemleniyor.

- Isıtıldıktan sonra levhanın alanı yüzde kaç artmıştır?

- Isıtıldıktan sonra levhanın çevresinin uzunluğunun ısıtılmadan öncekine oranı kaçtır

5) 2/7'si boş olan bir su deposundaki suyun 1/5'i kullanılınca deponun dolması için 45 litre su gerekmektedir. Buna göre bu depo kaç litreliktir?

6) 40 m ve 30 m uzunluğundaki iki direğe 60 m uzunluğundaki bir ip bağlanmıştır. Cambaz ipe tutunarak gösteri yapacaktır. Tutma noktasında ipin yerden yüksekliği 5m olduğuna göre iki direk arasındaki uzunluk nedir?

7) 20 kişilik bir sınıfta kızların yarısı ve erkeklerin 1/3'ü ayrılınca sınıfta 12 kişi kalıyor. Sınıfta başlangıçta kaç kız öğrenci vardır?

8) Daire biçimindeki bir masanın çevresine dizilen sekiz çocuk, saat yönünde 1'den 8'e kadar numaralanmıştır. Bu çocuklar şöyle bir sayma oyunu oynuyorlar. Herhangi bir çocuk 1 diyerek saymaya başlıyor. Numara sırasına göre, bir sonraki çocuk 2, ondan bir sonraki çocuk da 3 diyor. 3 diyen çocuk oyundan çıkıyor. Bir sonraki çocuk tekrar 1 den saymaya başlıyor ve yine 3 diyen çocuk oyundan çıkıyor. Sayma işi bu şekilde saat yönünde devam ediyor ve geriye iki çocuk kalınca oyun bitiyor.

- Saymaya 5 numaralı çocuk başlarsa, oyun bittiğinde kaç numaralı çocuklar kalır?

- Oyunun sonunda 5 ve 8 numaralı çocukların kalması için, saymaya kaç numaralı çocuk başlamalıdır?

9) Bir paltonun fiyatı pantolonun fiyatının 4 katıdır. Paltoyu % 10 karla pantolonu % 40 zararla satan bir satıcının bu satıştaki kar zarar durumu için ne söylenebilir?

10) 180 hayvanın bulunduğu bir hayvanat bahçesinde etçil veya otçul olan hayvanların sayısı; hem etçil hem de otçul olan hayvanların sayısının 9, yalnızca otçul olan hayvanların sayısının da 3 katıdır. Buna göre bu hayvanat bahçesinde yalnızca etçil olan hayvanların sayısı kaçtır?

11) 200 gram şekerli suyun % 25'i şekerdir. Şeker oranını % 40’a çıkarmak için kaç gram su buharlaştırılmalıdır?

12) A sürücü kursu 510 TL’ye 72 saat teorik, 20 saat direksiyon dersi veriyor. B sürücü kursu ise 585 TL’ye 60 saat teorik, 25 saat direksiyon dersi veriyor. Her iki kursta da direksiyon dersinin saat ücreti teorik dersin saat ücretinin 3/2’si kadardır.

- A sürücü kursunda 1 saat direksiyon dersi kaç TL’dir?

- B sürücü kursunda teorik derslere ödenen ücret kaç TL’dir ?

13) Şeker oranı % 25 olan 32 litre şekerli suyun şeker oranını % 20’ye düşürmek için kaç litre saf su eklenmelidir?

14) İki gezegen güneş etrafında dönmektedir. Gözleme başlama anında güneş ve iki gezegen odak noktalarını birleştiren bir doğru üzerindedir. Büyük gezegen güneş etrafındaki yörüngesini 19 yılda, küçük olan gezegen ise 8 yılda tamamlamaktadır. Bu üçlü aynı doğru çizgi üzerinde kaç yıl sonra buluşurlar?

15) 4 yıl önce babanın yaşı oğlunun yaşının 4 katından 2 eksiktir. 7 yıl sonra babanın yaşı oğlunun yaşının 2 katından 9 fazladır. Buna göre baba kaç yaşındadır?

16) İki araç çember biçiminde bir pist üzerinde aynı anda sabit hızlarla harekete başlıyor. Araçlar aynı yönde hareket ederse hızlı olan araç pist üzerinde bir tur atıp 30 dakika sonra diğer araca yetişiyor. Zıt yönde hareket ederse de araçlar 10 dakika sonra karşılaşıyorlar. Buna göre hızlı olan aracın hızı diğerininkinin kaç katıdır?

17) Bir kümeste tavuk ve tavşanlar bulunmaktadır. Toplam ayak sayısı 118 baş sayısı 39 olduğuna göre bu kümeste kaç tane tavşan vardır?

18) Bir apartmanın girişinde numaraları 1 2 3 4 5 ve 6 olan altı posta kutusu vardır. Bu posta kutularıyla ilgili olarak aşağıdakiler bilinmektedir. Her kutuda en az 1 mektup vardır. Her kutudaki mektup sayısı o kutunun numarasından farklıdır. Örneğin 5 numaralı kutudaki mektup sayısı 5 değildir. Kutulardaki mektup sayıları birbirine eşit ya da birbirinden farklı olabilir.

- 1 ve 2 numaralı kutularda eşit sayıda mektup olduğuna göre kutulardaki toplam mektup sayısı en az kaçtır?

- 2 ve 4 numaralı kutularda toplam 5 tane, 4 ve 5 numaralı kutularda toplam 7 tane mektup olduğuna göre 5 numaralı kutuda kaç mektup vardır?

19) Bir gruptaki erkeklerin sayısı kadınların sayısının 4 katıdır. Gruptan 18 erkek ayrılıp 3 kadın katılırsa erkeklerin sayısı ile kadınların sayısı eşit oluyor. Buna göre grup başlangıçta kaç kişidir?

20) Bir otelde 10'u tek kişilik, 15'i çift kişilik, 20'si 3 kişilik toplam 45 oda bulunmaktadır. Tam kapasite dolu olan bu otelle ilgili olarak aşağıdakiler bilinmektedir. Yerli müşteriler ya tek kişilik ya da 3 kişilik odalarda kalmaktadır. Yabancı müşteriler ya tek kişilik ya da çift kişilik odalarda kalmaktadır. Otelin 21 odasında yabancı müşteri kalmaktadır. Buna göre, otelde kaç yerli müşteri kalmaktadır?

APPENDIX C

Demographic Data Form

KATILIM ÖNCESİ BİLGİ FORMU – DEMOGRAFİK BİLGİ FORMU

Bu çalışma ODTÜ Enformatik Enstitüsü Bilişsel Bilimler Anabilim Dalı Öğretim Üyesi Yrd. Doç. Cengiz Acartürk ve yüksek lisans öğrencisi Fatma Demirel tarafından hazırlanmıştır.

Yapılan çalışmalar kısa süreli bellek ile işlem kapasitesi arasında bir ilişki olduğunu ortaya çıkarmıştır. Bu çalışmada matematiksel aritmetik soruların çözümünde kısa süreli belleğin rolü, metin işleme kapasitesi ile ilişkili olarak incelenmektedir. Ayrıca soru çözüm süreçlerinde ortaya çıkan uzamsal görsel öğelerin aritmetik kelime sorularının çözümündeki rolü de araştırılacaktır.

Aşağıda yer alan demografik bilgileri doldurmanız çalışma için önemlidir. Belirtmiş olduğunuz bilgiler gizli tutulacaktır.

1) Yaşınız:

2) Cinsiyetiniz:

( ) Erkek ( ) Kadın

3) Mesleğiniz:

4) Eğitim düzeyiniz:

( ) İlköğretim
( ) Lise
( ) Üniversite
( ) Lisansüstü

Çalışmamıza katıldığınız için teşekkür ederiz.

APPENDIX D

Voluntary Participant Form

Gönüllü Katılım Formu

Bu çalışma ODTÜ Enformatik Enstitüsü Bilişsel Bilimler Anabilim Dalı Öğretim Üyesi Yrd. Doç. Cengiz Acartürk ve yüksek lisans öğrencisi Fatma Demirel tarafından hazırlanmıştır.

Yapılan çalışmalar kısa süreli bellek ile işlem yapma kapasitesi arasında bir ilişki olduğunu ortaya çıkarmıştır. Bu çalışmada matematiksel aritmetik soruların çözümünde kısa süreli bellek kapasitesinin rolü metin işleme kapasitesi ile ilişkili olarak incelenmektedir. Ayrıca sou çözüm süreçlerinde ortaya çıkan uzamsal görsel öğelerin aritmetik kelime sorularının çözümündeki rolü de araştırılacaktır.

Anket, genel olarak kişisel rahatsızlık verecek soruları içermemektedir. Ancak, katılım sırasında sorulardan ya da herhangi başka bir nedenden ötürü kendinizi rahatsız hissederseniz cevaplama işini yarıda bırakıp çıkmakta serbestsiniz. Böyle bir durumda anketi uygulayan kişiye, anketi tamamlamadığınızı söylemek yeterli olacaktır. Anket sonunda, bu çalışmayla ilgili sorularınız cevaplanacaktır. Bu çalışmaya katıldığınız için şimdiden teşekkür ederiz.

Bu çalışmaya tamamen gönüllü olarak katılıyorum ve istediğim zaman yarıda kesip çıkabileceğimi biliyorum. Verdiğim bilgilerin bilimsel amaçlı yayımlarda kullanılmasını kabul ediyorum. (Formu doldurup imzaladıktan sonra uygulayıcıya geri veriniz).

İsim Soyad   Tarih   İmza

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APPENDIX E

Experiment Instruction Text

Deney Yönerge Metni

- Deney iki kısımdan oluşmaktadır. Bilgisayar ortamında yapılan kısım yaklaşık 5 dakika yazılı olarak uygulanan kısım yaklaşık olarak 25 dakika sürmektedir. Deney süresince bazı matematik soruları çözmeniz beklenmektedir.
- Lütfen deney süresince tüm soruları çözmeye gayret ediniz. Çözüme ulaşamasanız bile çözüm için yapmış olduğunuz hesaplamalar çalışma için önemlidir.

- Deney süresince süre bilgisi toplanmaktadır. Bu nedenle deneyi uygulayan kişi deney ortamında sadece süre bilgisi tutabilmek için bulunacaktır.

- Lütfen soru atlayarak çözüm yapmayınız. Her bir soru için sırasıyla çözüm yapınız. Sonucu bulamadığınız sorular için bir sonraki soruya geçiş süreniz kaydedilecektir.

- Geçmiş olduğunuz soruyu tekrar çözme şansınız bulunmamaktadır.

- Deney sırasında varsa sorularınızı çözümlerin arasında sormanız beklenmektedir. Lütfen çözüm esnasında deneyi yapan kişi ile konuşmayınız.

Katılımlarınız için teşekkür ederiz.

APPENDIX F

Time Record Form

Süre Bilgisi Formu

Test Tipi:

Denek Numarası:

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