# INDIVIDUAL DIFFERENCES IN PERFORMANCE ON PERCEPTUAL MULTIPLE CUE PROBABILITY LEARNING TASKS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF INFORMATICS INSTITUTE
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
PHILOSOPHY OF DOCTORATE
IN
THE DEPARTMENT OF COGNITIVE SCIENCES

JANUARY 2013

INDIVIDUAL DIFFERENCES IN PERFORMANCE ON PERCEPTUAL MULTIPLE CUE PROBABILITY LEARNING TASKS

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# ABSTRACT

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January 2013, 149 pages

What makes an individual, or as the initial motivation of this study, a pilot, perform above the average in a complex task where speed is the primary concern? The answer of this question is closely related to the task and the individual in the task environment. It is plausible to model such a task by mapping it to responding to several stimuli (cues) that are related to a environmental variable (criterion). This model actually corresponds to a judgment analysis paradigm, studied extensively in the literature, and known as Multi Cue Probability Learning (MCPL).
Properties of task, such as cue presentation mode (e.g. analog or digital), or individual differences in cognitive abilities (such as attentional mechanism, verbal and visual working memory, executive control, etc.) may effect the learning performance. Furthermore, presentation mode which is compatible with the decision maker's cognitive capability may create an advantage in learning performance.
Using MCPL paradigm, and manipulating the presentation and response modes in a typical MCPL task, as graphical and numerical, four experiments were conducted, and learning performance of the participants was measured as the dependent variable. Individuals' working memory capacity was assessed by means of several working memory capacity span tasks.
Results suggest that learning performance in graphical mode of MCPL task, is su-

perior as compared to numerical mode. The main effect of verbal working memory capacity measure is significant so that it can explain the variance in the learning performance irrespective of the presentation style. In certain task settings, visuo-spatial working memory capacity interacted with the presentation mode so that it affects learning performance when mode of presentation is graphical rather than numerical. As opposed to initial predictions, verbal working memory capacity does not interact with MCPL task modality, pointing in the direction of a single dissociation between the learning performances in graphical and numerical modes of the MCPL task.
As result of this study we have found that the numerical and graphical presentation and response modalities and working memory capacity of decision maker is effective in the performance of MCPL tasks. Furthermore these factors interacts with each other such that when the cognitive ability and the modality are congruent with each other, there occurs a significant performance increase in learning. This and follow-up studies may have implications on designing human computer interfaces and predicting performance based on measured cognitive abilities.

Keywords: decision making, MCPL, working memory, individual cognitive differences

# ÖZ

ALGISAL "ÇOKLU İŞARET OLASILIKSAL ÖĞRENME" GÖREVLERİNİN PERFORMANSINDA KİŞİSEL FARKLILIKLAR

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Ocak 2013, 149 sayfa

Bir bireyin veya bu çalışmanın motivasyon kaynağı olarak bir pilotun, çabukluğun öncelikli olduğu karmaşık görevlerde, ortalamanın üstünde performans sergilemesine yol açan etkenler nelerdir? Bu sorunun cevabı görevin kendisi ve bireyin içerisinde bulunduğu çevre ile yakından ilişkilidir. Böyle bir görev birkaç uyarıcının (ipucu) oluşturduğu desenlere çabuk ve uygun (kriter) bir şekilde karşılık vermek olarak karakterize edilebilir. Bu tür bir görev aslında literatürde Çoklu İşaret Olasılık Öğrenme olarak bilinen ve oldukça yoğun bir şekilde irdelenen bir hüküm analiz paradigmasına karşılık gelmektedir.

Bir görevin işaret gösterim modu gibi farklılıkları veya bireyin görsel ve sözel belleği, dikkat mekanizmaları veya yönetimsel kontrol gibi bilişsel farklılıkları öğrenme performansını etkileyebilir. Dahası, bireysel farklılıklar ile uyuşan gösterim modları öğrenme performansında avantaj yaratabilir.

Bu çalışmada, Çoklu İşaret Olasılık Öğrenme paradigması kullanılarak, işaret ve geri besleme ekranlarının gösterim ve yanıt biçimleri değiştirilerek ve çeşitli çalışma belleği ölçümleri kullanılarak, dört adet deney yürütülmüş, bireyin öğrenme performansı bağımlı değişken olarak ölçümlenmiştir.

Elde edilen sonuçlara göre grafiksel gösterim durumunda oluşan öğrenme perfor-

mansının sayısal gösterim ile karşılaştırıldığında daha üstün olduğu anlaşılmaktadır. Ayrıca sözel çalışma belleğinin öğrenme performansı üzerindeki etkisi incelendiğinde, gösterim modu ne olursa olsun, istatistiksel olarak anlamlı bir etkiye sahip olduğu görülmüştür. Belli görev ayarlarında, görsel belleğin gösterim biçimi ile etkileşime girdiği ve görsel bellek kapasitesinin yüksek olmasının grafiksel moddaki başarıyı etkilerken sayısal modda bir etkisinin olmadığı görülmüştür. Beklentilerin aksine, sözel belleğin böyle bir etkileşime girmediği görülmüştür.

Bu çalışmanın sonuçlarına göre sayısal ve grafiksel gösterim ve yanıt biçimlerinin ve karar vericinin çalışma bellek kapasitesinin öğrenme performansında etkin olduğu anlaşılmıştır. Ayrıca bilişsel yeteneğin gösterim ve yanıt biçimi ile uyumlu olması durumunda perfromansın kayda değer bir biçimde artığı bulunmuştur. Bu ve takip eden çalışmaların insan makina arayüzü tasarlanması ve öğrenme performansının ölçülen bilişsel yetenekler ışığında tahminlenmesinde kullanılabileceğini yönünde sonuçları bulunmaktadır.

Anahtar Kelimeler: karar verme, çoklu işaret olasılık öğrenme, bireysel bilişsel farklılıklar, çalışma belleği

*To my loved, precious and sweet wife and twins. To my father, whose lack will always be felt.*

# ACKNOWLEDGMENTS

This was a very long journey and during this journey, I have been supported by a great number of individuals. My supervisors, Bilge Say and Fergus Bolger have been a guiding mentor and motivator with immense knowledge. I would like to express my sincere gratitude to them for their support, encouragement and patience.

I am heartily thankful to my administrative supervisors and Thesis Progress Committee members, Kürşat Çağıltay and Didem Gökçay. They were always supportive with their questions, comments and suggestions.

I would like to thank the rest of my thesis committee: Murat Perit Çakır, Erol Özçelik and Cengiz Acartürk for their helpful comments, and guiding questions.

I am indebted to my colleague, Serkan Çak who supported me with his comments and proof reading.

Last but not the least, I would like to thank my family: my wife, for her love and support in each step of this long journey; my parents for their endless encouragement and support.

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| | |
|---|---|
| **AOSPAN** | Automated Operation Span |
| **BDS** | Backward Digit Span |
| **CBT** | Corsi Block Tapping |
| **MCPL** | Multi Cue Probability Learning |
| **METU** | Middle East Technical University |
| **OSPAN** | Operation Span |
| **PC** | Personal Computer |
| **SJT** | Social Judgment Theory |
| **STM** | Short Term Memory |
| **WMC** | Working Memory Capacity |
| **WM** | Working Memory |

# CHAPTER 1

# INTRODUCTION

This study aims to investigate the factors that affect the performance of individuals judging about a criterion, where the criterion is probabilistically linked to a set of cues available to the decision maker. The investigation will be done by identifying performance differences for different kind of presentation/response styles and identifying the effects of individual differences in working memory capacity (WMC) that may take role in the performance.

What makes an individual, or as the initial motivation of this study, a pilot, perform above the average in a complex task where speed is the primary concern? The answer of this question is closely related to the task that is executed. Such a task can logically be characterized by responding appropriately to a set of stimuli (cues) in an environment in which some uncertainties exist. Being a good judge, in such an environment, requires learning the relationship between the stimuli and criterion and respond accordingly. How well and how quick the relationship is learned, presumably, is effected by the cognitive capabilities of the judge.

The environment of a pilot navigating in the air is the cockpit in which there are a lot of display devices such as flight instrument displays, additional navigational aids and tactical information. The information provided by the sensors and other sources contains some degree of error. Additionally, this information is used to compute several criteria at a level of uncertainty caused by unreachable information. The errors and uncertainties existing in the cockpit environment introduce a probabilistic environment in which pilots must adapt themselves in order to judge about criteria before taking actions. In literature, one way of studying the learning probabilistic relationships is using a paradigm known as Multi Cue Probability Learning (MCPL). MCPL researchers investigate the learning by focusing on the accuracy of the decision maker in a probabilistic environment. MCPL is a branch of Social Judgment Theory (SJT) (Hammond, Stewart, Brehmer & Steinmann, 1975) which is the application of Egon Brunswik's ideas (Brunswik, 1955) about perception, to the Judgment and Decision Making (JDM) research.

Egon Brunswik is one of the key scholars, who virtually initiated a prominent judgment research paradigm. According to Brunswik, the environment in which the organism is functioning, is the key element that defines the behavior of the individual. Brunswik (1955) actually proposes the "Lens model" as the metaphor to capture the behavior of the individual. This model is called as "lens" because the explanation provided by it analogous to the physics of a lens. As the ray of light coming from a distal object is finally integrated into an image by passing through a lens, cues of the distal variable are selected during perception by the organism and integrated into the final perceived object.

According to Brunswik, an organism can never be sure about environment and this produces an *uncertainty* (Doherty & Kurz, 1996). Therefore, the relationship between the organism and the environment can only be defined by using a *probabilistic* approach. This approach is probabilistic because the relationship between distal stimulus and proximal cues are not one-to-one and casual, but some kind of stochastic process. As a result, proximal cues are probabilistic indicators of the distal variable (Dhami, Hertwig & Hoffrage, 2004).

In one branch of the judgment and decision making research, which is based on the Brunswik's ideas, Multi Cue Probability Learning (MCPL) paradigm is extensively used for assessing the learning performance of the decision makers. As being an application of Social Judgment Theory (Hammond, 1971) which provides quantitative analysis of judgments, this paradigm provides experimental methods and analysis tools for assessing the learning performance of the individual. In this methodology, participants first experience usually a large number of trials where, in each trial, a combination of cues is presented, then the individual responds by making a judgment, and then usually an outcome feedback is given. Participants' learning (known as "achievement") is evaluated by means of a set of trials where judgments are made without taking feedback. In a typical MCPL task, there are a variety of factors, related to task and environment in which the task is executed. These factors affect the cognitive processes that occur during learning. Relevance of cues to the criterion, interdependence or redundancy of the cues, complexity and dynamics of the task environment, polarity of the relationship between cues and the criterion, presentation style of cue values and feedback values, and the response mode are among those factors. The effect of polarity of the relationship between cues and criterion is experimentally studied by several researchers (e.g. Chasseigne, Mullet & Stewart, 1997 and Rolison, Evans, Dennis & Walsh, 2012). Cues and feedback can be presented in a variety of ways, for example, a pilot may receive information on the cockpit instruments in either analog or digital (numeric) form. Potentially, these different ways that cues are presented could influence the speed and quality of learning.

MCPL tasks involve cognitive processes such as learning, problem solving, hypothesis generation and information integration. Learning is formed as the resultant of these processes. Which cognitive abilities affect the learning performance seems as an important question to be answered in MCPL-based research. On the other hand, this question was not studied well in the literature (Evans, Clibbens & Harris, 2005). Finding the effect of individual differences in particular, may contribute to close this gap. Studying the decision maker in terms of individual differences is worthwhile, as the individual differences in cognition increasingly play important roles in modern models of cognition (Conway, Kane, Bunting, Hambrick, Wilhelm & Engle, 2005). Being significantly effective in higher level cognitive abilities such as reasoning, comprehension and problem solving (Engle, 2002), Working Memory is considered as the individual difference to be studied. Working Memory (WM) is a system for temporarily storing and managing information required to carry out complex or higher level cognitive tasks such as learning, reasoning, and comprehension (Conway et al., 2005). WM has a limited capacity and varies individually - some individuals have high working memory capacity and some others have low. Working Memory Capacity (WMC) is a measure of how an individual utilizes his or her working memory.

Our critical review of the MCPL literature showed that task modalities in terms of cue/feedback presentation and response collection is not studied cumulatively. In the studies that investigated the effect of modalities of display format, the general conclusion is that graphically presented information is more effective as compared to non-graphical presentations. Hammond (1971) examined using different presentation formats in feedback information during MCPL tasks, and found that graphical presentations are noticeably more effective. Another study about the display formats in MCPL context has been carried by Kerkar (1984). He found some precision differences in the applied policy but the accuracy of judgments did not differ significantly when numerical or graphical presentations was used in the task. Wickens & Scott (1983) compared the different presentation methods in a complex information integration task inspired from tactical decision making. What they found was performance increases in case of graphical displays. After observing differences emerging from format differences, Wickens et al. (1983) claimed that the performance is dependent to compatibility between the display, cognitive processing and response mode. This means that, if the stimulus presented corresponds to the required processing mode and the response mode is same as stimulus mode, then a performance increase is observed in this task as compared to unmatched cases. The problem with these results was that it was not possible to generalize them because of contradictory findings and dependency to task settings (Kerkar, 1984; Williams, 2001). Starting from this point, we are considering to handle the differences in the display format of cues profiles, outcome feedback and response mode together, and observe the cumulative effect so that, in this way, we will able to see a clear performance increase in case of graphical modality. Furthermore, when we reviewed the MCPL relevant literature, we saw that graphical and numerical modalities of cue presentation, outcome feedback presentation and response mode together was not studied before. We thought that studying these combinations would reveal the contrast between the modalities. Therefore according to us, this is gap in MCPL research is needed to be filled.

When we examined the literature specifically noticing the studies exploring the individual differences in working memory capacity in MCPL tasks, we saw that only a few studies (e.g. Rolison et al., 2011; Chasseigne et al., 1997) exist that may be related to this specific issue. Actually the work done by the Rolison et al. (2011) was the first published study that directly investigated the relationship between the WMC and learning performance. Chasseigne et al. (1997)'s study was indirectly related, because by assessing the learning performances of older people in MCPL tasks, they found performance drops which may be associated with WMC. Our study differs from Rolison et al. (2011)'s previous study in that, they examine the engagement of WM in MCPL from the perspective of dual processing theories of cognition. Our perspective, on the other hand, is more inclined to examine a finer grained interaction between different types of WMC span measures as individual differences interacting with MCPL task properties.

When we have reviewed the literature, taking Baddeley (2000)'s working memory model as a basis, we saw that the relationship between MCPL and working memory components was never examined before. Furthermore as stated before, the difference between the modalities of display formats and response was studied from different perspectives but not from the perspective of individual differences in working memory capacity. We think that this is another gap in the research literature, and filling this gap will make a genuine contribution to the related research.

As a result of these considerations within the scope of the stated problems and the related literature, in this dissertation, we look for the answers of the following research questions:

1. What is the effect of numerical and graphical modalities of cue, outcome feedback and response on learning performance in MCPL tasks?

2. How do the components of working memory indicated by relevant working memory capacity measures affect learning performance in MCPL tasks?

3. How do the components of the working memory capacity interact with learning performance in numerical and graphical task MCPL task modes?

4. How do the MCPL task properties, especially the polarity of cue-criterion relation, affect the relationship between working memory capacity and learning performance in MCPL tasks?

Our aim in this dissertation is to start with an artificially derived MCPL task and its variations, so that the study can be further continued with practical implications. For example our finding about the effect of settings of MCPL task may contribute to design of displays for increasing performance. Besides that, the individual differences based results may be used for selection and assessment of pilots. Although we consider the findings of this study to be relevant for practical applications where different displays and active use of Working Memory is involved, the correspondence of the findings with real situations must be validated through judgment analyses methods.

Organization of the dissertation is as follows:

In Chapter 2, a review of the related work found in the literature, is given by summarizing the general concepts related to Judgment and Decision Making (JDM) research. Our hypotheses regarding to research questions are given at the end of this chapter in a separate section.

The conducted four experiments, are given in separate chapters (Chapters 3, 4, 5 and 6) together with results and discussions relevant to them.

Chapter 7, contains the general discussion, future work and conclusion.

# CHAPTER 2

# LITERATURE REVIEW

This chapter contains a review of the literature in the scope of the dissertation, which aims to explore the factors that affect the achievement of individuals when making judgments about a situation by using identifiable cues in the environment. This exploration will be based on a widely used experimental Judgment and Decision Making framework known as Multi Cue Probability Learning (MCPL). In Section 2.1, starting with the a general view, relevant topics from Judgment and Decision Making (JDM) will be reviewed.

Another aim of this study is to identify the relationship between the performance on perceptual MCPL tasks and individual differences in working memory capacity (WMC) that are in our focus. Therefore, in the subsequent section, the research based on individual differences will be summarized by focusing on the MCPL paradigm and Working Memory Capacity (WMC) measures.

In the remaining sections our hypotheses about the identified problems in the literature will be given and a summary will be made together with found gaps.

## 2.1 Judgment and Decision Making

Judgment and Decision Making (JDM) research contains many subtopics which are studied from several perspectives with distinct research agenda. The popularity of research on Judgment and Decision Making (JDM) is related to its impact on human life because of its practical consequences and its central role in human cognitive activity. Historically, its roots can be traced back to several centuries ago. The popularity, long years of research and attention of researchers from different perspectives produced a significant amount of knowledge on Judgment and Decision Making.

The judgment and decision making process is executed by individuals and result in decisions. The important aspects of any decision making task are the state of the world as much as it is provided by the environment and the individual who is deciding about a course of action or making judgment about the situation. While trying to answer the question of what makes a decision good, it is possible to focus on these aspects from different point of views (Fischhoff, 2012). Normative research focus on describing the best possible choice given the state of the world and the individual's values. Descriptive research, on the other hand, focus on how the individual actually decides. Prescriptive research aims to close the gaps between the norms and actual behaviors. This brief introductory paragraph is given to mention different aims of the research in broad JDM field. In the following paragraphs, a historical perspective will be given in order to reveal the position of the JDM paradigm used this dissertation.

History of psychological JDM can be traced to events took place in 1940s and 1950s (Goldstein & Hogarth, 1997). Two different research programs, which are asking distinct research questions, began about at that time.

In the field of preferential choice some group of psychologists have focused on the motivation of economists and statisticians about giving advice to decision makers based on the normative theories of the related field. They have asked questions like: How do individuals decide on a course of action? How they choose what to do next? Are their choices rational in following normative theory of the context? The students of this trend were inspired from Neumann and Morgensterns' (1947) work (Goldstein, 2005). Their axiomatic theory of expected utility is used as a reference in testing people's behavior in choice tasks. Furthermore taking this theory as the base for comparison, the deviations from the *rational* behavior is experimentally tested by the psychologists, interested in mathematical modeling and measurements (Goldstein, 2005). The captured violations to the expected utility theory produced some impacts on the Judgment and Decision Making research (Newell et al., 2007). First, treating decision makers as rational thinkers was questioned. Herbert Simon (Simon, 1955) raised his doubts about rational behaving capacity of a real person in a real environment. This was because human beings have had limited processing capacity and the environment providing information about the real world is limited. In other words, it is not always possible to obtain the real unambiguous information in the environment. Simon (1955) proposed that instead of fully rational, humans should be considered as boundedly rational. Secondly, findings such that a typical person does not update his/her belief about probability of an outcome provided a departure point for investigating probability judgments(Goldstein, 2005). This line of research mainly driven by Amos Tversky and Daniel Kahneman (Kahneman et al., 1982). The research program initiated by their work was named as "Heuristics and Biases" program, emphasizing heuristics as the shortcuts applied by the decision maker and biases as the fallacies that push decision maker into erroneous behavior (Kahneman & Frederick, 2002).

Almost at around the same period another group of psychologists, motivated by an analogy with perception, started to deal with totally different kind of questions. They wanted to examine how a judge, as in the clinical judgment, come in to conclusion and made a judgment about the situation by integrating multiple fallible cues? The analogy was the visual perception, in which for example visual system must rely on possibly erroneous cues when determining distance to an object. Therefore, for the psychologists dealing with such situations, the main questions were: How do people integrate multiple probabilistic, possibly conflicting cues, to come into an understanding of the situation? What is the accuracy of judgments made? Is it possible to increase accuracy by means of training and experience? How do people identify relevant cues and proper weight to be used in integration process? How does the nature of task environment affect learning and performance? (Goldstein & Hogarth, 1997)

In 1954 Meehl published a book, in which he stated that judgments made by experienced individuals are invariably inaccurate as compared to simple statistical models based on the available information (as cited in Goldstein & Hogarth, 1997). This study drew attention of researchers working on Judgment (Goldstein, 2005). Shorty after Meehl's book, Hammond (1955) argued that Brunswikian principles of perception is applicable to study of judgment. Brunswik described perception as an inferential construction process based on the incomplete and fallible sensory cues. During perception process distal stimulus (environmental objects) excites sensory organs in which multiple cues are produced about the environmental object. Hammond (1955) adapted Brunswik's ideas to the judgment research by exemplifying the process with clinical judgment domain. In clinical judgment, while diagnosing a patient, a physician employs several ambiguous cues like test scores, patient's behaviors and expressions. This process actually is very similar to processing ambiguous information from environment as provided by sensory cues (Hammond, 1955). In this type of processing, judge uses multiple cues or indicators and comes into conclusion about something that is partially and sometimes erroneously represented by the cues

Another idea of Brunswik which is adapted to judgment domain by Hammond is "Probabilistic Functionalism" (Goldstein, 2005). It is a *Darwinian* approach in the sense that organisms' psychological processes are adapted to the environment in which they function. According to *functionalism*, in order to examine the behavior of an organism, we must understand aspects of the environment that organism is interacting in order to succeed its goals. In this functionalist approach to JDM research, *achievement* is defined as the degree to which organism succeeds its goals (Doherty & Kurz, 1996). Therefore, instead of the behavior that does not conform to normative theories like Expected Utility Theory or Bayes' theorem, judgment theorists are concerned with the accuracy in the sense that whether judgments reflect the true state of the world.

Following their initial ideas of using Brunswikian research in Judgment, Hammond and his colleagues constructed a theory known as Social Judgment theory (SJT) (Hammond et al., 1975) which is applicable to wide range of situations involving multi-attribute judgment. This theory uses Lens Model and its equation, which is a metaphor of thinking about the world and linking the distal stimulus to proximal cues, as the main tool for predicting the degree of accuracy.

Probably due to the difference between the initially targeted domains, studies on the accuracy focused decision research was not seen of interest as much as the decision and preferential choice program, but it continues to be fertile and influential (Newell et al., 2007).

Due to the nature of the tasks, of which motivation of this dissertation is related to, we have considered to use the correspondence tradition in which the accuracy of the judge is measured by comparing the subjective and environmental states. Therefore in the remaining part of the review, SJT and one of its specific experimental application to the learning cue-outcome relations called as MCPL will be addressed in detail.

### 2.1.1 Brunswik's Approach and Lens Model Based Judgment Research

In this section foundations and principles of the Brunswik's ideas will be briefly mentioned and its application of the JDM research will be provided in the scope of this dissertation.

Brunswik proposes the Lens model to capture the behavior of the individual functioning in real environment. The scattered light from an object is recombined by the lens in the eye. Similarly, a distal cause in the environment scatters its effects and the organism recombines them (Hammond & Summers, 1965).

According to Brunswik, even though the task is deterministic, the organism can never be sure about the environment and this produces *ambiguity* (Doherty & Kurz, 1996). Although the processing in the organismic system, that is the integration process using proximal cues, is deterministic, because the relationship between distal stimulus and proximal cues are not one to one and casual, overall process becomes probabilistic (Dhami et al., 2004). Furthermore on the organismic system there is also some ambiguity although obtained information is deterministic. Brunswik explains this by giving the example of perceiving a trapezoidal figure through visual system. It is not possible directly to come into conclusion about the type of the object because, it could be actually a trapezoidal or a rectangular object seen at an angle.

In Brunswikian approach, the term ecological validity is used to refer to validity of cues in the ecology, not for emphasizing the real world validity of experimental design, as this term is commonly used in psychology. Instead, the term 'Representative Design' is used to refer to real world resemblance. However, the meaning of representative design differs from systematic design in which experimenters manipulate the stimuli and conditions to produce independent and orthogonal variables. Brunswik argued that the experimental design must be representative of the real task conditions including the judges and stimuli. Consequently, it is problematic to randomly select participants and stimuli. For example,as related to stimuli selection, making the inter correlations of cues different than the real settings may impact inference mechanisms.

As previously mentioned, Brunswik's ideas are successfully applied to the judgment and decision making by Hammond through a meta-theory called as Social Judgment Theory (SJT) (Hammond et al., 1975). In the following subsections, this theory and its applications will be reviewed briefly.

### 2.1.2 Social Judgment Theory and Multiple Cue Probability Learning

Social Judgement Theory (SJT) has evolved from probabilistic functionalism over the last four decades (Doherty & Kurz, 1996). Hammond applied the Brunswik's approach to clinical judgment by emphasizing an analogy between perception and clinical judgment. SJT not only shows applicability of Brunswik's principles but also provides a framework (meta theory) for assessing achievement, modeling the environments, modeling the organism and comparing the models of environment and organism (Goldstein, 2005).

Figure 2.1 shows the Hammond's interpretation of Lens Model metaphor while applying it to judgment research. We can briefly explain the mapping of decision process onto lens model by means of a concrete judgment example adopted from Doherty &

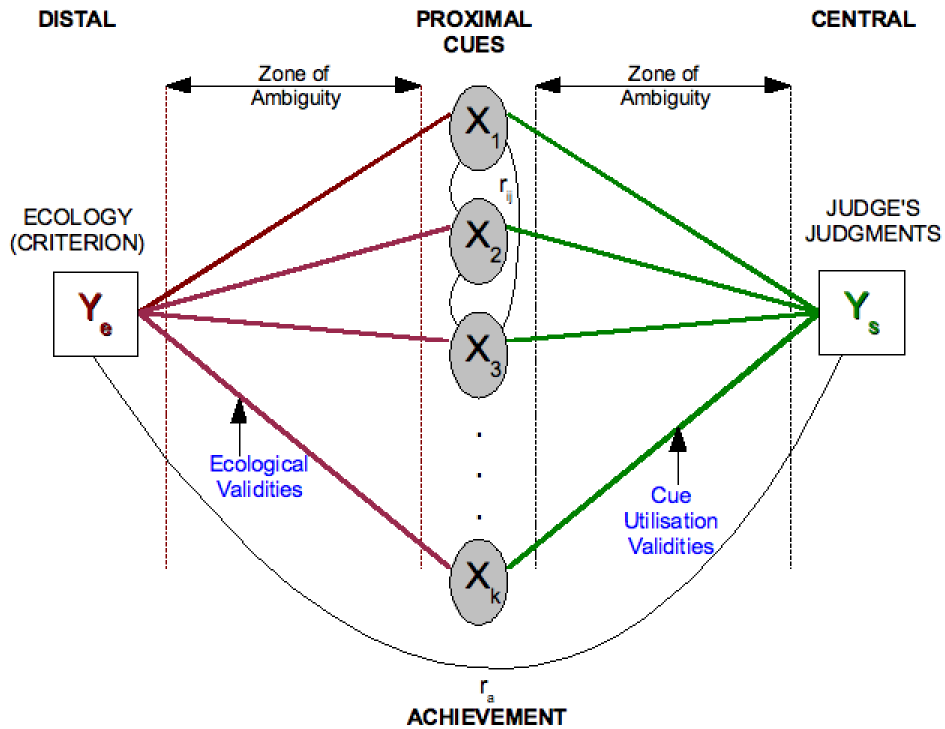



Figure 2.1: Brunswik's Lens Model adapted for the study of human judgement in the context of Social Judgement Theory (Adopted from Cooksey, 1996).

Kurz (1996). Suppose a physician is to decide about the disease of a patient according to some symptoms. In this judgment example, the real disease of the patient is distal variable or criterion, $Y_e$. The symptoms obtained from several sources such as X-ray, blood test, etc. are proximal cues, $X_i$. And the disease diagnosed by the physician is decision $Y_s$. The achievement ($r_a$) in learning or performance of the individual is measured as the correlation of judgment ($Y_s$) with the real criterion ($Y_e$).

Hammond accepts the same perspective with Brunswik in that, the relationship between the decision maker and the environment (ecology), in which decision maker is embedded, is the focus of analysis (Cooksey, 1996). In this scheme, *cues* are the information obtained from environment by perception. They are *proximal*, because they are near to our senses. These cues are probabilistically related to the distal variable/criterion. This scheme produces two types of uncertainty. The uncertainty in the relation between criterion and cues and the uncertainty in the utilization of cues by decision maker during judgment process. According to Brunswik these uncertainties can be measured by using correlation statistics. Consequently *ecological validity* is defined as the correlation between criterion and cues, and *cue utilization validity* is defined as the correlation between cues and judgment made by the decision maker (Cooksey, 1996). *Achievement* corresponds to success of decision maker, which in this scheme, is the correlation between actual decision given and the criterion. This concepts are shown in Figure 2.1.

In Figure 2.1, there exist two zones of ambiguity, first one is between distal variable and proximal cues, and the second one is between proximal cues and actual decision making. These ambiguity zones are called as zone of ambiguity of the ecology and zone of ambiguity of the judge's cognitive system. Decision maker or judge must deal with this ambiguity zones by *vicarious functioning* [1]. According to Brunswik vicarious functioning is the key process to cope with ambiguities.

Using this basic framework, it is possible to analyse judges in their real environment and infer how they utilize the information from multiple fallible cues while making judgments about outcomes (Newell et al., 2007). This kind of employment of SJT can be named as Judgment Analysis and can be used for analyzing the decisions and decomposing them into components, in other words, finding out the cues and relations between cues.

In this subsection, briefly, basic principles of Social Judgment Theory were given. In the following subsection another usage of Lens Model which is focused on studying the learning of novel cue-outcome relations will be given.

### 2.1.3 MCPL Research

When an individual is faced with a decision making need, if the environment provides meaningful feedback, then a learning activity starts. Feedback may be explicit information or implicit in the results of course of action. In Brunswikian JDM research,

[1] *vicarious functioning* is the process that, at the end which, we can arrive at an understanding of the environment, so that we can make a judgement based on a variety of sources of information, or cues (Doherty & Kurz, 1996)

learning is actually the result of adaption to environments in which distal variables are probabilistically related to proximal cues. Searching for understanding and learning such kind of probabilistic relationships, produced large amount of literature by using a paradigm called Multi Cue Probability Learning (MCPL). This corresponds to a variant of employment of Lens model in SJT.

In the paradigm of MCPL, the individual, exposed to a profile of cue instances, predicts the criterion value. If the feedback is explicitly given as the real value of criterion, which is called as outcome feedback, individual is expected to learn cue-criterion relationship by examining the difference over many trials. The key meta processes in a typical MCPL task execution can be (Newell et al., 2007); (1) Discover information: which cues in the ecology available and useful? (2) Acquiring and searching through information: what is the importance of cues with respect to each other? (3) Combining information: how to combine cues to come to a judgment? (4) Feedback: after making a prediction and knowing the actual value, how to use the difference information?

In a typical MCPL design a relatively large number of learning trials are used. The number of trial may vary from 100 to 400 or even more (Cooksey, 2007). The required number of trials is a function of task characteristic which determine the learnability or complexity of the task.

Criterion, cues and judgment are the three important variables in the MCPL environment. The attributes attached to these variables constitute the characteristics of MCPL tasks. We can list some important attributes as follows:

1. Cue(s) - Criterion relationships.
   (a) Function Form: linear vs. nonlinear.
   (b) Ecological validity of cues: the correlation between cues and criterion.
   (c) Polarity of cue-criterion relation: negative vs. positive.
2. Type of feedback : outcome, cognitive and evaluative feedback.

3. Inter-cue correlations or cue redundancy.
4. Number of cues.
5. Cue Presentation Mode : graphical, numerical and auditory modes.
6. Feedback Presentation Mode: graphical, numerical and verbal modes.
7. Response Mode: verbal, graphical, numerical.
8. Individual Differences[2]: attentional mechanism, verbal and visual working memory, executive control, and others.

In a typical MCPL research task, a typical *linear* "distal variable-cue relation" function is of the form $Y_e = A_1X_1 + A_2X_2 + ... + A_kX_k$. Some of other function forms investigated in the literature can be counted as; negative linear, U shaped and inverted U shaped nonlinear forms (Charles & Monroe, 1974). Charles & Monroe (1974) found that linear function forms were learned easily as compared to non linear ones. Furthermore, although nonlinear forms are examined, participants first search for linearity (Charles & Monroe, 1974). Another relationship between the criterion and cues is their correlation or ecological validities. They affect the cue discovering sub process. Castellan (1973) examined the effect of irrelevant cues, that is cues with validity equal to zero, and found out that irrelevant cues diminish the performance interacting with relevant cues, such that the performance loss being greatest for relevant cues with moderate validity.

Inter-cue correlation is an important characteristics for the representativeness of the MCPL experimentation environment. Setting them near to zero is a common practice as seen in literature, but some researchers examined their effect on task performance. Lindell & Steward (1974), for example, empirically showed that in combination with regression weights in the function form, when inter-cue correlation is higher, performance is lower.

There are three types of feedback used in the MCPL studies (Tsao, 1994). These are

[2] Although not an attribute of the task characteristics, the judge's cognitive as well as other characteristics (e.g. personality differences) is deemed to contribute to the achievement in the MCPL task.

*outcome feedback*, *cognitive feedback* and *evaluative feedback*. *Outcome feedback* is informing the decision maker by giving the correctness of his or her judgment after it has been made (Cooksey, 1996). *Cognitive feedback*, on the other hand, is giving some detailed information about the key relationships and statistics associated with his or her performance after judge has made an entire series of judgments (Cooksey, 1996). Finally, *evaluative feedback* is an ambiguous but frequently encountered feedback type. Rather than giving just outcome or detailed information about the decisions, evaluative feedback is providing some evaluation for the prediction made. We can exemplify this feedback type with informing about only the results for the exam (Tsao, 1994), i.e. informing the participant about the success of his/her judgments (e.g. informing the participant that (s)he has passed the exam without showing the correct answers).

The effect of feedback type on learning performance is examined in detail by many researchers including Hammond himself in his influential study (Hammond et al., 1975). Tsao (1994) examined the feedback types and concluded that cognitive feedback had some positive effects on learning. Rather than the type of the feedback, Atkins, Wood & Rutgers (2002) observed the effect of the form of the feedback and obtained the applicability of different types of formats to different environments. In other words, they have experimented with different forms of feedback such as verbal or graphical and observed the performance of the participants. Another important variable in feedback is the polarity that is negativity or the positiveness of it. Evans et al. (2005) examined in two experiments the effect of polarity and prior belief. As a result they have found that, positive feedback results in better learning performance and conformity to prior belief also effect learning directly.

According to empirical findings, outcome feedback is slow and limited (Goldstein, 2005). Actually, outcome feedback makes improvements in performance, when the environment is relatively simple and number of trials is very high (Newell et al., 2007). In this context simple may correspond to two or three cues that are positively and linearly correlated to criterion. Furthermore, outcome feedback inhibits the effects of cognitive feedback if they are used together (Hammond et al., 1975).

Presentation of cues profiles and feedback can be done by means of several methods depending on the nature of the task. In MCPL literature a considerable large proportion of the studies has used quantitative cue profiles. These quantitative values were displayed numerically using some sort of measuring scale, e.g 1-10 scale, or the real scale of the values with real units (Cooksey, 2007). Other formats for presenting the cue profiles were using graphical representations such as bar graphs. Steward (1988) stated the advantages of bar graphs as (1) They are easy to read (2) They provide a pictorial view of the cue profile (3) It is easy to capture where a specific cue stands as compared to its range and other cues. Numerical and graphical presentations have some advantages and disadvantages over each other. Numerical displays may cause the judge employ an intuitive averaging strategy. Bar graphs, on the other hand, suffer from lack of precision and some judges may encounter problems in processing visual/spatial information. Bastick (1982) claimed that presentation format may induce employment of particular cognition modes, such that graphical display induces intuitive cognition whereas numerical information induces analytic cognition. Same discussion may be done for the presentation of outcome feedback information. In literature, graphical presentations were generally used for displaying cognitive feedback. In one of the rare studies comparing the effect of information displays Balzer et al. (1994) found that the presentation format of cognitive feedback information doesn't have a significant effect on performance. Response mode is another factor that might affect judgment performance. As Cooksey (2007) stated response mode especially numerical vs. graphical response mode is not studied widely.

As stated in Chapter 1 of the dissertation, our critical review of the MCPL literature revealed that task modalities in terms of cue/feedback presentation and response collection is not studied cumulatively. In most of the studies the performance in graphical presentations was superior as compared to other forms of presentation (e.g. verbal or numerical). However there were exceptions (Balzer et al., 1994; Williams, 2001) in which performance differences were not significant. Another conclusion derived from the literature was that the results were mainly task dependent (Kerkar, 1984; Williams, 2001). Wickens & Scott (1983) examined the response mode modalities in accordance with presentation modalities, and found that, if the stimulus, central processing and response mode matched, the performance considerably increases. However they have only investigated only auditory and graphical modalities, the numerical and graphical response modes were not investigated in their study.

Being the actual actor of examination, the decision maker is in the spotlight of probabilistic learning environment provided by the MCPL paradigm. The accuracy measurement provided by Lens Model equation is about the performance of the individual so that the properties of the decision maker may have the greatest importance in the performance. Background knowledge, for example, is one of the key attributes of decision maker who is functioning in real environments. Evans et al. (2005) stated that the background knowledge or the experience of the decision maker is an important parameter in MCPL studies, because it may effect performance of the decision maker, positively or negatively. For example, background knowledge may boost the performance of decision maker by helping in extracting cue parameters. This positive effect can be controlled during selection of the judges (Cooksey, 1996). While experimenting with some experienced learners, it is important to neutralize biases caused by prior belief, by making some abstractions in the objects used in the experiments (Tsao, 1994). For example, in a company assessment task, Tsao (1994) gave dummy names to companies so that the judges didn't use their previous knowledge about them.

Our aim in this dissertation is to reveal some of the task specific and individual specific factors that affect the learning performance in MCPL tasks, and find out their relationship. In the literature review, as will be seen in the next section, individual differences is not extensively studied in MCPL context. We think that variances caused by the individual differences of decision makers are other important factors that affect the performance. Furthermore, examination of variations caused by individual differences may provide some insights into the mechanism of mental activities that occur during probabilistic learning. Actually, as Evans et al. (2003) mentioned, and revealed from our literature review, there is scarcity in the cognitive theories of MCPL tasks.

Consequently, in this dissertation, we aimed to examine variances caused by one individual difference namely Working Memory Capacity (WMC) of the judgments in probability learning tasks. The following section provides a review of Working Memory in general and in the context of previous MCPL research.

## 2.2 Individual Differences in Working Memory and Probability Learning

Individual differences based studies aim to find out the variances in the behavior of the individuals due to differences caused by their associated abilities. Human decision making process is a high level cognitive faculty and it is related to basic cognitive faculties. For example, reasoning is done by relying on the belief state and mental representation of the problem. Information retrieval and processing processes need some resources from cognitive abilities such as attention, short term and long term memory (Payne & Bettman, 2005). Emotions affect all other cognitive processes (Payne & Bettman, 2005). Creating mental representations are affected by the previous experiences (episodic memory) and knowledge (semantic/declarative memory). These cognitive faculties build up a generalizable cognitive system but also produce some individual differences, that is, differences caused by basic cognitive faculties, such as *working memory*, or differences caused by cognitive faculties at different levels of human cognition such as, *remembering patterns* and *association building ability.*

In descriptive Judgment and Decision Making research, behavior of the decision maker is in the focus. In general JDM context, there is a large amount research on individual differences (Appelt et al., 2011). The individual difference measures used in JDM were generally at a higher level of cognition like intelligent tests. There were also some studies that aimed to describe the decision making process by means of low level cognitive faculties such as working memory (e.g., De Neys & Dieussaert, 2005; DeCaro, Thomas & Beilock, 2008). De Neys & Dieussaert (2005) experimentally found that when there is a conflict in the belief and the logic, WM measure correlates with the results whereas when the belief is in accordance with logic, low and high span individuals performs equally.

As exemplified in the previous paragraph, working memory is a short term system involved in the control, retrieval and maintenance of limited amount of information. The capacity of working memory, as to be elaborated later in this chapter, is an individual difference, because some individuals have more of it whereas some individual have less (DeCaro et al., 2008). It is directly related to higher level cognitive processes; the more working memory capacity individuals have at a given time, the better performance will be on the types of reasoning, problem solving, and comprehension tasks encountered, in both laboratory and complex real world tasks (Conway et al., 2005).

As a Brunswikian JDM theory, Social Judgment theory and consequently MCPL, deal with accuracy of the judgments, not the internal processes in the decision maker's mind. As Evans et al. (2005) stated, there is a scarcity in the cognitive theory for the MCPL task and accordingly Social Judgment meta theory. One and to our knowledge, the only effort, trying to explain how cognition and MCPL interact is carried out by Evans and his colleagues (Evans, 2008; Evans et al., 2005; Rolison et al., 2011). The study particularly relevant to this dissertation is Evans (2008) in which he provides a framework of dual processing accounts by exemplifying over MCPL tasks. In this account of reasoning and judgment, Evans (2008) provides a framework to give an explanation of higher level activities. This account of higher level cognition focuses on the existence of two architecturally different systems which are separated from each other as characterized by some attributes clustered by several point of view (Evans, 2008). For example, from individual differences point of view one of the systems (System 1) is independent of working memory, and other system (System 2) is limited by working memory capacity. If System 2 is active during a high level cognitive activity then working memory is effectively employed, whereas if System 1 is active then working memory is not a determiner.

As a contribution to the cognitive theory of MCPL tasks, studying internal processes that occur during MCPL tasks by linking them to some basic cognitive faculties is relatively rare in literature. Chasseigne et al. (1997) empirically found that in case of existence of negatively polarized cues, there exists a significant performance difference between older and younger people. Chasseigne et al. (1997) explained this result with memory capacity decrease in aging accompanied with decrease in flexibility in functioning. Rolison et al. (2011), directly studied working memory and MCPL relationship by using operational span task (Unsworth & Engle, 2007), a verbal WMC measure. They used several MCPL tasks by manipulating the polarity of cues and looked at the correlations between performance and WMC measure. They have found that when there are negatively polarized cues, WMC measure may predict the performance and when all cues are positively correlated with criterion, WMC measure does not have an effect on judgment performance. They have concluded with linking the results to dual system theories of judgment and decision making, stating that negative ecological validity in a MCPL task induce explicit processing, but positive ecological validity induce implicit processing. Rolison et al. (2011) proposed their findings as an evidence to dual processing in judgment and decision making process.

Our concentration on WMC measures in this dissertation will involve different aspects of WMC and task properties than the above cited works. For example, one of our aims in this dissertation is to study the effect of graphical settings in Multi Cue Probability Learning framework. By graphical setting we mean usage of graphical presentation (for both cues and outcome feedback) and providing a graphical response mode. We think that this type of settings provide a learning environment superior in terms of achievement as compared to numerical rich settings. Furthermore, we propose that visually rich environment is linked to visual working memory whereas numerically rich environment is linked to verbal memory. In the following subsections a brief review of Working Memory will be given in the scope of this view.

### 2.2.1 Working Memory Capacity

As previously mentioned, Working Memory (WM) has a central role on the high level cognitive activities such as, reasoning, problem solving and decision making (Engle, 2002). This makes the Working Memory one of the central constructs in cognitive psychology research (Conway et al., 2005).

In the multiple component view of the working memory, Baddeley (2000) models working memory as composed of three different components. There are two slave systems that holds short term information and a central executive, which is responsible for the coordination of the slave systems and for managing the information to be stored. Slave systems are phonological loop and visuo-spatial sketchpad. Phonological loop holds the phonological information by continuously looping the articulation. Visuo-spatial sketchpad on the other hand holds, visual (color, shape, texture) and spatial (location related) information. Full review and the contemporary status of the theory of Working Memory is beyond the scope of this dissertation. In the remaining parts literature on measuring working memory capacity will be emphasized.

As a measure of working memory, Working Memory Capacity (WMC) can be defined operationally, as the number of items that can be held and recalled during a suitable task. Complex working memory tasks have the common property of having successive (1) storage (holding information available for a later recall) (2) processing (manipulating information for an ongoing computation) components (Barrett & Tugade, 2004).

In parallel with the Baddeley and Hitch's multi component working memory model (Baddeley, 2000) , WMC measures can be classified into two main groups according the type of information stores: one group measuring the capacities related with the phonological loop and called as verbal WMC measures, and the other measuring the capacities related to visuo-spatial sketchpad and called as visuo-spatial WMC measures. In the following sections the WMC tasks used in our study will be given under Verbal WMC Measures and Visual WMC Measures titles.

#### 2.2.1.1 Verbal WMC measures: Automated Operation Span (AOSPAN) and Backward Digit Span

For verbal content like letters, numbers, words, etc., in literature, there are several reliable measurement methods called as "span tasks" (Conway et al., 2005). The counting span, operation span, and reading span are the most popular or highly mentioned and used span tasks.

Among the working memory capacity measuring tasks such as Reading Span Task (Daneman & Carpenter, 1980) and Counting Span Task (Case, 1985) we have selected Operation Span Task (OSPAN) (Turner & Engle, 1989) as the task for measuring verbal Working Memory, because the results obtained with this task are in accordance with the other span tasks' measures and not affected by cultural differences (Turner & Engle, 1989). OSPAN is also highly demanding as it involves a second task, that also must be performed to a predetermined level of achievement. Whereas this may prevent any possible ceiling effects, it also raises the question of what cognitive faculty exactly OSPAN measures (Turner & Engle, 1989).

A practical version of operation span task is developed by Unsworth et al. (2005) and called as "Automated Operation Span Task (AOSPAN)". In the original task, participants solve a series of algebraic operation and at the same time they are supposed to remember set of unrelated letters. They read aloud the algebraic operations and the letters are presented. After reading the letter, the next algebraic operation is displayed to them. At the end, participants try to recall all words in the presented order. In the automated version (AOSPAN) there is no need for experimenter's intervention and participants can run the experiment by themselves so that the results are collected and calculated automatically.

In AOSPAN, the basic idea is to interfere recall, in a simple letter remembering task, with calculation of arithmetic operations. Participants complete an arithmetic operation and select true or false when an answer for that operation is presented. After selecting true or false, a new letter, to be remembered is presented. This sequence is repeated multiple times and the participant enters the sequence of remembered letters at the end. During the exercise session mean value of arithmetic operation completion time is calculated by the computer and this mean value is used in the experiment session. If participants waits longer than this value, true/false screen is not displayed and arithmetic operation is recorded as *false* and a new letter is shown. Participants have to have at least %85 correct arithmetic operation level and their progress displayed to them in each trial. If such a limitation was not applied then the participant would wait on arithmetic operation screen and rehearse the letters.

In Backward Digit Span task, a variant of digit span task, individuals recall the digits in the reverse of displayed order. In literature there are two contradicting findings as to whether that backward digit span task measures short term memory or working memory. Engle et al. (1999), in their analysis, found that mental transformation is not enough to turn an immediate memory task (i.e. task without an interfering secondary task) into Working Memory task. Oberauer (2000), on the other hand, found that, simple transformation span tasks, such as backward digit span task, measure the same construct as WM. Currently, the reason for this contradiction is not clear, but if BDS and AOSPAN measure different kind of capacities in WM, their interaction with different paradigms - as done with MCPL in this dissertation- may bring out what the differences can be. We have selected AOSPAN and BDS measures as the verbal WMC measures to be used in our experiments. The main reason for selecting these tasks was their easy-to-administrate procedures. In literature there is a consensus about what AOSPAN measures; the central executive and verbal short term components. However BDS is different because it is not clear what is measured by this task. Choosing an alternative that employs a different procedure would have the possibility to reveal the relationship between working memory and learning performance in MCPL tasks.

#### 2.2.1.2 Visual WMC measures: Corsi Block Tapping Test

Corsi Block Tapping (CBT) test is one of the best known memory span procedures, which is named after, Corsi who invented it, in collaboration with Brenda Milner(Cornoldi & Vecchi, 2003). In Figure 2.2, the main component of the procedure is shown - a table and wooden cubes. Test administrator sees the numbers for interpreting results. In the presentation phase, the examiner presents a sequence by touching the cubes with hand, and in the recall phase, the participant is asked to repeat the sequence. In the computerized version, rectangles are displayed instead of cubes and the third di-

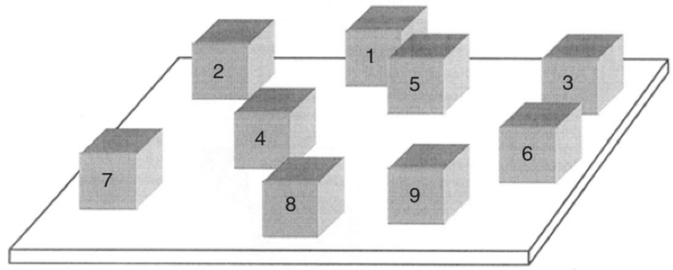



Figure 2.2: Wooden board and cubes used for the Corsi Block Tapping test (Adopted from Cornoldi & Vecchi, 2003).

mension is omitted. Another difference in computerized version is the absence of the movement indicator, i.e. the hand in the original version (Cornoldi & Vecchi, 2003).

It was empirically shown that CBT measures a WM component different than articulatory auditory components (e.g. phonological loop) (Vandierendonck, Kemps, Fastame & Szmalec, 2004). For example, participants with normal digit span and high Corsi scores have a better memory of film and pathway descriptions. A backward version Corsi test, similar to backward digit span also exist. In this task, recall is made in the reverse order of presentation. The analogy between Backward Digit Span is partial because performance decrease in being backward as opposed to forward is not seen Backward Corsi Test. This is because it is more natural as compared to BDS, because it is a kind of return journey (Kessels et al., 2008). Although, CBT is known as the one of the most widely used indicator of visuo-spatial working memory, there are findings that it measures a construct different that visuo-spatial working memory, with the inclusion of central executive components of WM (Cornoldi & Vecchi, 2003). Still for the scope of this dissertation, it is evaluated as the simplest visuospatial WM measure, as other measures (Cornoldi & Vecchi, 2003) have components such as path planning or transformation of shapes, which are unrelated to the nature of MCPL tasks.

Backward Digit Span task and Corsi Block Tapping tests are widely used to assess verbal and visuo-spatial working memory components. Engle et al. (1999) regard BDS task as a short term memory measure. It is a short term memory construct and measures the verbal slave component of the working memory called as the phonological loop in Baddeley (2000)'s Working Memory model. However, there are conflicting findings about the involvement of central executive in BDS task. Some researchers argue that because of reverse ordering, central executive must be involved in the task. In contrast, some other researchers claim that simple reversing is not enough, an interfering activity involved with the central executive (such as a mathematical operation as in operation span) is needed between items (St Clair-Thompson, 2010). The status of Corsi Block Tapping and its reversed version, in terms of their relation working memory components, is clearer in literature. Kessels et al. (2008) have found that both CBT and backward versions rely on similar components. They have also found that although backward version of digit span task is more difficult as compared to forward BDS, they also relied on the same cognitive constructs.

We have generated our hypotheses, by considering that using different types of presentation/response modes in MCPL tasks may activate different types of representations in the mind, and these representations may be processed differently or even independently. This consideration suggests that there might be an interaction between individual cognitive abilities and the presentation/response mode of cues such that cue-criterion relations that are presented in a manner congruent to someone's abilities are learned more quickly than in-congruent ones. For instance, working memory ability might be predominantly verbal or alternatively predominantly visual and consequently, the mode of presentation/response as being numerical or graphical may interact with the type of working memory ability. Furthermore, other task properties such as number of available cues and the way cue contribute to criterion value may trigger the allocation of decision makers' resources differently. Therefore when manipulating the MCPL task with different presentation modes and other attributes, we aimed to measure the activated Working Memory components by means of Verbal and Visual WMC measures.

### 2.2.2 Experimenting with Capacity Measures

There are two experimentation approaches used to assess about the role of working memory capacity in learning (Schüler, Scheiter & Genuchten, 2011) : *capacity approach* and *dual task approach*.

According to the capacity approach; the capacities of the subsystems are measured and linked to learning outcomes to test whether individual differences in working memory capacity explain the variance in learning outcomes (Andrade, 2001). If the capacity differences in one of the subsystems of working memory are associated with different learning outcomes, we can assess that this subsystem was involved during learning (Schüler et al., 2011).

In the dual-task approach, participants perform a secondary task along with the learning task. This dual task requires information processing in one of the subsystems of working memory, so that, if there is an interference between the primary learning task and the dual task, it can be deduced that this subsystem was involved during learning. The interference can be deduced by comparing the learning outcomes with a controlled condition in which no dual task is employed (Schüler et al., 2011).

We have chosen a capacity based approach in our experimentation because capacity approach is easy to implement as capacity measures are easy to administer and they can be conducted before and after the actual learning experiment. But, as a handicap, appending extra capacity tests to the beginning or end of the experimentation session may extend the duration and consequently may cause some fatigue and decreases the motivation (Schüler et al., 2011).

There are some alternative options in scoring working memory span tasks, such as, "all-or-nothing unit scoring", "partial-credit unit scoring", "partial-credit load scoring" and "all-or-nothing load scoring" (Conway et al., 2005). In "all-or-nothing unit scoring" only the number of correctly remembered sequences are taken into account. In "all-or-nothing load scoring", as distinct from "all-or-nothing unit scoring", instead of one for each sequence, the length of the correctly remembered sequence is added to the score. For the partial scoring, a partial score is added for the items remembered in the correct position. The effect of scoring of WM span tasks is not taken into account in most of the research literature (Conway et al., 2005). However there may be some drawbacks of scoring with different alternatives, because different scoring procedures not only may affect the rank order of subjects, but also change the results of data analyses (Conway et al., 2005). In our experimental methodology and analysis we have both used absolute and partial scoring and did not find a significant difference between them and we stuck on "all-or-nothing unit scoring" in most of the analyses, exceptions stated and justified where applicable in the following chapters.

In our experimental methodology (see Section 3.4, Section 4.4 and Section 5.4) we have followed the capacity approach because of its practical administration. Now that the literature related with the research motivation of this study is reviewed, we do want to state our hypotheses in the next section.

### 2.3 Hypotheses

We have stated our research questions in the Introduction (see Chapter 1) part of the dissertation. Related to first research question, based on the previous findings in the literature, we are predicting to see a superior performance in graphical presentation/response mode in MCPL tasks.

***$H_1$:*** Graphical presentation/response mode has a superior effect on learning performance as compared to Numerical Mode of presentation/response.

Our other research questions address the effect of individual differences in working memory capacity. In our literature review we have seen that working memory is effective in MCPL tasks, as it is effective in other higher level of cognitive abilities such as reasoning and problem solving. Furthermore, we think that when task modality becomes inline with cognitive capabilities, the learning performance in MCPL will increase significantly so that in case of graphical modality, visuo-spatial working memory could be more effective, whereas, in case of numerical modality verbal working memory components are more effective. Related to this brief justification, the following hypotheses could be stated:

***$H_2$:*** WMC measures are positive predictors of learning in MCPL tasks.

***$H_3$:*** Verbal WMC interacts with mode of presentation so that, learners with high Verbal WMC outperform the learners with low Verbal WMC in case of numerical mode of presentation, but learning in graphical mode is unrelated to verbal WM performance.

***$H_4$:*** Visual (spatial) WMC interacts with mode of presentation so that, learners with high visual (spatial) WMC outperform the learners with low Visual WMC in case of graphical mode of presentation, learning in numerical mode is unrelated to visual (spatial) WM performance.

Last two hypotheses construct a double dissociation about the interaction of visual and verbal components of WMC with the graphical and numerical MCPL conditions. Double dissociation demonstrates that two experimental manipulations affects two functions differently. If only one of manipulations affect one of the functions and not the other function, this is called single dissociation. In addition to this, if the other manipulation affects the second function but not first one, then this means a double dissociation between the functions. When this idea is applied to our case, the effect of visual and verbal WMC abilities on visual (graphical condition) and verbal (numerical condition) MCPL are such that, being low in visual (spatial) ability impairs the achievement in visual (spatial) condition but do not effect the achievement in verbal condition. Being low in the verbal ability, on the other hand, impairs the achievement in verbal condition but do not effect the achievement in visual (spatial) condition. If either Hypothesis 3 or Hypothesis 4 is supported, this is a single dissociation between achievement in numerical modality and achievement in graphical modality. If both hypotheses are validated, this implies double dissociation.

Detecting a dissociation, statistically, can be done via interactions. Suppose there are two functions - function1 (e.g. achievement in graphical modality) and function2 (e.g. achievement in numerical modality) - and two components namely component1 (e.g. visual memory as measured by visuo-spatial WMC) and component2 (e.g. verbal memory as messured by verbal VMC) in a hypothetical system. If there is a dissociation, typical interaction graphs must be something like the figures given in Figure 2.3 and in Figure 2.4. Figure 2.3 represents the impairment in function1 and function2 in case of normal (or high) and impaired (low) for component1. Similarly, Figure 2.4 represents the impairment in function1 and function2 in case of normal (or high) and impaired (low) component2. For dissociation to exist, we must expect interaction graphs similar to these graphs and the interactions must be statistically significant.

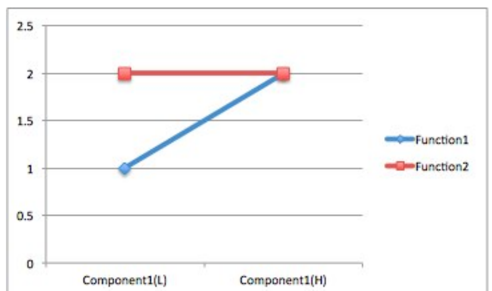



Figure 2.3: Interaction in case of impairment in Component1

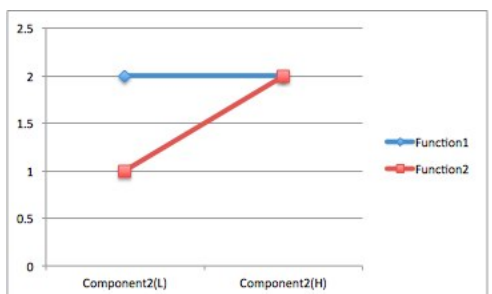



Figure 2.4: Interaction in case of impairment in Component2

## 2.4 Summary and the Gaps Found in the Literature

In MCPL literature review, we have seen that the effect of presentation of cues and feedback explored in several studies. Although it has been thought that graphically rich presentations are intuitively processed (Bastick, 1982) and have some advantages on numerical displays, the empirical findings did not support this idea (Kerkar, 1984).

In our literature review, we have seen that, in MCPL paradigm, the effect using graphical or numerical modalities in presentation of cues/outcome feedback and collecting response was not studied before. We believe that if the modalities in presentation and response collection matches then this will help revealing the effect of different modalities.

At the start of this study we have aimed to investigate the employment of working memory capacity in MCPL tasks. In MCPL we have found only one study that explored the relationship between working memory capacity and performance. In that study, Rolison et al. (2011) used only one WM measure. Observing the relationship between performance and WMC as indicated by different memory span tasks will help to reveal effect of WMC on MCPL performance. On the other hand, the relationship between working memory components as proposed in Baddeley's model, and the performance in different MCPL modalities was not studied before. Therefore it is unknown, in literature, whether different WM capacities effect performance in graphical and numerical MCPL modalities differently.

In this chapter a brief literature review within the scope of of this dissertation is given. First, MCPL paradigm and its theoretical background is explored. Then individual differences in working memory are mentioned. One aim of this dissertation is to explore the effect of numerical and graphical presentation of cues and feedback in MCPL paradigm. Another aim is to find out the effect of working memory capacity on the learning performance in MCPL. In order to find answers to our research questions introduced in Chapter 1 and test our hypotheses, four experiments were designed and conducted. Experiments are based on the manipulating the MCPL tasks by means of several conditions related presentation/response modes and other MCPL attributes and measuring learning performance, accompanied with several working memory capacity measurement tasks. The details of the experiments are given in Chapters 3, 4, 5 and 6.

# CHAPTER 3

# EXPERIMENT 1

In this experiment, we have focused our interest in understanding whether the presentation and response modes have an effect on the learning performance in MCPL tasks. Hence numerical and graphical modalities of MCPL tasks, differentiated according to graphical and numerical display formats and responses, were generated. By numerical modality we mean, presentation of the cues and the outcome feedback in MCPL task is numerical and the response of the decision maker is collected numerically. In graphical modality on the other hand, presentations are made graphically and response is given graphically.

Another aim of this experiment is to find out how Working Memory Capacity (WMC), specifically AOSPAN (Unsworth et al., 2005) affects learning performance in MCPL tasks. We particularly investigated whether the role of WMC depends on numerical and graphical modalities in MCPL task.

## 3.1 Participants

A total of fifty one (51) individuals participated in this experiment. All of the participants were undergraduate university students (18-23 years old) from Bilkent University[1]. Thirty five (35) of them were female; sixteen (16) of them were male. Twenty six of the participants attended to graphical MCPL condition (10 male, 16 female)

[1] Participants attended to the experiment for course credits.

and twenty five of the participants attended to numerical MCPL condition (6 male, 19 female). All participants received AOSPAN task.

### 3.2 Design

The primary aim of the experiment was to observe the judgment achievement of decision makers in MCPL task and understand the achievement differences caused by numerical and graphical modalities. Therefore two conditions called as numerical and graphical modes of the same MCPL task were generated. The details of the task are given in the next section. Because our focus was the achievement in MCPL task, the independent variable in this experiment was MCPL task modality (i.e. numerical and graphical presentation and response mode). The dependent variables, achievement scores, were calculated as the correlation of judgment responses and criterion values. Seven different achievement scores were produced. One of them was the overall achievement, the correlation between judgments and criterion values calculated for 300 trials. The remaining six were the block achievements which were obtained by splitting the 300 trials into six blocks and calculating correlations between judgment and criterion values for 50 trials existing in each block. The experiment employed between-subjects design and participants were randomly allocated to the graphical or numerical modes.

### 3.3 Apparatus

Each participant completed one condition of the MCPL task (numerical or graphical condition) and the AOSPAN WMC measurement task. These tasks were computerized by means of E-Prime (version 2) software and executed by this tool on a personal computer (PC). Each task was completed without any time restriction. However, if a participant waited longer than a predefined time frame (20 seconds) when responding to a cue profile, a warning was shown. Desktop and notebook computers with 15 and 15.4 inch display sizes were used in the experiment. The visual components used in the screens of the tasks, were large enough to see when seated at a fair distance, invariant to the size of the display.

### 3.3.1 MCPL Tasks

MCPL task was designed with two conditions. Two conditions became different in presenting cues and feedback and collecting response. The criterion function and flow of the task were same in each condition. We have adapted the criterion function and the task flow from a previous study (Chasseigne et al., 1997). Chasseigne et al. (1997) used their task to investigate the effect of inverse relationships between cues and criterion on elder people. There were three cues in their task. In their study, information cards were used to present cues to the participants. Cues were presented using vertical bars. Cards had the criterion values on their back sides. Participants were shown the criterion value as outcome feedback after making their decision.

We have adopted their methodology in terms of number of cues, form of criterion function, presentation method of stimuli and feedback. The criterion function was not exactly same but similar to function in the original study in terms of polarity of cues. By contacting the researchers (E. Mullet, personal communication, August 19, 2009), we tried to obtain the stimuli set so that we can exactly replicate the study, but we couldn't get them but only the correlation values and other settings they have used were obtained. Thus, we used the same correlation and weight values but generated our own stimuli set. In our study we have used the criterion function below:

$$Y = 0.63A + 0.40B - 0.60C$$

In this equation, $Y$ is the criterion value to be predicted, $A$, $B$, $C$ represents the three cues. This criterion function contains both positive and negative relationships between the cues and the criterion. Two of the cues ( $A$ and $B$) are positively related to criterion and one of them ( $C$) is negatively related.

Cue values, that were presented to decision maker, were selected such that inter-correlations of cues were near to zero as the original experiment. In other words, the cues were nearly independent of each and this made the task settings less complicated and easier to learn (Lindell & Steward, 1974). Another restriction for selecting cue profiles was that the criterion value must be between 1 and 9. Therefore, 300 cue profiles were selected among 9x9x9 different possible cue profiles such that range of the criterion value was between 1 and 9, and the inter-correlations were near to zero. At the beginning of selection procedure, criterion values were calculated by using the weight values 0.7, 0.4 and 0.6, but the weights shown in the above equation were found after regression analysis conducted with cue values and corresponding criterion value. The change in the weight values were mainly introduced by the truncation errors. The histogram of the criterion values for which the cue profiles were presented are shown in Figure 3.1.

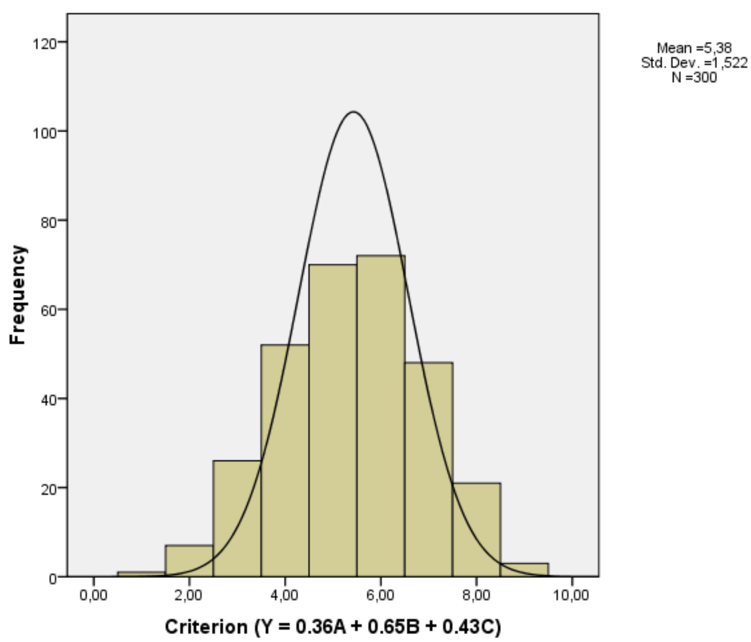



Figure 3.1: Histogram of criterion values corresponding to displayed cue profiles

MCPL experimentation generally follows the same phases (Chasseigne et al., 1997; Cooksey, 2007) : first an introductory and explanatory material about the experiment is given, then several training trials are performed by the participants, finally the actual trials that will be taken into account are given.

Each trial of a typical MCPL task, consists of presentation of cue(s), collecting responses from the participants and giving outcome feedback. In the test phase the last 50 trials were given without outcome feedback, in order to measure what has been learned. These 300 cue profiles were presented randomly to the participants. As a result of randomization, each participant exposed to a differently ordered cue profiles.

Following the general MCPL flow, in both numerical and graphical task conditions, first an introduction was made and the steps were explained. Then a story about the cue-criterion relationship was given. The same phenomenon as in the original study was used to explain the cue criterion relation. The English version of the explanation is as follows (the actual used Turkish version is given in Appendix-A).

*A Boiler is a device used to convert water into steam. A special type of boiler is shown in the figure (Figure 3.2 ). The temperature of the water delivered by the boiler could be controlled by the three knobs. There is a relationship between the levels of the three indicators presenting the settings for each knob and the temperature of the water. But exact prediction of the temperature was impossible because of a safety mechanism acting independently.*

Figure 3.2 is used in the graphical condition. For the numerical condition, the screen shown in Figure 3.3 was displayed to the participants.

As we mentioned previously, a typical trial in a MCPL task consists of three basic steps (Cooksey, 2007). In the presentation step, a specific profile of the cues are shown to the participant. Then the prediction (judgment) about the criterion value is collected. Finally, the correct criterion value associated with the specific cue profile is shown as outcome feedback. This sequence continues repeatedly until all trials are presented to the participant. The task consists of 300 hundred trials and it generally lasts between 30 minutes and 1 hour. Different modes in these three steps constitutes, the two conditions of our MCPL task. In the numerical condition, cues are displayed as numbers, input boxes were used to collect numerical criterion values, and outcome feedback is displayed as a number. In the graphical condition, cues are presented by using vertical bar graphics, responses are collected by means of a user controlled

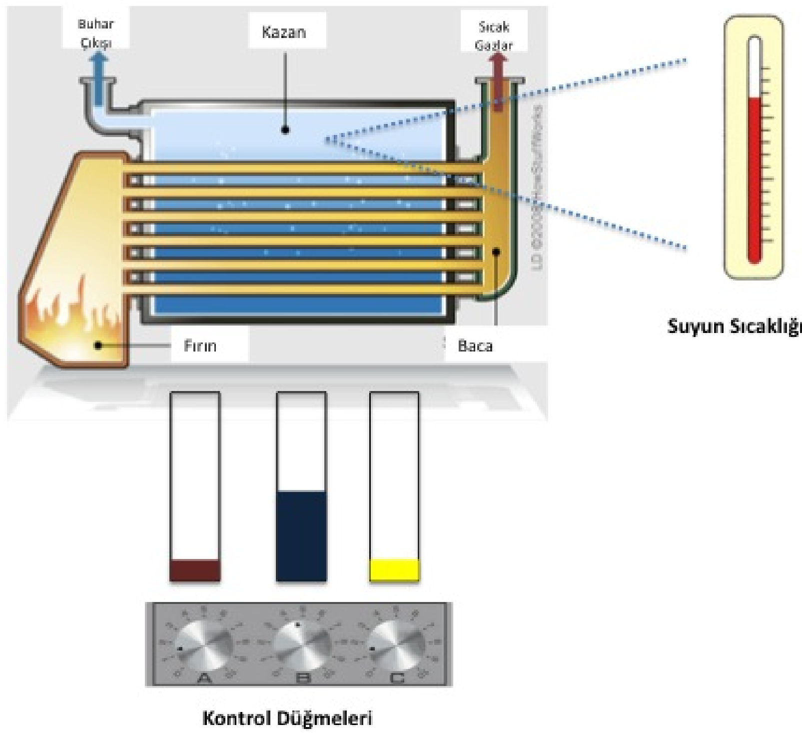



Figure 3.2: Figure Used to Explain Phenomenon (Graphical Condition)

vertical bar and outcome feedback is presented graphically.

#### 3.3.1.1 Numerical Condition

Figure 3.4 presents a sample cue display screen for the numerical condition. In this condition, cue values are displayed numerically and their position was distributed vertically on the screen. The judgment about these cue configuration is collected via a pop-up window. Participant directly enters the intended value on the pop-up window.

The feedback used in our MCPL task is a simple outcome feedback - the correct criterion value for the presented cue profile. Feedback presentation screen displays the judgment made by the participant and the real criterion value collaterally (see Figure 3.5).

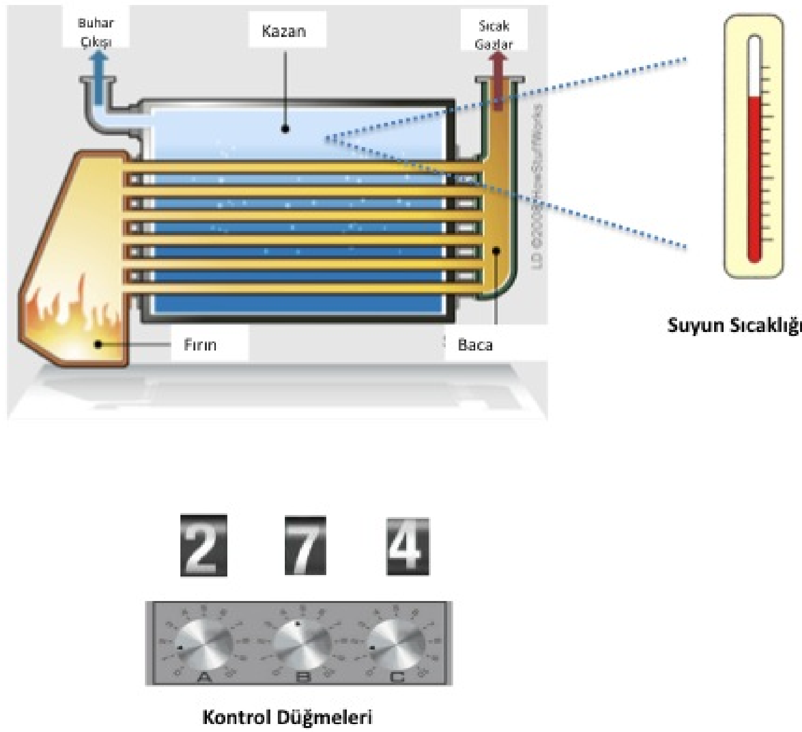



Figure 3.3: Figure Used to Explain Phenomenon (Numerical Condition)

#### 3.3.1.2 Graphical Condition

Figure 3.6 represents a sample cue display screen for the graphical condition. The bars representing the cue values are distributed horizontally on the screen. The judgment about these cue configuration is collected via "up" and "down" arrow keys, which increases or decreases the height of the bar representing the judgment. Participant provides their judgment by pressing the "enter" key after they set the height of the bar at an intended position.

Feedback presentation screen displays the judgment and the real criterion value side by side as vertical bars. (see Figure 3.5).

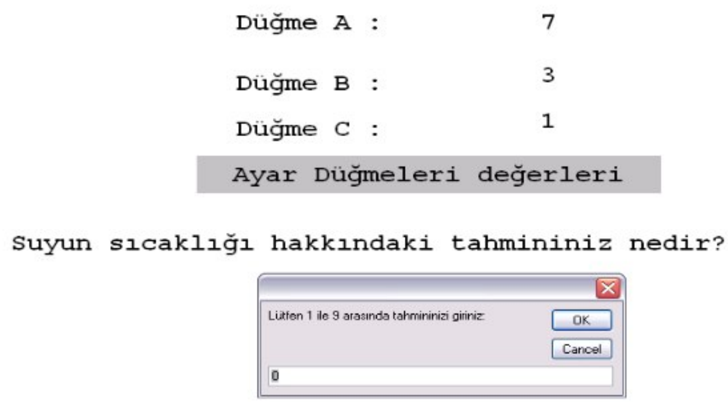



Figure 3.4: Cue presentation screen for the numerical condition

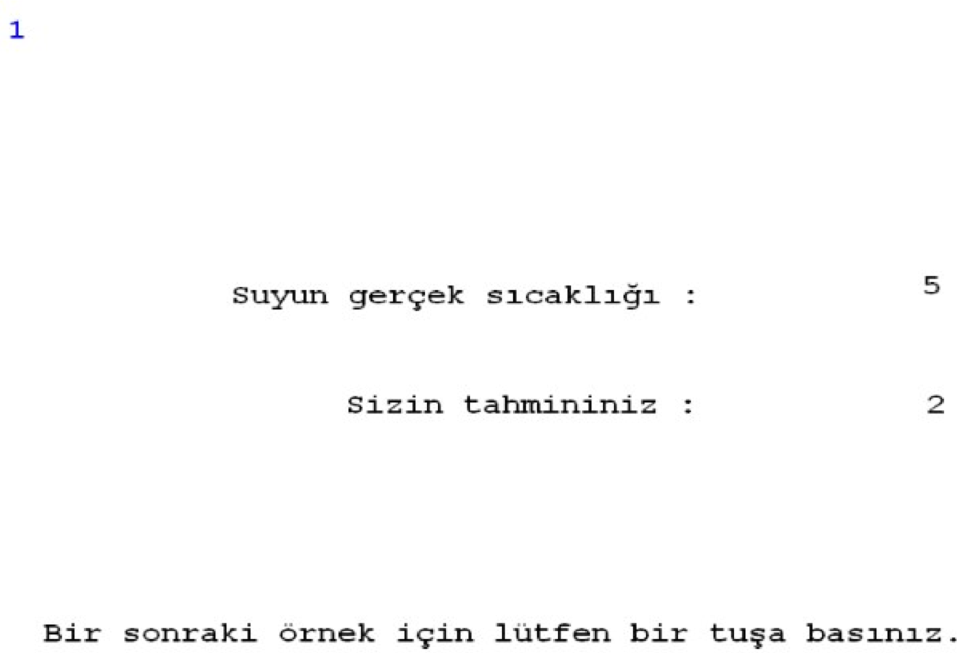



Figure 3.5: Feedback presentation screen for the numerical condition

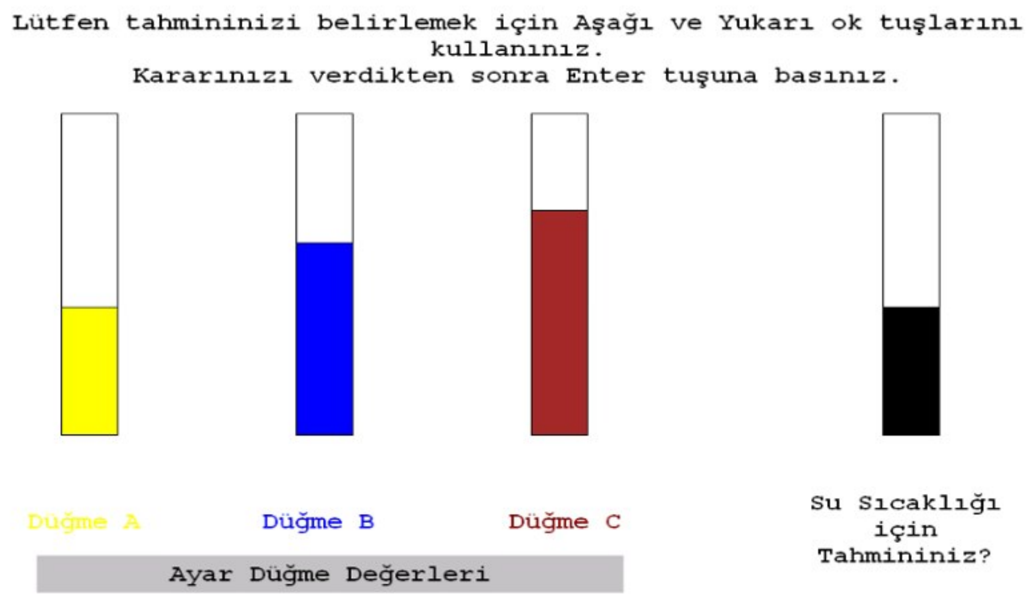



Figure 3.6: Cue presentation screen for the graphical condition

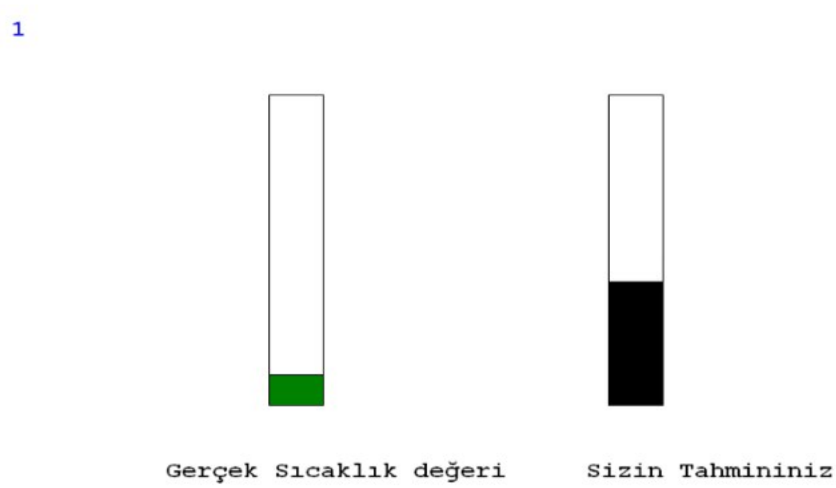



Figure 3.7: Feedback presentation screen for the graphical condition

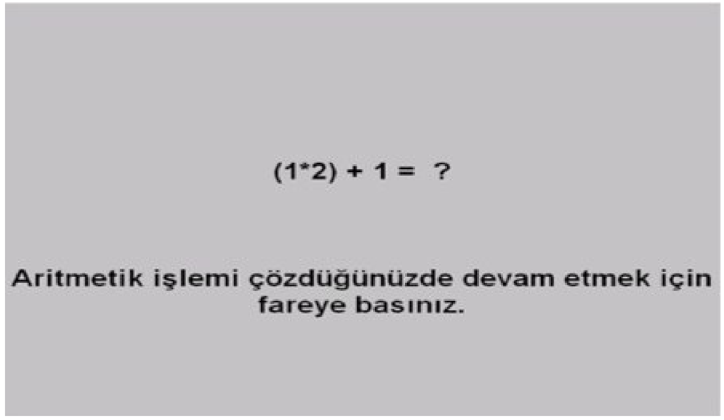



Figure 3.8: AOSPAN Task Operation Screen

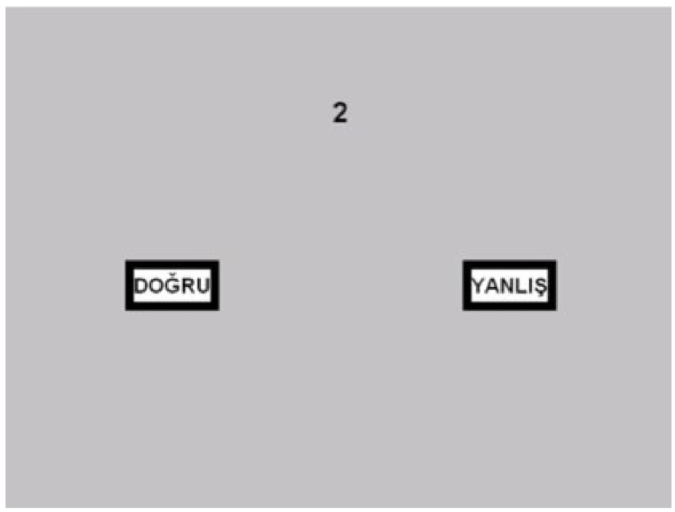



Figure 3.9: AOSPAN Task Operation Recall Screen

### 3.3.2 AOSPAN Task

As mentioned before AOSPAN procedure is conducted on computer by means of E-Prime software [2]. According to AOSPAN task procedure, participants complete an arithmetic operation (like "(1*2)+1") and select true or false when an answer for that operation is presented (see Figure 3.8). After selecting "true" or "false", a new letter to remember is presented (see Figure 3.9). This sequence is repeated multiple times and subject enters the sequence of remembered letters at the end. Length of the sequence varies from 3 to 7.

[2] The E-Prime script was originally developed by Unsworth, Heitz, Shrock & Engle (2005) and translated into Turkish by Çak (2011)

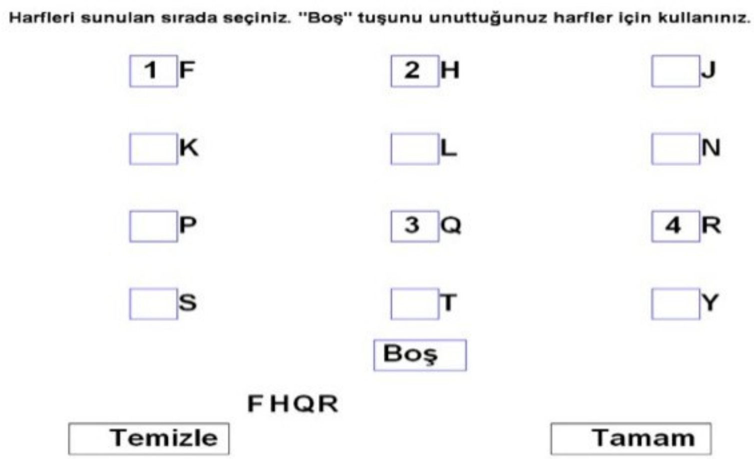



Figure 3.10: AOSPAN Recall Screen

At the recall screen, participants try to recall letters in the presented order (see Figure 3.10 ). For 80 different letter sequences having various lengths from three to seven, the procedure is repeated. After each recall, the computer provides feedback about the number of the letters correctly recalled in the current letter sequence. Procedure finishes after completion of 80 letter sequences. The duration of AOSPAN was measured by means of pilot experiments. It was seen that it lasts about twenty minutes on average.

Only the results in which 85% of mathematical operations correctly answered is accepted as valid (Unsworth et al., 2005). AOSPAN task have two different scores which are calculated automatically by the script. In absolute scoring only the correctly remembered sequence is taken into account. In partial scoring, on the other hand every letter remembered at the correct position is taken into account. For example for FQTSRH letter sequence, if a participant remembers FQS at the correct position, in partial score calculation, only the 3 letters are taken into account but in absolute scoring calculation, nothing is added to total absolute score. We have employed both scores in our analyses to see whether they cause different results.

## 3.4 Procedure

Participants attended to the tasks in a room with maximum of 3 seats. They have been given Information Consent Form[3] (see Section A.2 in Appendix A) before starting and Debriefing Form (see Section A.3 in Appendix A) after finishing the tasks. They were assigned to one of the MCPL conditions and the AOSPAN task. First MCPL task, then AOPSAN task was conducted. Participants were instructed as explained in the related apparatus. No break was given between the tasks, except when requested by the participant. This choice of giving no breaks was chosen as a result of pilot experiment where a great majority of participants did not want to wait. If a participant requested a break between the tasks, the break's duration was a few minutes. Participants assigned to MCPL conditions by first considering to balance number of attendees to graphical and numerical conditions, then considering to balance the gender of the participant's in each MCPL condition.

## 3.5 Results

### 3.5.1 Data Preparation

Lens model correlations were calculated by using the data collected by means of E-Prime software. To calculate MCPL achievement scores, participants' predictions have been divided into 6 blocks. Because there were 300 trials, each block consisted of 50[4] trials. Because we have 300 trials in total, it was possible to allocate the highest number of trials suggested by literature, for calculating the achievement for a block. For this reason, an individual's achievement (Pearson's coefficient, $r_a$) was calculated by correlating her/his predictions with the criterion values over 50 trials (for block achievements) and over 300 trials (for overall achievement). The achievement scores

[3] The permission for experiments was given by the Ethics Committee at 7 April 2010 before the experiments started. The signed approval letter (given after the dissertation is is successfully completed) is given in Section A.4 in Appendix A.

[4] In the literature the number of trials used in the statistical analysis varies between 20 to 50 (Cooksey, 2007). Higher number of trials is better because this produces statistically more reliable results.

of the individuals are shown in Table B.1 and Table B.2 in Appendix B.

Typical sample based correlations are not normally distributed. To reduce the errors caused by this non-normality, they should be corrected. Any Lens model based correlations (e.g. validity and achievements) used in an ANOVA analysis as an dependent variable should also be corrected. Fisher transformation is an appropriate transformation for this correction (Cooksey, 2007) :

$$z_r = \frac{1}{2} ln \left( \frac{1+r_a}{1-r_a} \right)$$

The calculated correlation values were transformed according to Fisher's formula, before they were used in any ANOVA analysis. To easily interpret the result when reporting mean values for each level of each effect in the ANOVA a back transformation should be applied using the inverse function:

$$r = \frac{e^{2z_r}-1}{e^{2Z_r}+1}$$

When presenting values in the correlation domain, this back transformation is applied on the transformed correlation scores. Fisher transformed achievement scores were labeled by adding the prefix "FT" in front of the previous label. For example, Fisher transformed Block 6 achievement was labeled with the label "FTB6". Overall achievement on the other hand was labeled with "FTAch". Please consider this legend in the rest of the dissertation.

### 3.5.2 Analysis

The mean values of achievement scores for each block is depicted together for numerical and graphical modalities in Figure 3.11. The progresses in the learning can be clearly seen in this figure.

As related to the effect of task modality, we can say that, means of achievement for

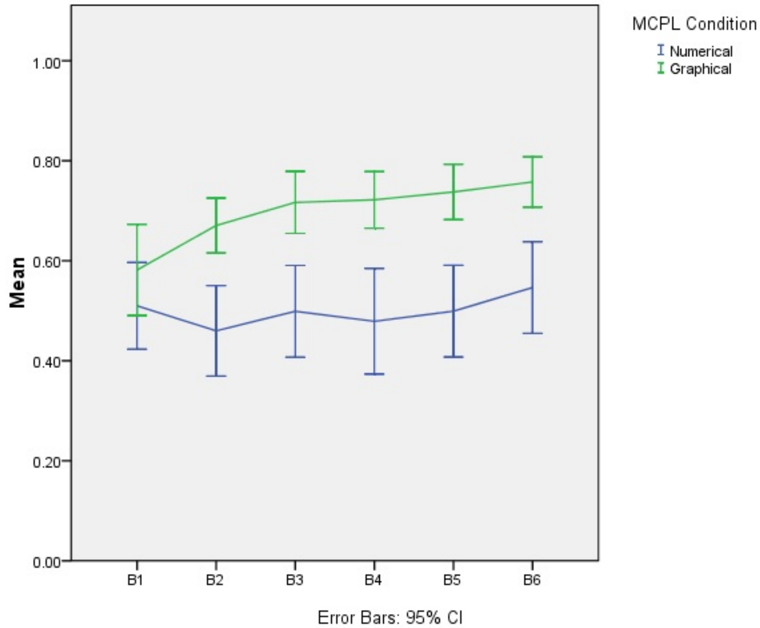
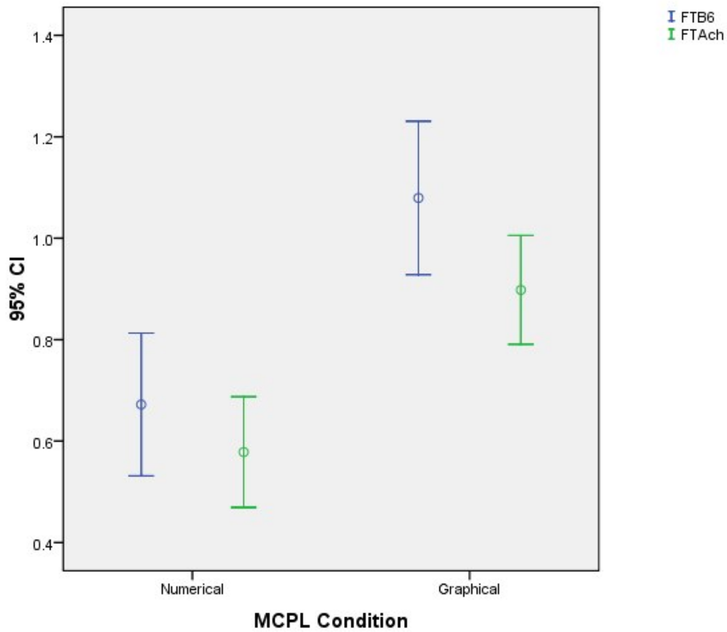



Figure 3.11: Mean achievements for each Block

graphical condition group was higher and clearly separated from numerical condition group. This inference can be observed in the plot shown in Figure 3.12. This plot depicts the errors (confidence interval) bind over the mean values of Fisher Transformed achievement values for "Achievement for the Block-6" and "Overall Achievement". Block-6 is the block in which no outcome feedback was presented. It can be assumed that Block-6 achievement represents participant's tested learning performance. Overall Achievement, on the other hand, represents the cumulative achievement. What we expect to see is that Block-6 achievement will be greater than Overall Achievement. However it is possible that, in Block 6, not seeing feedback may effect participant negatively. Therefore examining the overall achievement can be an alternative way of assessing learning performance.

One-way ANOVA was conducted as mode of presentation (MCPL condition) being the independent variable (see Table 3.1). ANOVA results showed that there is a strong effect of MCPL task modality (independent variable) on the variance of "Block 6 Achievement" and "Overall Achievement" scores. The main effect of mode of presentation on "Block-6 Achievement" was significant, $F(1,49)=16.44$, $p<.01$. Cohen's effect size value ($d = .50$) suggested a moderate practical significance. Effect was also




FTB6=Fisher transformed Block 6 achievement. FTAch=Fisher transformed overall achievement.

Figure 3.12: Error plot for the Block-6 and Overall Achievements (Experiment-1)

significant for the "Overall Achievement", $F(1,49)=18.52$, $p<.01$. Cohen's effect size value ($d = .50$) again suggested a moderate practical significance.

In order to examine the effect of working memory capacity on the MCPL achievement, first a correlation analysis was conducted between achievement scores and AOSPAN scores. As explained in section 3.3.2, in general, two different methods are used when scoring working memory capacity (WMC). In our analysis, we have labeled the absolute scoring with AOSPANSCORE and partial scoring with AOSPANTOTAL. The achievement and AOSPAN scores for each participant are shown in Table B.1 and Table B.2 in Appendix B.1.

Correlation analysis showed that, neither of the AOSPAN scores significantly correlated with the "Block-6 Achievement" and "Overall Achievement". The correlation table for this analysis is given in Table 3.2.

For examining how AOSPAN scores correlated with the numerical and graphical modes of MCPL task, the data was grouped according to the mode of presentation and separate correlation analysis was conducted for both of groups. In graphical condition, there was a significant correlation (r=.476) of total achievement with AOSPAN score at 0.05 level. But, for the numerical case there wasn't a significant correlation. The correlation tables are shown in Table 3.3 and Table 3.4. The scatter plots given in Figure 3.13 reveals the same results presenting the linear relationship between learning performance and AOSPAN for the graphical modality. However the scatter plot of learning performance and AOSPAN score for numerical modality shows that there is no association between them.

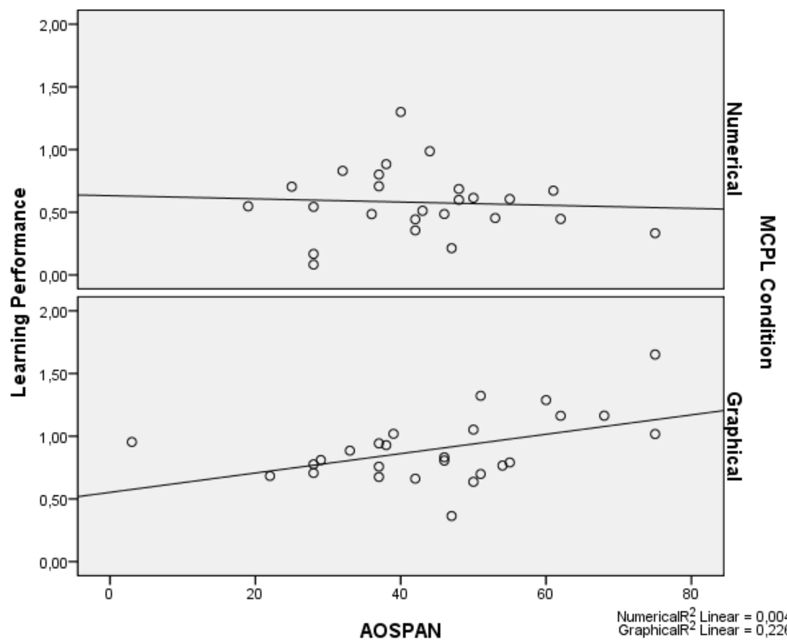



Figure 3.13: Scatter plots of learning performance (overall achievement) and AOSPAN for numerical and graphical conditions (Experiment-1).

Table 3.1: One Way ANOVA conducted for the dependent variables, FTAchv and FTB6 (Experiment-1)

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| FTB6 | Between Groups | 2,114 | 1 | 2,114 | 16,437 | ,000 |
| | Within Groups | 6,302 | 49 | ,129 | | |
| | Total | 8,416 | 50 | | | |
| FTAch | Between Groups | 1,303 | 1 | 1,303 | 18,523 | ,000 |
| | Within Groups | 3,446 | 49 | ,070 | | |
| | Total | 4,749 | 50 | | | |

Table 3.2: Correlation analysis for overall data (Experiment-1)

**Correlations**

| | | AOSPAN | AOT | FTB6 | FTAch |
|---|---|---|---|---|---|
| AOSPAN | Pearson Correlation | 1 | .894** | .214 | .247 |
| | Sig. (2-tailed) | | .000 | .131 | .081 |
| | N | 51 | 51 | 51 | 51 |
| AOT | Pearson Correlation | .894** | 1 | .146 | .181 |
| | Sig. (2-tailed) | .000 | | .308 | .203 |
| | N | 51 | 51 | 51 | 51 |
| FTB6 | Pearson Correlation | .214 | .146 | 1 | .878** |
| | Sig. (2-tailed) | .131 | .308 | | .000 |
| | N | 51 | 51 | 51 | 51 |
| FTAch | Pearson Correlation | .247 | .181 | .878** | 1 |
| | Sig. (2-tailed) | .081 | .203 | .000 | |
| | N | 51 | 51 | 51 | 51 |

**. Correlation is significant at the 0.01 level (2-tailed).

Table 3.3: Correlation analysis for graphical condition data (Experiment-1)

**Correlations**[a]

| | | AOSPAN | AOT | FTB6 | FTAch |
|---|---|---|---|---|---|
| AOSPAN | Pearson Correlation | 1 | .906** | .383 | .476* |
| | Sig. (2-tailed) | | .000 | .053 | .014 |
| | N | 26 | 26 | 26 | 26 |
| AOT | Pearson Correlation | .906** | 1 | .201 | .314 |
| | Sig. (2-tailed) | .000 | | .326 | .118 |
| | N | 26 | 26 | 26 | 26 |
| FTB6 | Pearson Correlation | .383 | .201 | 1 | .830** |
| | Sig. (2-tailed) | .053 | .326 | | .000 |
| | N | 26 | 26 | 26 | 26 |
| FTAch | Pearson Correlation | .476* | .314 | .830** | 1 |
| | Sig. (2-tailed) | .014 | .118 | .000 | |
| | N | 26 | 26 | 26 | 26 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

a. MCPL Condition = Graphical

Table 3.4: Correlation analysis for numerical condition (Experiment-1)

**Correlations**[a]

| | | AOSPAN | AOT | FTB6 | FTAch |
|---|---|---|---|---|---|
| AOSPAN | Pearson Correlation | 1 | .874** | -.056 | -.061 |
| | Sig. (2-tailed) | | .000 | .789 | .771 |
| | N | 25 | 25 | 25 | 25 |
| AOT | Pearson Correlation | .874** | 1 | .025 | -.013 |
| | Sig. (2-tailed) | .000 | | .906 | .952 |
| | N | 25 | 25 | 25 | 25 |
| FTB6 | Pearson Correlation | -.056 | .025 | 1 | .842** |
| | Sig. (2-tailed) | .789 | .906 | | .000 |
| | N | 25 | 25 | 25 | 25 |
| FTAch | Pearson Correlation | -.061 | -.013 | .842** | 1 |
| | Sig. (2-tailed) | .771 | .952 | .000 | |
| | N | 25 | 25 | 25 | 25 |

**. Correlation is significant at the 0.01 level (2-tailed).

a. MCPL Condition = Numerical

### 3.6 Discussion

An experiment to test the effect of task modality in a typical Multi Cue Probability Learning (MCPL) task is designed and conducted. Our first two hypotheses were tested in this experiment.

The statistical analysis suggests that the task modality, that is whether the cue presentation/judgment collection and feedback presentation is done by means of graphical or numerical methods, affects the performance of the decision maker. In other words, there exist a difference in the performance of the individual that is caused by the presentation method. Furthermore, the judgment performance of the decision maker in graphical mode is higher than the performance in numerical mode. This results supports our first hypothesis which predicts the superiority in performance in case of graphical modality.

Regarding to the hypothesis about the prediction ability of WMC on MCPL, in the experiment, we have measured the verbal working memory component capacity via a frequently used and cited WMC measurement method called AOSPAN. It has been seen that AOSPAN score did not correlate significantly with MCPL performance of an individual. Our third and fourth hypotheses were about interactions between working memory components and MCPL task modality. To see the interactions, AOPSAN scores were correlated with those groups separately. These correlations values suggested that, when graphical mode of presentation is used, there occurs a strong correlation between AOSPAN score and MCPL score. This result implies that if an individual has a high AOSPAN score (and verbal WM capacity consequently), than it is probable that, that individual will succeed graphical mode MCPL task. This significant correlation was for the overall achievement (FTAchv), which was calculated by taking into account all 300 trials.

In the correlation analysis, it was seen that AOSPAN measure only correlates with only total achievement scores. This observation suggested us to inspect different working memory capacity measures available in literature. Furthermore, as capacity measurement based experiments brings some methodological problems (Schüler et al., 2011), such as causing fatigue, we considered to decrease the duration of WMC span task. Therefore, in addition to AOSPAN measure, Backward Digit Span (BDS) task was used as a verbal WMC measure in the next experiment.

# CHAPTER 4

# EXPERIMENT 2

In the first experiment, as predicted, we have found a moderate effect (effect size= 0.5) of presentation and response mode in MCPL task with three cues. Verbal WMC as indicated by AOSPAN task, on the other hand, has had a limited effect in contrast to our predictions. Therefore in this experiment we have intended to employ another verbal WMC measurement task which may interact with performance in MCPL differently. Furthermore, because we have planned to add some other WMC measurements in the scope of the thesis, we have considered an easy to administer, low duration alternative to AOSPAN task. Among the already examined verbal working memory measurement tasks, we have settled on Backward Digit Span (BDS) task, because it was the lowest duration task as measured in our pilot studies. The details of this task is given in the apparatus Section 4.2.

Another reason for designing this second experiment was to tune some display formats in the MCPL conditions, and consequently observe the effect of this correction. We have concluded that the following recommendations may be applied in order to avoid extra interference that may be caused by material design[1]:

1. Making the cue display screens in numerical condition in accordance with graphical condition in terms of spatial distribution: In the first experiment, in the numerical modality, cues were distributed vertically across the screen whereas they were horizontally distributed in the graphical case.

[1] As suggested in the relevant Thesis Progress Committee meetings after reviewing of the results of the first experiment

2. Use of uni color (black) bars in the graphical condition: They were colored in the first experiment and it was considered that this may effect learning because it may be captured by decision makers as an extra information about the task. In MCPL literature this kind of information is known as one type of cognitive feedback(Harvey, 2012).

3. For both numerical an graphical conditions, in feedback screen, instead of just outcome feedback and judgment values, showing also cues values: The reason for this modification was to support decision maker during learning.

MCPL tasks used in the first experiment was updated by implementing these recommendations. The resulting screens are given in the Section 4.2.

## 4.1 Participants

This experiment was done with several participant groups from METU and ATILIM universities' psychology and computer science departments. Fifty eight participants[2] attended to this experiment.

Thirty nine (39) of the participants (18-23 years old) were undergraduate university students who were taking "Introduction to Psychology" course (from METU and Atılım University) and "Computer Science" students from METU. Remaining 19 were recently graduated Computer Engineers (25-30 years old). Thirty one (31) of them were female, twenty seven (27) of them were male. 30 of the participants attended to graphical MCPL condition (15 males, 15 females) and twenty eight (28) of the participants attended to numerical MCPL condition (16 males, 12 females). All participants received Automated Operation Span and Backward Digit Span tasks.

[2] Participants attended to the experiment for a small amount of participation fee or course credit.

## 4.2 Apparatus

As the previous experiment, this experiment was planned to test hypotheses about the effect of MCPL modality and the effect of AOSPAN score as a Working Memory Capacity measure on learning performance. Additionally, Backward Digit Span task was also included as another measure of verbal Working Memory Capacity test.

### 4.2.1 MCPL Tasks

As already mentioned, the MCPL task in Experiment 1, was redesigned according to the recommendations given before. The presentation style used in the previous experiment changed as previously stated. Briefly, cues were displayed as distributed horizontally in numerical condition (See Figure 4.1), the black colored vertical bars used in cue and feedback presentation screens of graphical condition (See Figure 4.2), in the outcome feedback screens the cue values were shown together with outcome feedback and judgment made by the participant (See Figure 4.4 and Figure 4.3).

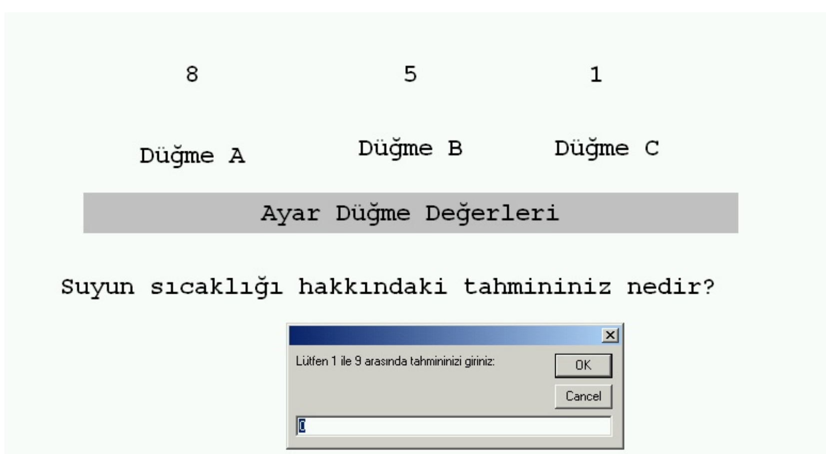



Figure 4.1: Cue presentation screen for the numerical condition (horizontally oriented)

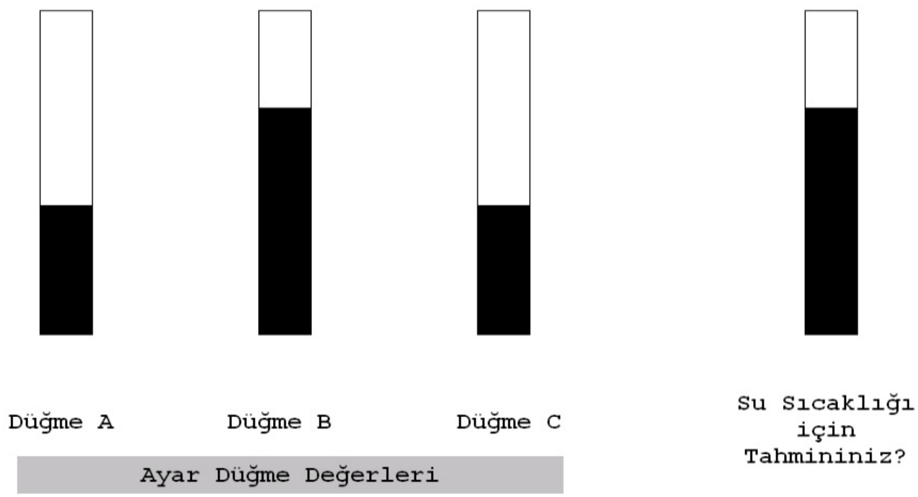



Figure 4.2: Cue presentation screen for the graphical condition (black)

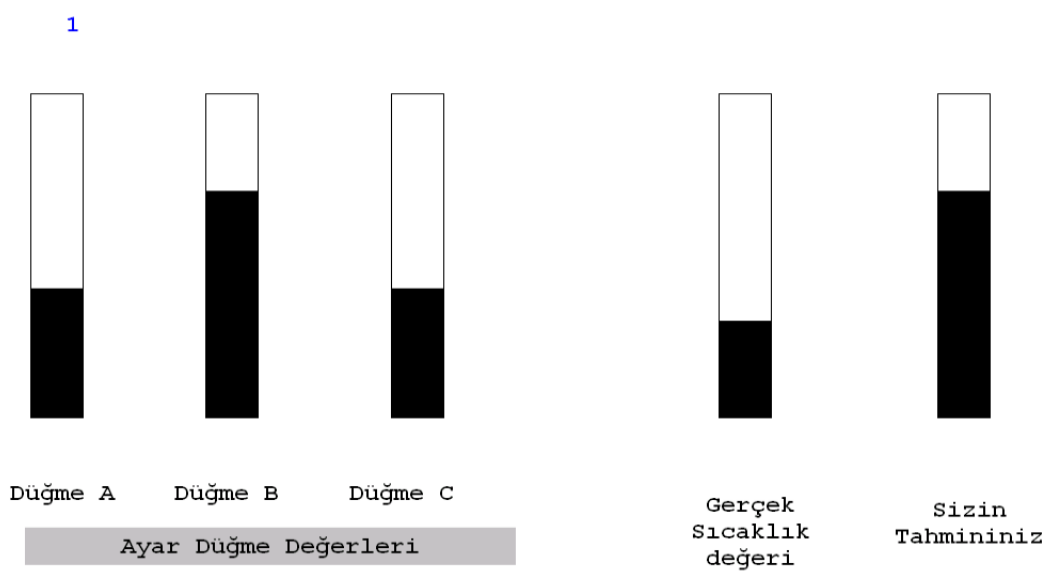



Figure 4.3: Feedback presentation screen for the graphical condition (with cues)

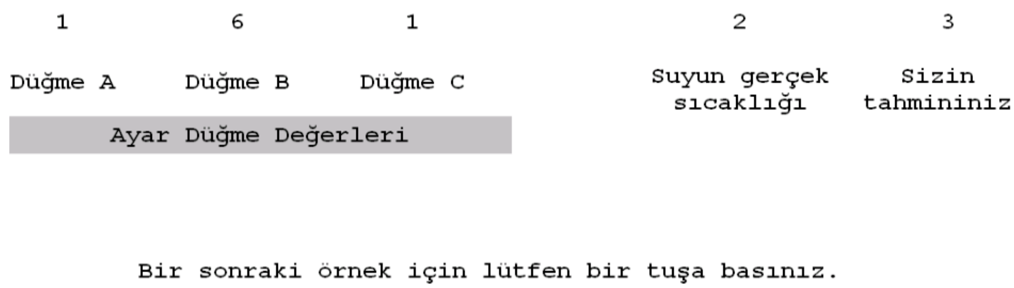



Figure 4.4: Feedback presentation screen for the numerical condition (with cues)

### 4.2.2 WMC Tasks

Automated Operation Span (AOSPAN) task of Experiment 1 was used without any modifications as the first measure of verbal WMC. As already mentioned, after analyzing the results of Experiment 1, we have considered to include another span task to find an alternative verbal WMC measure that may more strongly correlates with learning performance. Among several alternatives, Backward Digit Span (BDS) task was selected.

Digit span task measure the digit spans of individuals by presenting digits and measuring the correctly remembered numbers in the given order. Backward Digit Span (BDS) task, on the other hand, is relatively complex because participants make an additional transformation during rehearsal. In this task, digits are presented to participants and they are instructed to recall and type the numbers in the reverse order.

The design of stimuli and collecting recall is very simple. A sequence of digits are displayed in the screen successively. After the sequence is displayed, participant enters the displayed digits in the reverse order. The length of the digit sequences starts from 3 and increases until 8. Sequences are displayed 5 times for each length. Therefore in total 30 stimuli is displayed. The task ends either the 30 stimuli is displayed or number of correctly remembered sequences is less than 3 in a sequence group of a length. BDS task lasts about ten minutes on average. The absolute scoring is calculated by summing correctly remembered sequences.

## 4.3 Design

Independent variable used for this experiment was MCPL task modality (i.e. numerical and graphical presentation and response mode). The dependent variables were the achievements (correlation of criterion with the judgment) for the blocks (of size 50) and overall achievement. The experiment used between-subjects design - participants were randomly allocated to the graphic or numeric presentation conditions.

## 4.4 Procedure

Participants attended to the experiment's tasks in rooms in METU, ATILIM University and in a software company. The maximum number of participants in a single session was ten, which occurred in the computer laboratory located in the METU Informatics Institute. They have been given Information Consent Form (see Section A.2 in Appendix A) before starting and Debriefing Form (see Section A.3 in Appendix A) after finishing the tasks. Those who were paid, have been paid after finishing all three tasks.

Participants were assigned to one of the MCPL conditions, AOSPAN and BDS tasks, respectively. Participants were instructed as explained in the related apparatus section. No break was given between the tasks, except requested by the participant. MCPL assignment were done by first considering to balance number of attendees to graphical and numerical conditions, then considering to balance the gender of the participant's in each MCPL condition.

## 4.5 Results

### 4.5.1 Data Preparation

The same data preparation process, in the Experiment-1, was applied. The achievement and WMC measurement scores are shown in Table B.3 and Table B.4 in Appendix B.

### 4.5.2 Analysis

The mean values of achievement scores for each block is depicted together for numerical and graphical modalities in Figure 4.5. Although they are not clearly separated the learning progress for numerical and graphical modalities can be seen in this figure.

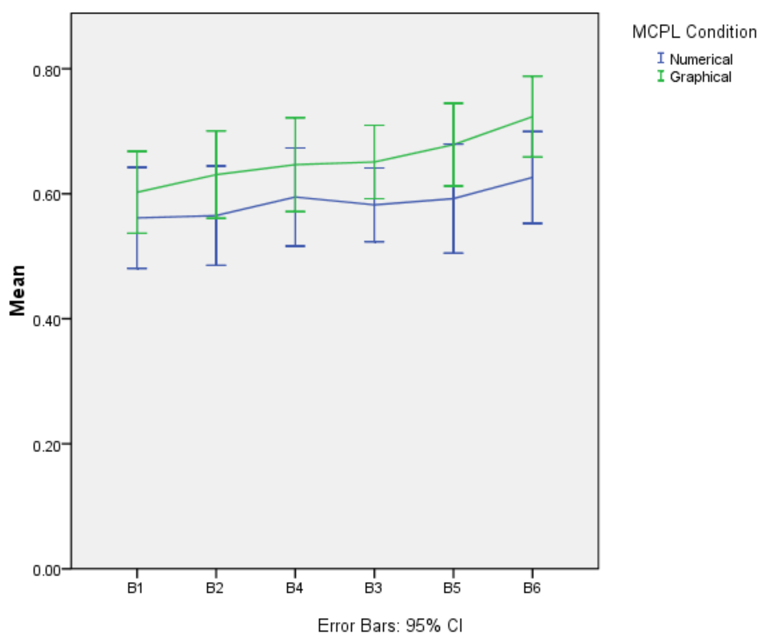
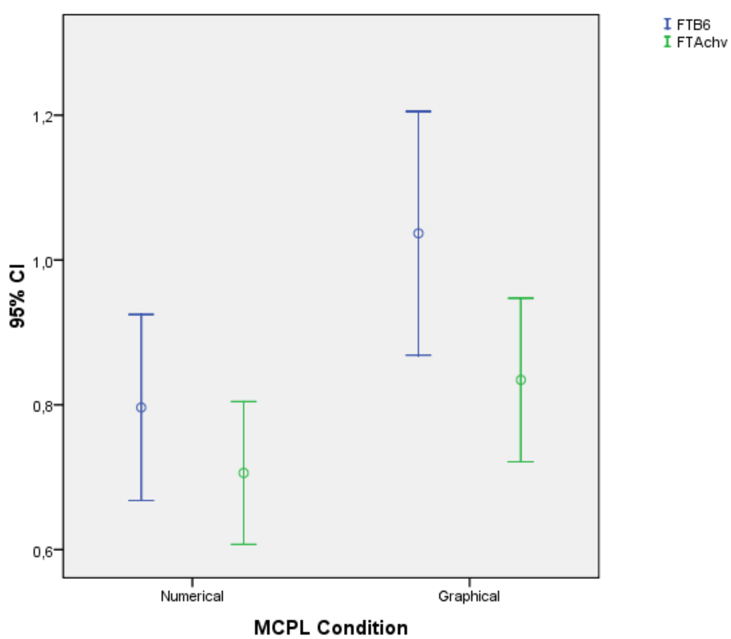



Figure 4.5: Mean achievements for each Block

The analysis results of the experiment data have shown that the effect of mode of presentation exist significantly for the dependent variable "Block-6 Achievement" but it does not for the "Overall Achievement". The mean values of the "Block-6 Achievement" and "Overall Achievement" for the two experiment conditions are depicted in Figure 4.6. This figure also shows the error bar attached to mean values. As it can be seen in this figure, mean values for the two groups are separated from each other. To test the hypothesis numerical and graphical task modality groups are not similar one way ANOVA was conducted (see Table 4.1). According to this analysis the effect of MCPL task modality was not significant for the dependent variable "Overall Achievement", $F(1,56)=3.045$, $p>.05$. Cohen's effect size value ($d = .29$) suggested a small practical significance. The effect was significant at the 0.05 level, for the "Block-6 Achievement", $F(1,56)=5.305$, $p<.05$. Cohen's effect size value ($d = .23$) suggested a small practical significance. This results implies that there exists an effect of two conditions on "Block-6 Achievement", but there is not any effect for "Overall Achievement".




FTB6=Fisher transformed Block 6 achievement. FTAch=Fisher transformed overall achievement.

Figure 4.6: Error plot for the block-6 and overall achievements (Experiment-2)

Table 4.1: One Way ANOVA conducted for the dependent variables, FTAchv and FTB6 (Experiment-2)

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| FTAchv | Between Groups | ,239 | 1 | ,239 | 3,045 | ,086 |
| | Within Groups | 4,403 | 56 | ,079 | | |
| | Total | 4,642 | 57 | | | |
| FTB6 | Between Groups | ,839 | 1 | ,839 | 5,305 | ,025 |
| | Within Groups | 8,854 | 56 | ,158 | | |
| | Total | 9,693 | 57 | | | |

A correlation analysis was conducted among the independent variables AOSPAN score, Backward Digit Span Score (BDS), and dependent variables Block-6 Achievement and Overall Achievement. Results showed that AOSPAN was positively correlated with Block-6 Achievement, r=0.227, p=0.095, and Overall Achievement, r=0.218, p=0.110, but correlations were not significant. BDS, on the other hand, was significantly and positively correlated with both Block-6 Achievement and Overall Achievement. Correlation values were r=0.456, p<.01 and r=0.348, p<.01, respectively. The correlation table for this analysis is given in Table 4.2.

Table 4.2: Correlation analysis for overall data (Experiment-2)

**Correlations**

| | | FTAchv | FTB6 | AOSPAN | BDS |
|---|---|---|---|---|---|
| FTAchv | Pearson Correlation | 1 | ,821** | ,218 | ,348** |
| | Sig. (2-tailed) | | ,000 | ,110 | ,007 |
| | N | 58 | 58 | 55 | 58 |
| FTB6 | Pearson Correlation | ,821** | 1 | ,227 | ,456** |
| | Sig. (2-tailed) | ,000 | | ,095 | ,000 |
| | N | 58 | 58 | 55 | 58 |
| AOSPAN | Pearson Correlation | ,218 | ,227 | 1 | ,511** |
| | Sig. (2-tailed) | ,110 | ,095 | | ,000 |
| | N | 55 | 55 | 55 | 55 |
| BDS | Pearson Correlation | ,348** | ,456** | ,511** | 1 |
| | Sig. (2-tailed) | ,007 | ,000 | ,000 | |
| | N | 58 | 58 | 55 | 58 |

**. Correlation is significant at the 0.01 level (2-tailed).

The analysis made for the Experiment-1, by grouping the data was repeated to provide a comparison basis. The data was grouped according to MCPL task modality and separate correlation analysis was conducted for both groups of data. As opposed to previous experiment, AOSPAN Score, was not correlated significantly with either "Block-6 Achievement" or "Overall Achievement" in any of the conditions. BDS score, for the graphical MCPL condition, as opposed to AOSPAN score, was positively and significantly correlated with both Block-6 Achievement ($r=0.550$, $p<.01$) and Overall Achievement ($r=0.368$, $p<.05$). However, for the numerical MCPL condition, BDS was not significantly correlated neither with Block-6 Achievement Score, nor with Overall Achievement score. The correlation tables are shown in Table 4.3 and Table 4.4.

The relationship between learning performance (overall achievement) and working memory measure (AOSPAN and BDS) can be seen in Figure 4.7 and 4.8. According to the plots given in Figure 4.7, learning performance is not associated with AOSPAN for either graphical or numerical modalities. There is, on the other hand, a linear relationship between learning performance and BDS for graphical modality (see Figure 4.8). For numerical modality, although there seems to be a tendency of a linear relationship between BDS and learning performance, it is very weak.

Table 4.3: Correlation analysis for graphical condition data (Experiment-2)

**Correlations**[a]

| | | FTAchv | FTB6 | AOSPAN | BDS |
|---|---|---|---|---|---|
| FTAchv | Pearson Correlation | 1 | ,814** | ,216 | ,368* |
| | Sig. (2-tailed) | | ,000 | ,270 | ,046 |
| | N | 30 | 30 | 28 | 30 |
| FTB6 | Pearson Correlation | ,814** | 1 | ,233 | ,550** |
| | Sig. (2-tailed) | ,000 | | ,233 | ,002 |
| | N | 30 | 30 | 28 | 30 |
| AOSPAN | Pearson Correlation | ,216 | ,233 | 1 | ,522** |
| | Sig. (2-tailed) | ,270 | ,233 | | ,004 |
| | N | 28 | 28 | 28 | 28 |
| BDS | Pearson Correlation | ,368* | ,550** | ,522** | 1 |
| | Sig. (2-tailed) | ,046 | ,002 | ,004 | |
| | N | 30 | 30 | 28 | 30 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

a. MCPL Condition = Graphical

Table 4.4: Correlation analysis for numerical condition data (Experiment-2)

**Correlations**[a]

| | | FTAchv | FTB6 | AOSPAN | BDS |
|---|---|---|---|---|---|
| FTAchv | Pearson Correlation | 1 | ,807** | ,178 | ,355 |
| | Sig. (2-tailed) | | ,000 | ,373 | ,064 |
| | N | 28 | 28 | 27 | 28 |
| FTB6 | Pearson Correlation | ,807** | 1 | ,169 | ,306 |
| | Sig. (2-tailed) | ,000 | | ,400 | ,113 |
| | N | 28 | 28 | 27 | 28 |
| AOSPAN | Pearson Correlation | ,178 | ,169 | 1 | ,518** |
| | Sig. (2-tailed) | ,373 | ,400 | | ,006 |
| | N | 27 | 27 | 27 | 27 |
| BDS | Pearson Correlation | ,355 | ,306 | ,518** | 1 |
| | Sig. (2-tailed) | ,064 | ,113 | ,006 | |
| | N | 28 | 28 | 27 | 28 |

**. Correlation is significant at the 0.01 level (2-tailed).

a. MCPL Condition = Numerical

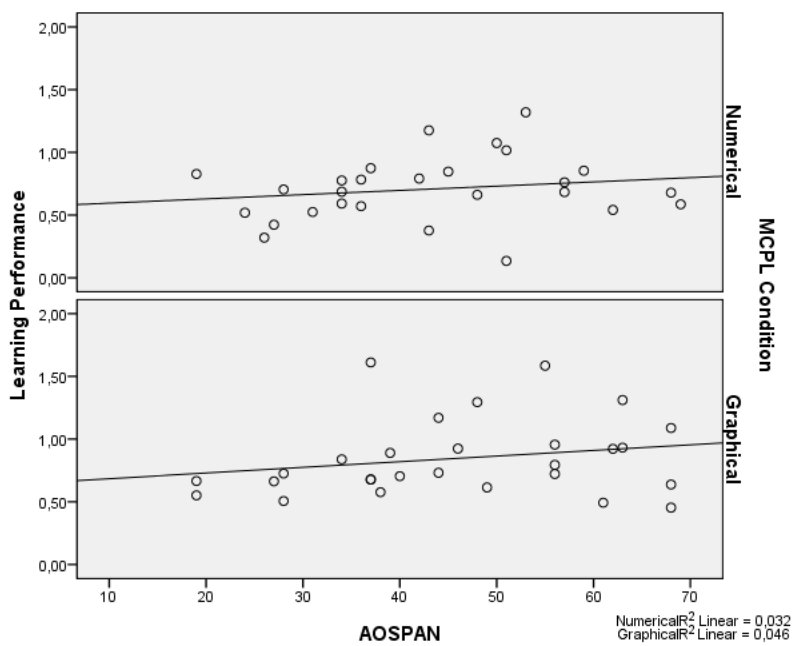



Figure 4.7: Scatter plots of learning performance (overall achievement) and AOSPAN for numerical and graphical conditions (Experiment-2)

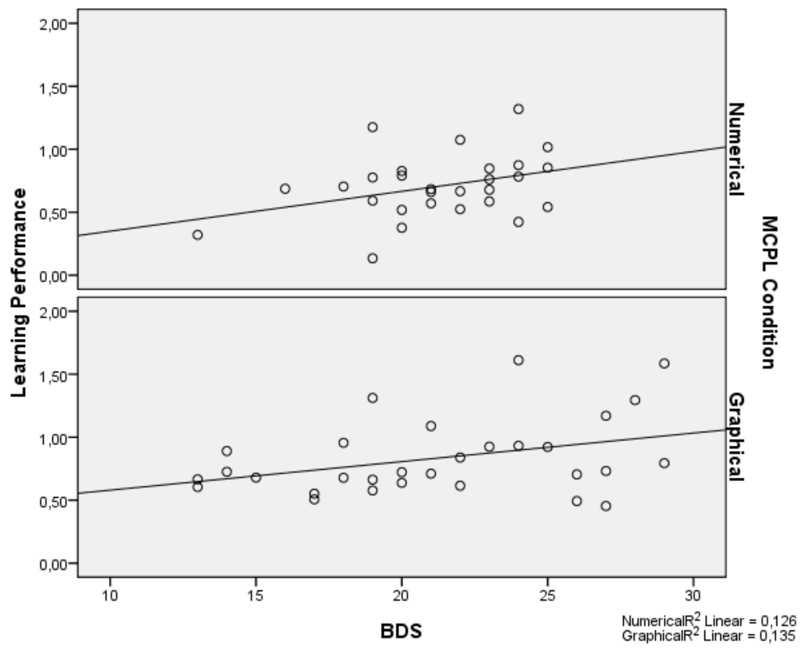



Figure 4.8: Scatter plots of learning performance (overall achievement) and AOSPAN for numerical and graphical conditions (Experiment-2)

## 4.6 Discussion

In this experiment we aimed to confirm the results of previous experiment by improving the MCPL design and employed one more WMC measure called as Backward Digit Span (BDS) by expecting a more strong prediction capability as compared to AOSPAN measure.

The results of the experiment confirmed the effect of presentation method in MCPL task. Unlike the first experiment, this effect has been seen only for the "Block-6 Achievement". We argue that, this could be because of high variance in the individual differences of participants, who are especially from different universities. Actually by using the AOSPAN and BDS measures, we analyzed whether there is a difference between the cognitive abilities of participant groups such as university, gender and background and no significant difference found. Therefore we think that the difference between Experiment 1 and Experiment 2 may arise from other individual difference related factors.

In this experiment, the effect size of the differences in achievements in numerical and graphical modes has been decreased from moderate to small as compared to Experiment 1. Two major changes have been applied in Experiment 2. In numerical mode, spatial distribution of cue values was changed from vertical to horizontal. In graphical mode, on the other hand, instead of colored, black bar graphs were used. One plausible explanation would be that the colored representation matched the polarity of cues and this caused an advantage in graphical mode, so that a performance difference was observed.

As in the first experiment, AOSPAN did not correlate significantly with MCPL achievement scores (Block-6 and overall). Furthermore, when data is grouped according to the presentation condition, AOSPAN scores didn't correlate significantly with any of the achievements for any of the groups. In the first experiment we had found a significant correlation with the graphical condition.

BDS score, on the other hand, correlated with both Block-6 Achievement and Overall Achievement significantly. For graphical modality, BDS score significantly predicted the learning performance. When numerical condition is in question neither AOSPAN nor BDS has been correlated with the achievement scores. It seems that, the high correlation values obtained in graphical modality group causes the overall correlation to be significant, so overall correlation values does not mean BDS has a general relation with achievement in MCPL tasks.

This results partially support our hypotheses about the relationship between working memory and learning performance in MCPL. We have expected to see WMC as a significant predictor of MCPL task performance, in general. But, WM as indicated by BDS was only able to predict performance in case of graphical modality.

These observation caused us to suspect from the relation of AOSPAN as a measure of WMC with this typical MCPL task. It seems that, abilities needed by MCPL were not related to abilities measured by AOSPAN. More interestingly, BDS score correlated with achievement significantly. This result may be explained in terms of cognitive constructs that the two WMC tasks measure. AOSPAN and BDS may be measuring different aspects of WMC and as such what BDS is measuring can be more effective in a graphically presented MCPL task. We will take up this point again in Chapter 7 and but the further details of differences between two measures (as briefly summarized in 23 of Chapter 2) is beyond the scope of this dissertation. Our aim for employing BDS in this experiments, was to compare the effectiveness and duration of BDS with AOSPAN measure. In the light of the findings the BDS was better to meet our intentions, so that we decided to use BDS instead of AOSPAN in the other experiments.

# CHAPTER 5

# EXPERIMENT 3

Previous two experiments have shown that for the MCPL tasks explained in Section 3.3.1 and Section 4.2.1, the learning performance in graphical modality was significantly higher than the numerical one. The apparatus used in the second experiment was slightly different than the one used in the first experiment. After comparing the achievement values of the two experiments we have concluded that the display designs used in the first experiment may provide some unfair advantageous to graphical modality which are not caused by the modality itself. Therefore, in the subsequent experiments, we have decided to use the the display style of Experiment 2.

Previously, we have also found that the verbal WMC measurement task, Backward Digit Span (BDS), is a better predictor of the performance in MCPL as compared to AOSPAN. Therefore BDS was employed in this experiment instead of AOSPAN. One of our interests in the scope of WMC - MCPL interaction is exploring the relationship with respect to verbal and visual modality existing in the Working Memory. Therefore we have added a visual memory capacity measurement task as a new independent variable. This two WMC measures provided us the opportunity to test our dissociation hypotheses.

In this new experiment, the MCPL conditions employed in Experiment 2, were used without change. Additionally, as a side issue, in order to find out the effect of polarity of cues on the performance, we have produced one more MCPL condition in which polarity of cues were set as positive for all three cues. Hence, in total, three conditions of MCPL task were employed in this Experiment. For exploring the effect of visuo-spatial working memory, a visuo-spatial WMC measurement task added beside BDS task.

## 5.1 Participants

This experiment was done among the students from METU. The experiment was announced via posters in the university. 163 participants[1] attended to this experiment. Ninety three (93) of the participants were female, seventy (70) of them were male.

Forty nine (49) of the participants attended to graphical, mixed cue polarization MCPL condition (27 males, 22 females) and forty nine (49) of the participants attended to numerical, mixed cue MCPL polarization condition (22 males, 27 females). Sixty five (65) of the participants attended to graphical, all positive cue polarization MCPL condition (44 females, 21 males). All participants received Backward Digit Span and Corsi Block Tapping tasks.

## 5.2 Apparatus

### 5.2.1 MCPL Tasks

The two conditions with numerical and graphical modalities were exactly same as the conditions used in previous experiment. These tasks were used to test our hypotheses.

In literature, polarity of cues in MCPL context, that is the direction the cues change the criterion value, was studied several times (Chasseigne et al. (1997), Chasseigne et al. (1999), Rolison et al. (2011)). As a general finding obtained from that studies, it may be concluded that existence of negatively polarized cues makes the tasks

[1] Participants attended to the experiment for a small amount of participation fee.

difficult, resulting employment of Working Memory during task execution. Rolison et al. (2011) found that working memory correlates with performance in MCPL when there were negatively polarized cues. In the light of these findings in the literature, after analyzing the data obtained from the two conditions and not seeing a dissociation between the performances in numerical and graphical conditions, we have added an extra MCPL condition to see whether negatively polarized cues are effective in revealing the effect of working memory.

In the third condition a new task was created for testing the performance in case of all positive polarization scheme for graphical mode of presentation/response. All-positive cue polarization task aimed to see the effect of existence of negative cue in the scope of our MCPL task. We have thought that graphical mode would be a better choice for seeing this because in this modality individuals performs better as understood from previous experiments. Detecting the effect in the high performance group may mean seeing the same effect in lower performance group.

The screens of the tasks were adopted from the MCPL tasks in Experiment 2. Note that, those task screens do not contain any information about the polarity of cues. So, just the cue profiles and corresponding criterion values were changed according to the new criterion function which was :

$$Y = 0.36A + 0.65B + 0.43C$$

Note that the cue profiles used in mixed polarization design may not be used in this case because the range of the criterion value may not fit in to 1-9 scale due to one negative weight replaced with a positive weight. Therefore, we have selected a different set of cue profiles. Consequently, 300 cue profiles were selected among 9x9x9 different possible cue profiles such that range of the criterion value was between 1 and 9, and the inter-correlations were near to zero. At the beginning of selection procedure, criterion values were calculated by using the weight weight values 0.3, 0,7 and 0.5, but the weights shown in the above equation were found after regression analysis conducted with cue values and corresponding criterion value. The change in the weight values were mainly introduced by the truncation errors.

The histogram of the criterion values for which the cue profiles were presented are shown in Figure 5.1. If the distribution of the criterion values used in mixed cue and all positive cue MCPL tasks as depicted by the histogram plots are compared it is seen that there is not a significant difference, because both distributions are normal like. This similarity is important because otherwise, beside the polarity of cues, the distribution may contribute to the difficulty of the task.

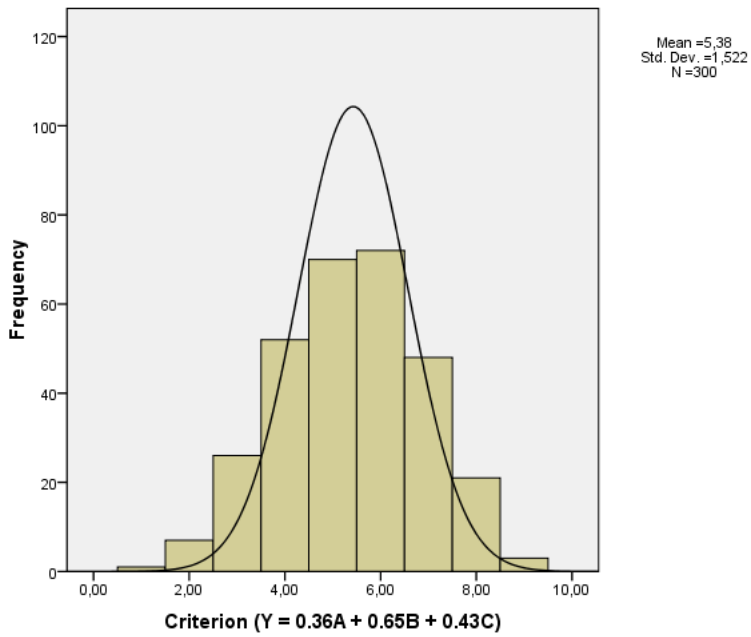



Figure 5.1: Histogram of criterion values corresponding to displayed cue profiles

As in the previous experiments, each trial of a typical MCPL task, consists of presentation of cue(s), collecting responses from the participants and giving outcome feedback. This procedure was also applied in this task. The 300 cue profiles were presented randomly to the participants. As a result of randomization, each participant exposed to a differently ordered cue profiles. The last 50 trials were given without outcome feedback.

### 5.2.2 WMC tasks

Beside the Backward Digit Span (BDS) task, a visuo-spatial WMC task, known as Corsi Block Tapping Span task, was used for measuring WMC. Corsi Block Tapping Span task is considered to measure the spatial component of working memory. Original Corsi Block Tapping (CBT) Test's (Corsi, 1972) method is to touch the blocks in front of the participant and ask for the touch sequence. Recall can be collected in forward or backward order. Score is calculated as the maximum number of correctly remembered block (partial credit) (Berch et al., 1998). The task ended after completion all sequences which can be eight at maximum. In a typical computerized version of CBT (Berch et al., 1998), blocks are displayed as 2 dimensional squares and instead of touching, a bold circle is displayed in the center of square. Participants give their responses by selecting the squares with mouse. We have developed the computerized version of the CBT test by using E-prime (version 2) software, as explained in Berch et al. (1998). In this computerized version of CBT task, a total of 24 sequences are displayed to participants and the task lasts about fifteen minutes as it was measured in our pilot studies.

## 5.3 Design

Independent variables used for this experiment was MCPL task modality (i.e. numerical and graphical presentation and response mode). The dependent variables were the achievements (correlation of criterion with the judgment) for the blocks (of the size 50) and overall achievement. The experiment used between-subjects design so that participants were randomly allocated to one of the three MCPL tasks.

## 5.4 Procedure

Participants were invited to the Computer Laboratory located in the METU Informatics Institute. They have been given Information Consent Form (see Section A.2 in Appendix A) before starting and Debriefing Form (see Section A.3 in Appendix A) after finishing the tasks. They have been paid after finishing all three tasks.

They were assigned to one of the three MCPL conditions and all of them completed BDS and CBT tasks. First MCPL task then BDS task and finally CBT task were conducted. Participants were instructed as explained in the related apparatus. No break was given between the tasks, except requested by the participant. MCPL task assignment were done by first considering to balance number of attendees to graphical and numerical conditions for all positive and mixed polarization conditions, then considering to balance the gender of the participant's in each MCPL condition.

## 5.5 Results

### 5.5.1 Data Preparation

The same data preparation process, in the Experiment-1, was applied on the test data. The achievement and WMC measurement scores are shown in Table B.5, Table B.6 and Table B.7 in Appendix B.

### 5.5.2 Analysis

Remember that MCPL task has had three conditions in this experiment and we have grouped data according to our focus before the analyses. In order to see the effect of numerical and graphical modalities, we have excluded the data of all positive cue polarization condition, because this condition introduces another factor that must be handled separately. Furthermore, because we didn't include the numerical modality of all positive cue polarization as a condition, a factorial analysis was not conducted for this data.

#### 5.5.2.1 Analysis on Numerical/Graphical Modality Mixed Cue Polarization Conditions

The mean values of achievement scores for each block is depicted together for numerical and graphical modalities in Figure 5.2. The progress in the learning can be clearly seen in this figure. The learning progresses was similar to progress observed in the previous two experiments. The separation of learning performances for numerical and graphical modalities was better as compared to the second experiment.

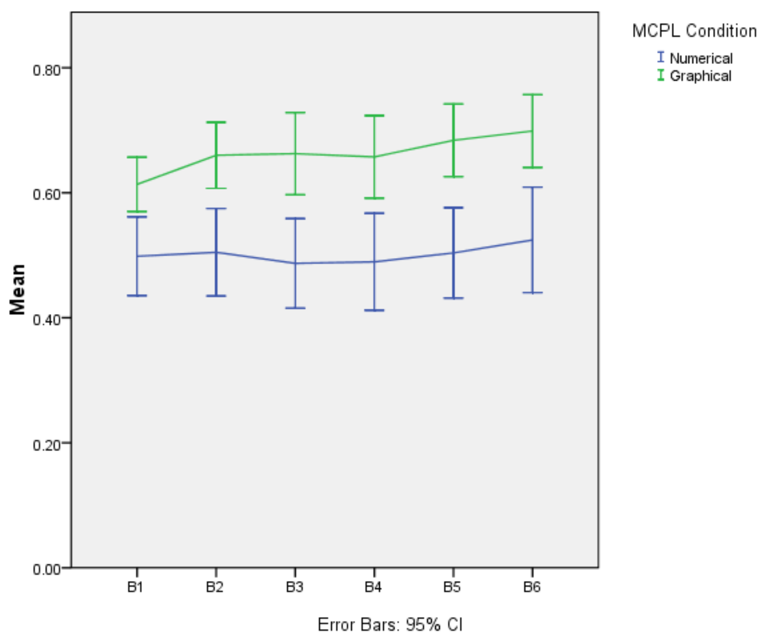


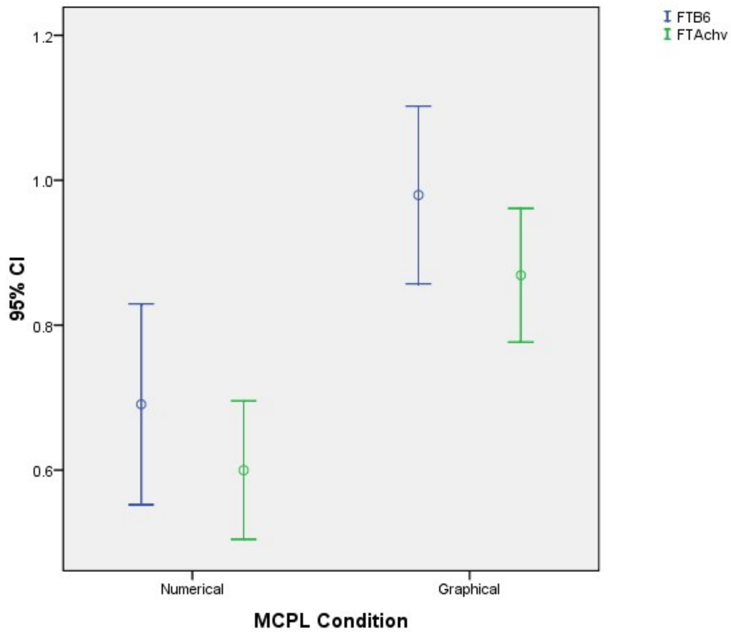

Figure 5.2: Mean achievements for each Block

For the data of mixed cue polarization, one way ANOVA analysis was conducted to analyze the effect of MCPL presentation condition as in the other two experiments. There was a significant effect of MCPL presentation condition on Block-6 Achievement, $F(1,96)=9.85$, $p<.01$. Cohen's effect size value ($d = .31$) suggested a small to moderate practical significance. There was also a significant effect of MCPL presentation condition on Overall Achievement, F(1,96)=16.588, p<.01. Cohen's effect size value (d = .38) suggested a small to moderate practical significance. The achievement scores were higher for graphical presentation condition as compared to numerical presentation condition. The ANOVA result is shown in Table 5.1. Figure 5.3 shows the means of the achievement values, for the two groups, with error bars on them. In these plots, error bars represent the confidence interval for the means. Non overlapping or slightly overlapping error bars indicate the existence of between group differences.

Table 5.1: One Way ANOVA conducted in the mixed cue polarization group for the dependent variables, FTAchv and FTB6 (Experiment-3)

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| FTB6 | Between Groups | 2.046 | 1 | 2.046 | 9.854 | .002 |
| | Within Groups | 19.929 | 96 | .208 | | |
| | Total | 21.975 | 97 | | | |
| FTAchv | Between Groups | 1.774 | 1 | 1.774 | 16.588 | .000 |
| | Within Groups | 10.266 | 96 | .107 | | |
| | Total | 12.040 | 97 | | | |




FTB6=Fisher transformed Block 6 achievement. FTAch=Fisher transformed overall achievement.

Figure 5.3: Error plot for the block-6 and overall achievements (Experiment-3)

With this experiment, in addition to Backward Digit Span score (BDS), we have used a new WMC measure to asses the visual working memory component. We have employed Corsi Block Tapping test as the indicator of visuo-spatial working memory. Scoring of this measure is done in the same manner with BDS. Remember that during the execution of these tasks a sequence of stimuli is given to participants, and they respond by recalling the sequence. Scoring[2] was done by summing the correctly remembered sequences (absolute scoring). Partial scores were also calculated. These scores were referenced with labels BDS, BDS-2, CBT and CBT-2, where number 2 indicates the partial scoring method.

A correlation analysis was conducted among the independent variables BDS absolute score (BDS), BDS partial score (BDS-2), CBT absolute score (CBT), CBT partial score (CBT-2) and dependent variables Fisher transformed Block-6 Achievement (FTB6) and Fisher transformed Overall Achievement (FTAchv).

[2] see Section 3.3.2 for scoring alternatives.

BDS was positively and significantly correlated with Block-6 Achievement, r=0.320, p<.01, and Overall Achievement, r=0.327, p<.01. Similarly BDS-2 was also positively and significantly correlated with Block-6 Achievement, r=0.217, p<.05, and Overall Achievement, r=0.204, p<.05. But in this case level of significance was lower. Absolute CBT score was also positively and significantly correlated with Block-6 Achievement, r=0.300, p<.01, and Overall Achievement, r=0.294, p<.01. CBT-2 score was positively and significantly correlated with Overall Achievement, r=0.231, p<.05, but non-significantly correlated with Block-6 Achievement, r=0.190, p=.050. The correlation table for this analysis is given in Table 5.2.

Table 5.2: Correlation analysis for overall data (Experiment-3)

**Correlations**

| | | FTB6 | FTAchv | BDS | BDS2 | Corsi | Corsi2 |
|---|---|---|---|---|---|---|---|
| FTB6 | Pearson Correlation | 1 | .906** | .320** | .217* | .300** | .190 |
| | Sig. (2-tailed) | | .000 | .001 | .032 | .003 | .060 |
| | N | 98 | 98 | 98 | 98 | 98 | 98 |
| FTAchv | Pearson Correlation | .906** | 1 | .327** | .204* | .294** | .231* |
| | Sig. (2-tailed) | .000 | | .001 | .043 | .003 | .022 |
| | N | 98 | 98 | 98 | 98 | 98 | 98 |
| BDS | Pearson Correlation | .320** | .327** | 1 | .802** | .492** | .440** |
| | Sig. (2-tailed) | .001 | .001 | | .000 | .000 | .000 |
| | N | 98 | 98 | 98 | 98 | 98 | 98 |
| BDS2 | Pearson Correlation | .217* | .204* | .802** | 1 | .422** | .404** |
| | Sig. (2-tailed) | .032 | .043 | .000 | | .000 | .000 |
| | N | 98 | 98 | 98 | 98 | 98 | 98 |
| Corsi | Pearson Correlation | .300** | .294** | .492** | .422** | 1 | .838** |
| | Sig. (2-tailed) | .003 | .003 | .000 | .000 | | .000 |
| | N | 98 | 98 | 98 | 98 | 98 | 98 |
| Corsi2 | Pearson Correlation | .190 | .231* | .440** | .404** | .838** | 1 |
| | Sig. (2-tailed) | .060 | .022 | .000 | .000 | .000 | |
| | N | 98 | 98 | 98 | 98 | 98 | 98 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlation analysis was repeated by splitting the data according to mode of presentation. The correlation tables are given in Table 5.3 and Table 5.4. In summary, none of the WMC scores was significantly correlated with any of the Achievements, for numerical mode of presentation of MCPL task. But, similar to previous experiments, for graphical MCPL condition, BDS was significantly and positively correlated with both Block-6 Achievement and Overall Achievement. The new WMC Score, CBT, was also significantly and positively correlated with both Block-6 Achievement and Overall Achievement, for graphical MCPL condition. When correlations for the partial scorings (CBT-2 and BDS-2) were examined it was seen that, only the correlation between Partial CBT scoring (CBT-2) and Block-6 Achievement was significant for graphical condition.

Table 5.3: Correlation analysis for graphical condition data (Experiment-3)

**Correlations[a]**

| | | FTB6 | FTAchv | BDS | BDS2 | Corsi | Corsi2 |
|---|---|---|---|---|---|---|---|
| FTB6 | Pearson Correlation | 1 | .892** | .415** | .277 | .423** | .290* |
| | Sig. (2-tailed) | | .000 | .003 | .054 | .002 | .043 |
| | N | 49 | 49 | 49 | 49 | 49 | 49 |
| FTAchv | Pearson Correlation | .892** | 1 | .339* | .205 | .341* | .252 |
| | Sig. (2-tailed) | .000 | | .017 | .158 | .016 | .081 |
| | N | 49 | 49 | 49 | 49 | 49 | 49 |
| BDS | Pearson Correlation | .415** | .339* | 1 | .812** | .540** | .486** |
| | Sig. (2-tailed) | .003 | .017 | | .000 | .000 | .000 |
| | N | 49 | 49 | 49 | 49 | 49 | 49 |
| BDS2 | Pearson Correlation | .277 | .205 | .812** | 1 | .428** | .435** |
| | Sig. (2-tailed) | .054 | .158 | .000 | | .002 | .002 |
| | N | 49 | 49 | 49 | 49 | 49 | 49 |
| Corsi | Pearson Correlation | .423** | .341* | .540** | .428** | 1 | .905** |
| | Sig. (2-tailed) | .002 | .016 | .000 | .002 | | .000 |
| | N | 49 | 49 | 49 | 49 | 49 | 49 |
| Corsi2 | Pearson Correlation | .290* | .252 | .486** | .435** | .905** | 1 |
| | Sig. (2-tailed) | .043 | .081 | .000 | .002 | .000 | |
| | N | 49 | 49 | 49 | 49 | 49 | 49 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

a. MCPL Condition = Graphical

Table 5.4: Correlation analysis for numerical condition data (Experiment-3)

**Correlations[a]**

| | | FTB6 | FTAchv | BDS | BDS2 | Corsi | Corsi2 |
|---|---|---|---|---|---|---|---|
| FTB6 | Pearson Correlation | 1 | .903** | .185 | .143 | .176 | .075 |
| | Sig. (2-tailed) | | .000 | .202 | .328 | .227 | .610 |
| | N | 49 | 49 | 49 | 49 | 49 | 49 |
| FTAchv | Pearson Correlation | .903** | 1 | .265 | .180 | .232 | .166 |
| | Sig. (2-tailed) | .000 | | .066 | .217 | .109 | .256 |
| | N | 49 | 49 | 49 | 49 | 49 | 49 |
| BDS | Pearson Correlation | .185 | .265 | 1 | .791** | .431** | .394** |
| | Sig. (2-tailed) | .202 | .066 | | .000 | .002 | .005 |
| | N | 49 | 49 | 49 | 49 | 49 | 49 |
| BDS2 | Pearson Correlation | .143 | .180 | .791** | 1 | .408** | .376** |
| | Sig. (2-tailed) | .328 | .217 | .000 | | .004 | .008 |
| | N | 49 | 49 | 49 | 49 | 49 | 49 |
| Corsi | Pearson Correlation | .176 | .232 | .431** | .408** | 1 | .792** |
| | Sig. (2-tailed) | .227 | .109 | .002 | .004 | | .000 |
| | N | 49 | 49 | 49 | 49 | 49 | 49 |
| Corsi2 | Pearson Correlation | .075 | .166 | .394** | .376** | .792** | 1 |
| | Sig. (2-tailed) | .610 | .256 | .005 | .008 | .000 | |
| | N | 49 | 49 | 49 | 49 | 49 | 49 |

**. Correlation is significant at the 0.01 level (2-tailed).

a. MCPL Condition = Numerical

The relationship between learning performance (overall achievement) and working memory measures (BDS and CBT) are depicted in Figure 5.4 and 5.5 for visual interpretation. There is a linear relationship between learning performance and BDS for graphical modality (see Figure 5.4). For numerical modality, although there seems to be a tendency of a linear relationship between BDS and learning performance, it is very weak. As it can be interpreted as the visualization of correlation analysis, the scatter plots for CBT scores shows results similar with BDS score (see Figure 5.5). That is, in case of graphical modality a moderate linear correlation between learning performance and CBT scores is observed as it can seen in Figure 5.5. However, for numerical modality, the relationship between BDS and learning performance is very weak although there is tendency of linearity.

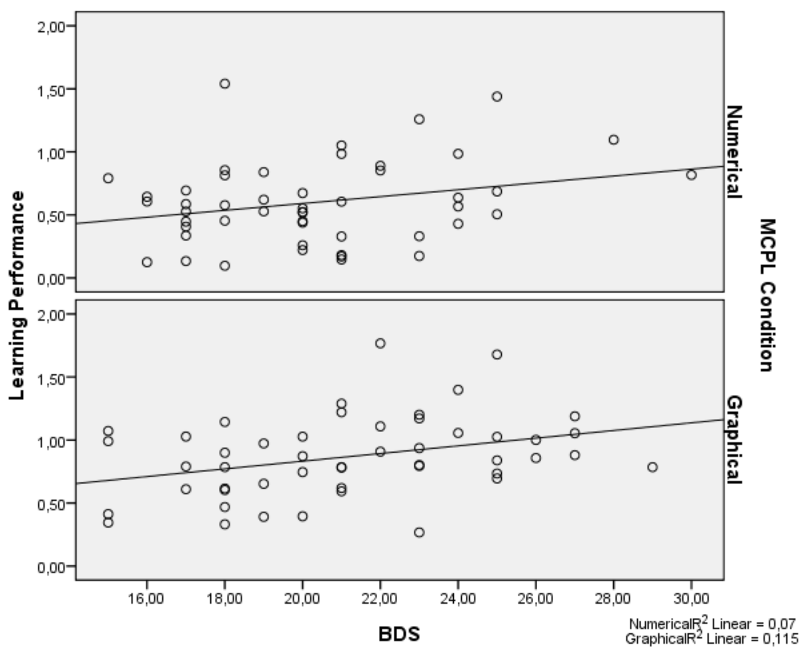



Figure 5.4: Scatter plots of learning performance (overall achievement) and BDS for numerical and graphical conditions (Experiment-3)

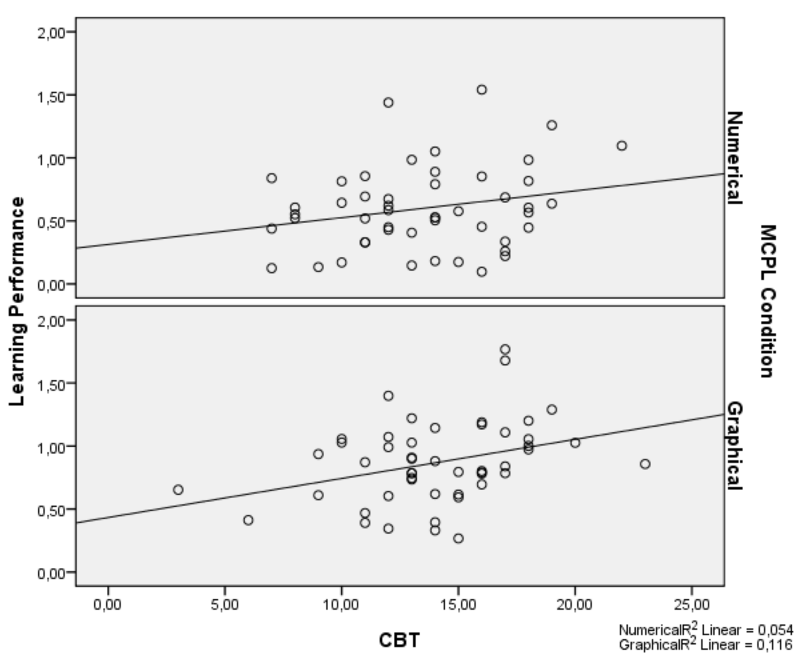



Figure 5.5: Scatter plots of learning performance (overall achievement) and CBT for numerical and graphical conditions (Experiment-3)

To analyze the interaction of different WMC scores with the MCPL condition, a three-way ANOVA was conducted. In order to conduct three way ANOVA, BDS and CBT Scores were grouped into high and low groups by using median split. As a result, two new variables were generated with name NBDS and NCBT. These new variables could be either 1, representing being low, or 2, representing being high. This new independent variables were used in factorial analysis. Summary table of three-way factorial ANOVA is given in Table 5.5 in Appendix B. According to the results of the analysis it has been found that, there was a significant main effect of the of MCPL presentation condition on Block-6 Achievement, $F(2,90)=7.92$, $p<.01$. There was a significant main effect of the of BDS on Block-6 Achievement, $F(2,90)=6.22$, $p<.05$. There was a non significant main effect of Corsi on Block-6 Achievement, $F(2,90)=.573$, $p=.451$.

With this experiment, we have constructed the experimental environment to demonstrate or detect the availability of double dissociation between the achievements in different task modalities. The factorial ANOVA results (See Figure 5.5) showed that there was not any dissociation between the achievements in numerical modality and achievement in graphical modality. This is because neither the interaction between the BDS score and task modality nor the interaction between the CBT score and task modality was significant.

Table 5.5: Three Way ANOVA conducted for the dependent variable FTB6 and the Factors MCPL Condition, NBDS and NCorsi (Experiment-3)

**Tests of Between-Subjects Effects**

Dependent Variable:FTB6

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 4.533[a] | 7 | .648 | 3.342 | .003 |
| Intercept | 53.772 | 1 | 53.772 | 277.470 | .000 |
| Condition | 1.535 | 1 | 1.535 | 7.921 | .006 |
| NDS | 1.205 | 1 | 1.205 | 6.220 | .014 |
| NCorsi | .111 | 1 | .111 | .573 | .451 |
| Condition * NDS | .328 | 1 | .328 | 1.694 | .196 |
| Condition * NCorsi | .026 | 1 | .026 | .135 | .714 |
| NDS * NCorsi | .138 | 1 | .138 | .712 | .401 |
| Condition * NDS * NCorsi | .136 | 1 | .136 | .699 | .405 |
| Error | 17.441 | 90 | .194 | | |
| Total | 90.330 | 98 | | | |
| Corrected Total | 21.975 | 97 | | | |

a. R Squared = .206 (Adjusted R Squared = .145)

The interaction plots also reveal the same results. According to the plots given in Figure 5.6 and Figure 5.7, both verbal memory (implicated by BDS score) and visuo-spatial memory (implicated by CBT score) affects the numerical and graphical modalities in the same way. In other words, being high in verbal WMC or visuo-spatial WMC means higher achievement for both numerical and graphical modalities as compared to being low in verbal WMC or visuo-spatial WMC.

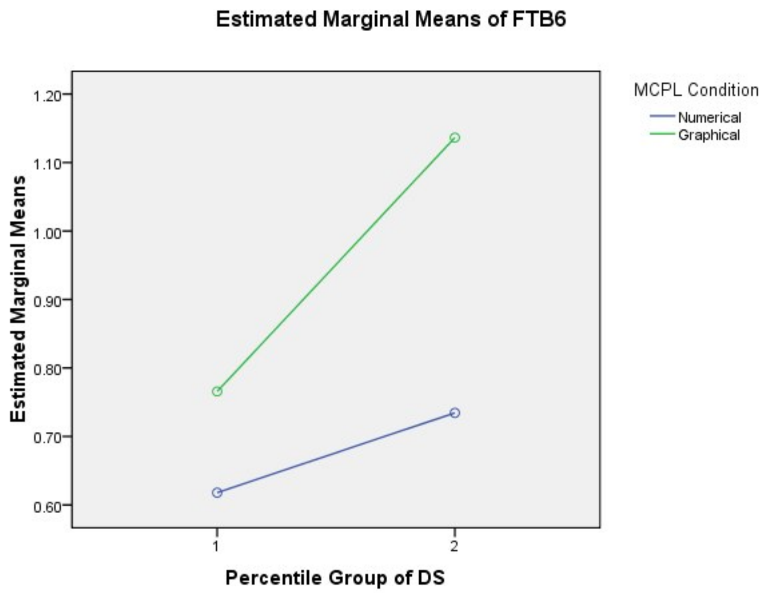



Figure 5.6: Interaction Graph for Backward Digit Span-Achievement Scores

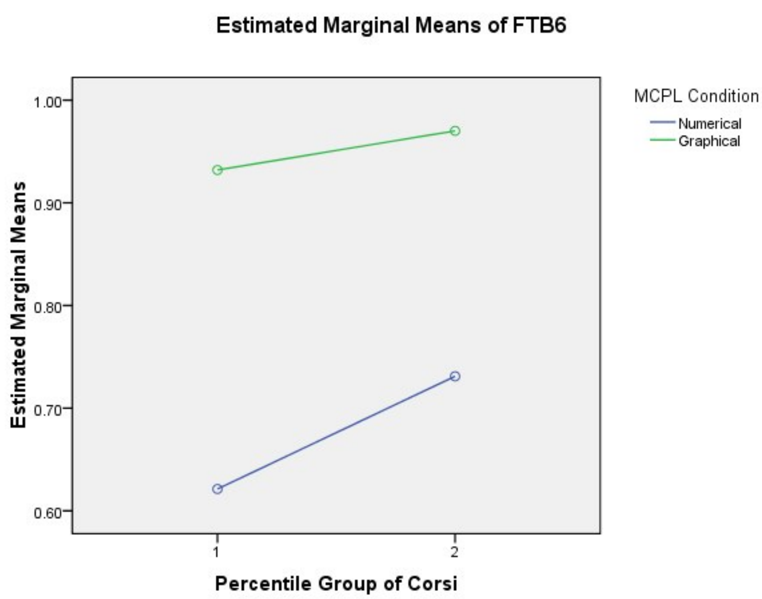



Figure 5.7: Interaction Graph for Backward Digit Span-Achievement Scores

#### 5.5.2.2 Analysis on Graphical Modality Mixed/All Positive Cue Polarization Conditions

The learning performances for the six blocks depicted for all positive and mixed cue conditions as shown in Figure 5.8. In all positive cue condition, the mean values of learning performances were higher for all six blocks. For the first two blocks, the learning performances for all positive and mixed cue conditions was separated from each other, but they became closer as the trials increased.

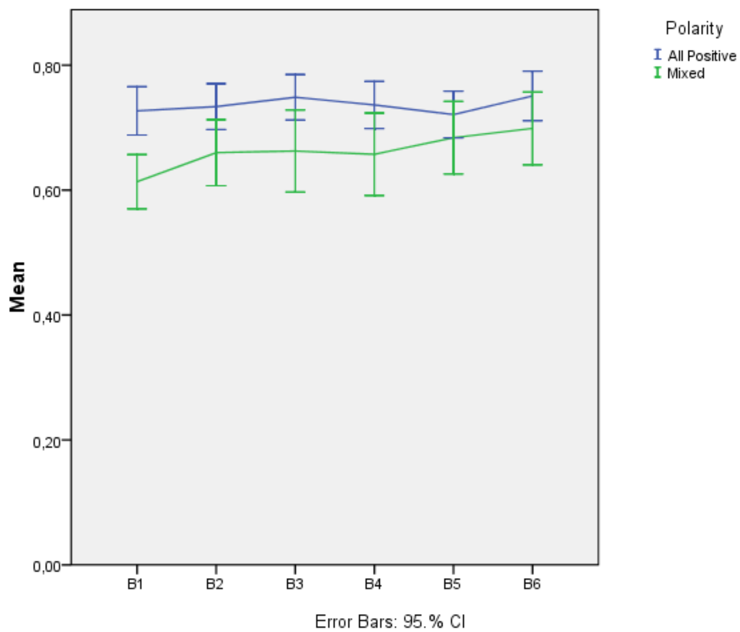



Figure 5.8: Mean achievements for each Block

For the data of graphical modality (both mixed and all positive cue polarization), one way ANOVA analysis was conducted to analyze the effect of polarity (see Table 5.6. There was not a significant effect of Polarity on "Block-6 Achievement", $F(1,82)=1.030$, $p=.312$. There was not also a significant effect of Polarity on "Overall Achievement", $F(1,82)=1.218$, $p=.273$.

Table 5.6: One Way ANOVA conducted in the graphical condition group (mixed and all positive cue polarization) for the dependent variables, FTAchv and FTB6 (Experiment-3)

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| FTAchv | Between Groups | ,108 | 1 | ,108 | 1,218 | ,273 |
| | Within Groups | 7,183 | 81 | ,089 | | |
| | Total | 7,291 | 82 | | | |
| FTB6 | Between Groups | ,141 | 1 | ,141 | 1,030 | ,312 |
| | Within Groups | 15,366 | 112 | ,137 | | |
| | Total | 15,507 | 113 | | | |

A correlation analysis was conducted to find the relation between the achievement and working memory capacity measures in case of all positive cue polarization condition. The analysis revealed that achievement did not correlate significantly with either of the working memory measures. BDS was non-significantly correlated with Block-6 Achievement, r=0.129, p=.307, and Overall Achievement, r=0.266, p=.128. CBT score was also non-significantly correlated with Block-6 Achievement, r=0.084, p=.505, and Overall Achievement, r=0.156, p=.378. The correlation table for this analysis is given in Table 5.7.

Table 5.7: Correlation analysis for graphical and all positive polarization condition (Experiment-3)

**Correlations**

| | | BDS | CBT | FTAchv | FTB6 |
|---|---|---|---|---|---|
| BDS | Pearson Correlation | 1 | ,227 | ,266 | ,129 |
| | Sig. (2-tailed) | | ,069 | ,128 | ,307 |
| | N | 65 | 65 | 34 | 65 |
| CBT | Pearson Correlation | ,227 | 1 | ,156 | ,084 |
| | Sig. (2-tailed) | ,069 | | ,378 | ,505 |
| | N | 65 | 65 | 34 | 65 |
| FTAchv | Pearson Correlation | ,266 | ,156 | 1 | ,839** |
| | Sig. (2-tailed) | ,128 | ,378 | | ,000 |
| | N | 34 | 34 | 34 | 34 |
| FTB6 | Pearson Correlation | ,129 | ,084 | ,839** | 1 |
| | Sig. (2-tailed) | ,307 | ,505 | ,000 | |
| | N | 65 | 65 | 34 | 65 |

**. Correlation is significant at the 0.01 level (2-tailed).

The relationship between learning performance (overall achievement) and working memory measures (BDS and CBT) are depicted in Figure 5.9 and 5.10 for visual interpretation. The random distribution data in both plots shows that CBT and BDS scores are not associated with learning performance.

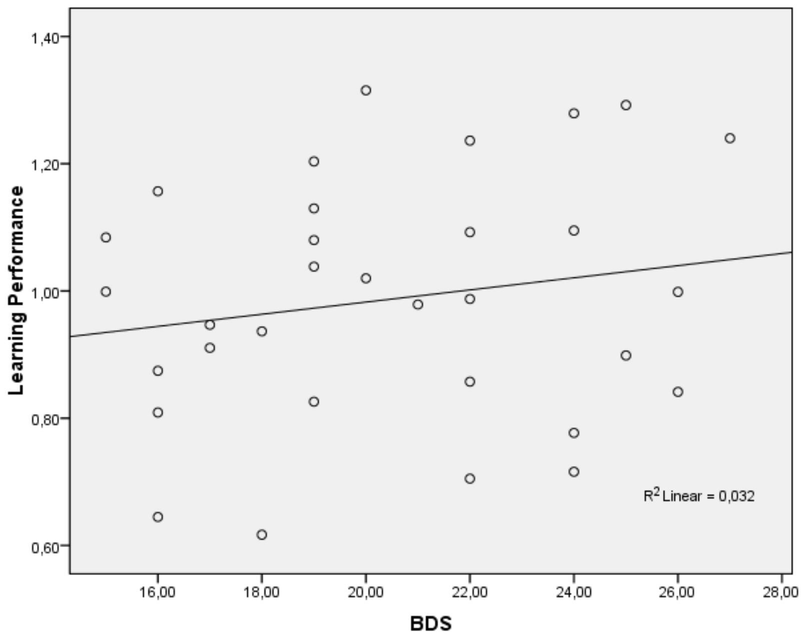



Figure 5.9: Scatter plots of learning performance (overall achievement) and BDS for all positive cue condition (Experiment-3)

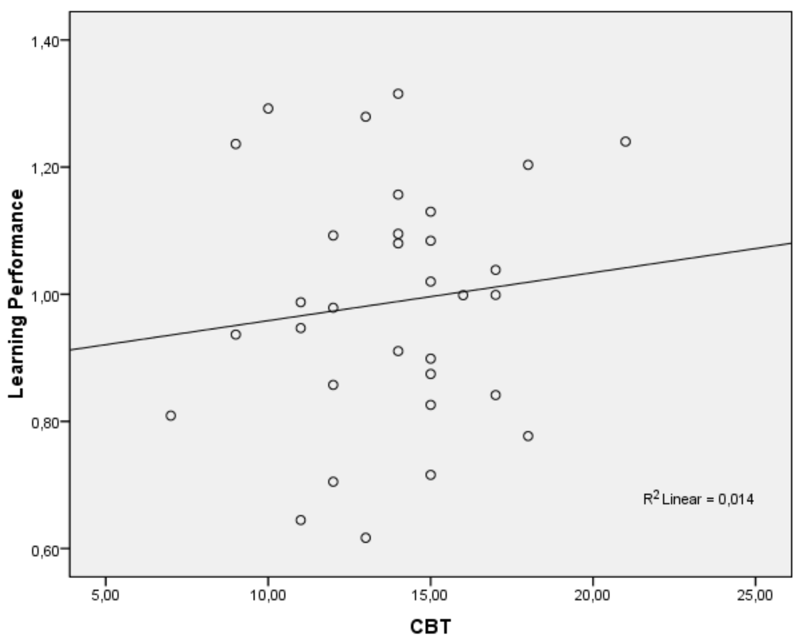



Figure 5.10: Scatter plots of learning performance (overall achievement) and CBT for all positive cue condition (Experiment-3)

## 5.6 Discussion

The result of the experiment confirms the effect of presentation condition on achievement, so that graphical mode of presentation result in higher achievement scores.

In this experiment, by considering its easy administration and the correlations results of BDS score, found in the previous experiment, we did not measure verbal WMC with AOSPAN task. Additionally, Corsi Block Tapping (CBT) task is added as a visuo-spatial Working Memory Capacity measure.

The correlation analysis suggests that verbal working memory component as measured by Backward Digit Span task is related to and consequently explains the performance in MCPL task with graphical modality. The same is true for visuo-spatial working memory component as measured by Corsi Block Tapping test. But for the numerical task modality, none of the working memory components correlates significantly with learning performance. Similar to correlation scores, in factorial ANOVA, BDS had shown main effect on the Block-6 Achievement. This suggest that individuals with high BDS score will perform significantly higher in MCPL task regardless of the MCPL task condition. That is even if they attend to numerical condition, individuals with higher BDS score will perform better as compared to individuals with lower BDS and attending to graphical presentation condition.

We have conducted another one way ANOVA analysis for the data of MCPL task with graphical modality taking the polarity variable as the factor. This analysis revealed that there is no difference between different cue polarity groups (mixed cue polarization group and all positive polarization group) in terms of learning performance. This means that, for our MCPL settings, the individuals performs in the same way regardless of the cue polarization. This was as opposed to our expectations because negative cues impairs the performance as it is stated by previous studies in the literature. However, this result may be interpreted as that, the effect of graphical modality is high enough to prevent the effect that may arise from the complexity of the MCPL task caused by polarity differences. To confirm this inference, a measurement with numerical modality and all positive cue polarization condition is needed. This condition was omitted because the reason for employing all-positive cue polarization condition was to see how absence of negative cue affects the relation between the working memory capacity and learning performance. Seeing this change in the effect in graphical condition provided us necessary support for designing future experiments.

One of the findings obtained in this experiment was when the polarity of cues were set to all positive, the correlations between the working memory capacity tests become insignificant. This result is actually in parallel with the results found in the literature (Rolison et al., 2011), suggesting the existence of negatively polarized cues causes the employment of working memory components during MCPL task execution.

Our analysis related to dissociation hypothesis did not suggest any dissociation. Considering this failure of dissociation hypotheses together with the results obtained from all-positive cue condition, we have concluded that, designing a new MCPL task by increasing the number of cues that are negatively polarized may cause employing working memory more effectively and consequently causing to observe the differences in learning that may arise from different working memory components. The next experiment is designed based on this consideration.

# CHAPTER 6

# EXPERIMENT 4

In the first two experiments we have found that the graphical modality in MCPL task positively effects the learning performance. In the third experiment the same phenomenon observed, but, we couldn't find out the anticipated dissociation (either single or double) of WMC components on predicting the learning performance in numerical and graphical modalities of MCPL. In experiment 3, with the help of all positive polarity criterion function, we have tested the employment of working memory capacity according to different cue polarization settings in the scope of our MCPL task. We found that WMC does not seem to be involved when all cues are positive (in our particular setup anyway). The results confirmed the Rolison et al. (2011)'s findings.

We think that dissociations due to advantage of particular WMC abilities will become more apparent when more involved employment of WM is needed for a task. Therefore, in order to increase the involvement of working memory during learning, we have decided to change the criterion function based on the findings obtained from third experiment expecting to increase WM need. Therefore we have increased the number of negatively polarized cues to 2. Furthermore, as it is considered that the difficulty in MCPL tasks increases the involvement of working memory (Hammond, 1990), we have added one more cue, increasing the total number of cues, in the criterion function, to 4. The details of the function is given in the apparatus section.

So by considering how the new criterion function - four cues, two of them negatively and two of them positively polarized - will affect the learning performance for numerical and graphical modalities in MCPL, we expect to observe dissociation of working memory components on predicting the learning outcomes of numerical and graphical modalities.

## 6.1 Participants

As in Experiment 3, the participants were university students from METU. The experiment was announced via posters in the university. 71 participants[1] attended to this experiment. Thirty seven (37) of the participants were female, thirty four (34) of them were male. Thirty five (35) of the participants attended to graphical MCPL condition (15 males, 20 females) and Thirty six (36) of the participants attended to numerical MCPL condition (19 males, 17 females). All participants received Backward Digit Span and Corsi Block Tapping tasks after completing the MCPL task.

## 6.2 Apparatus

### 6.2.1 MCPL Tasks

In this experiment, as explained in the introduction section of the chapter, criterion function is changed in order to make working memory components get involved in learning process of MCPL tasks. We have increased the number of cues in the criterion function and made two of them positively polarized and two of them negatively polarized. Consequently the following function is used as the criterion function.

$$Y = -0.25A + 0.5B - 0.6C + 0.8D$$

The previously used cue profiles couldn't be used in this experiment, because a new

[1] Participants attended to the experiment for a small amount of participation fee.

cue were introduced. Therefore, a new set of 300 cue profiles were selected among 9x9x9 different possible cue profiles such that range of the criterion value was between 1 and 9, and the inter-correlations were near to zero. At the beginning of selection procedure, criterion values were calculated by using the weight values -0.3, 0,5, -0.6 and 0.8, but the weights shown in the above equation were found after regression analysis conducted with cue values and corresponding criterion value. The change in the weight values were mainly introduced by the truncation errors. The histogram of the criterion values for which the cue profiles were presented are shown in Figure 6.1. This histogram representation of the criterion corresponding to presented cue profiles may be an indicator of difficulty of the task. The distribution of criterion values in this task design is also normal-like as in the 3 cue mixed and 3 cue all positive MCPL tasks. This similarity suggest that the contribution of criterion distribution may be ignored.

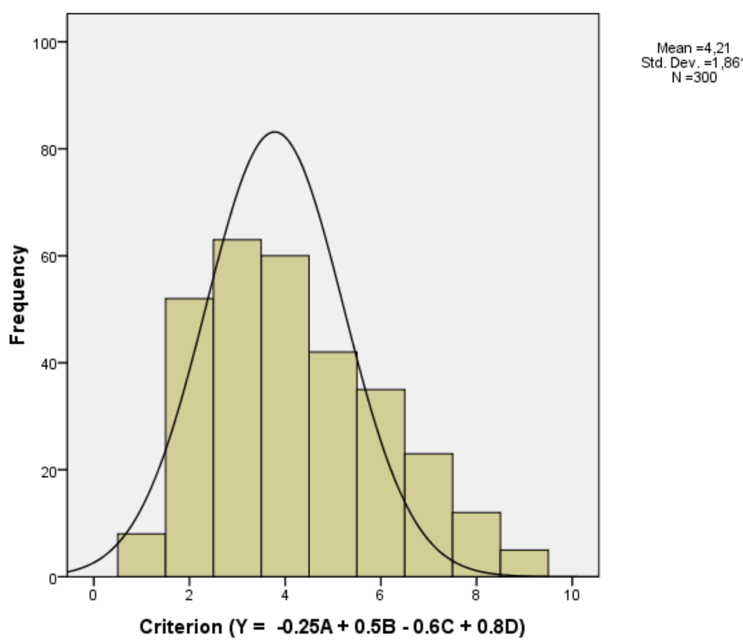



Figure 6.1: Histogram of criterion values corresponding to displayed cue profiles

In order to prepare these new MCPL tasks, by using the previous numerical and graphical MCPL task designs as a template, we have changed the necessary screens which are either mentioning the cues or presenting them. As a result, instruction screens remained same; in the story introducing screens, pictures were replaced with those containing four knobs as shown in Figure 6.2 and 6.3, in the cue presentation

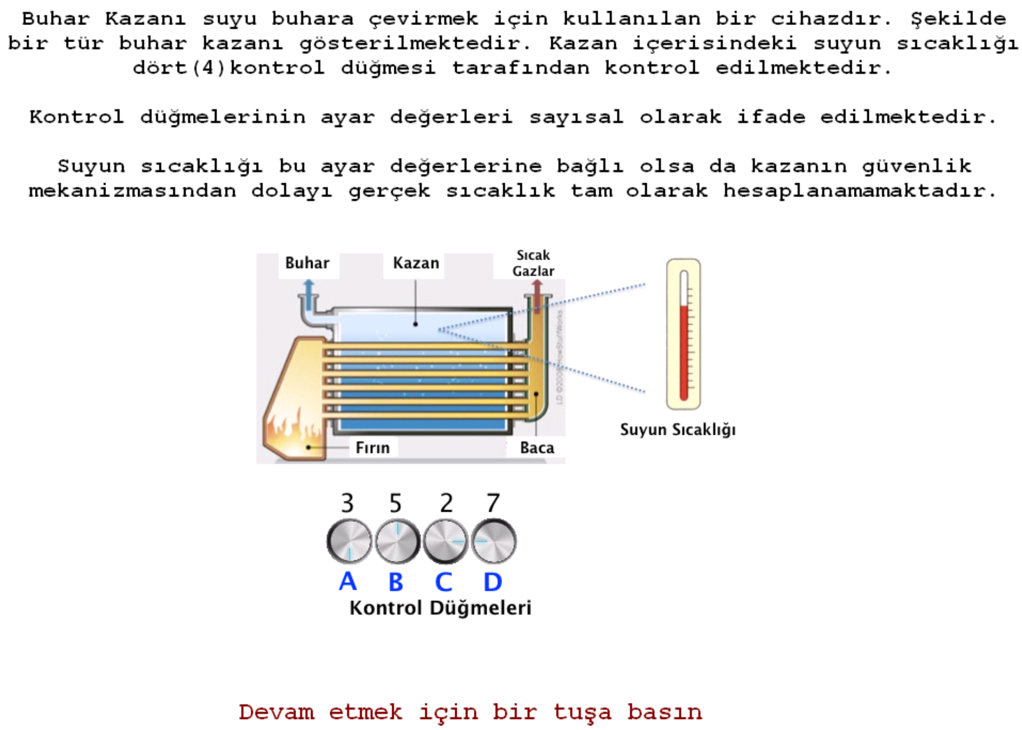



Figure 6.2: Story screen for four cues (numerical condition)

and feedback screens, the representation (either numerical or graphical) of the fourth cue was added as shown in Figures 6.4, 6.5, 6.6 and 6.7.

The previously used verbal (BDS) and visuo-spatial (CBT) WMC measurement tasks were employed without any modifications.

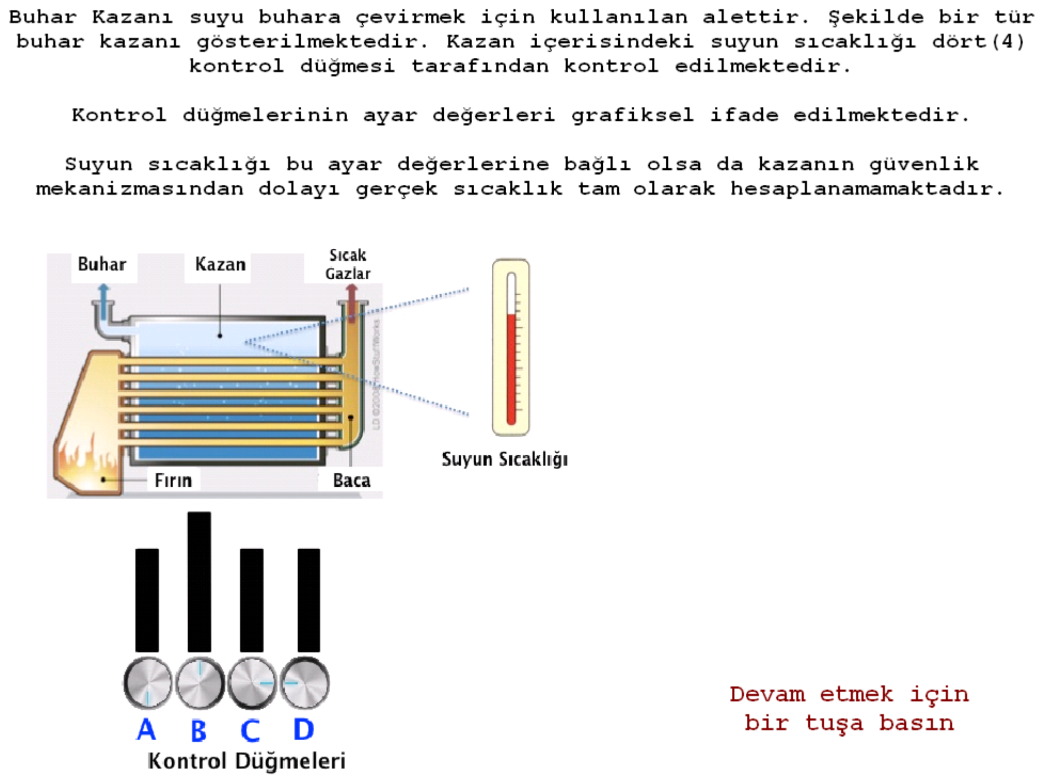



Figure 6.3: Story screen for four cues (graphical condition)

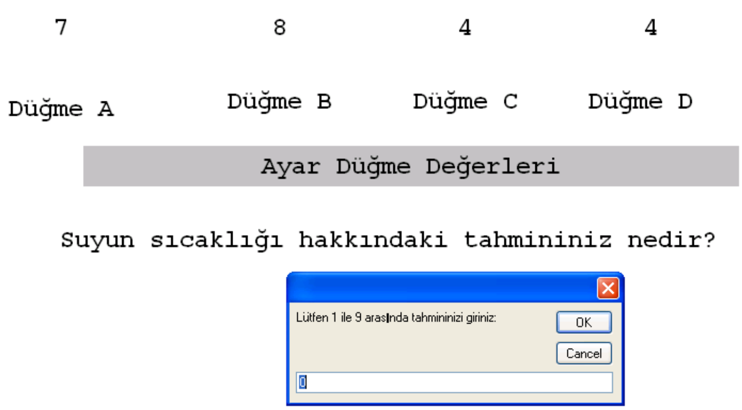



Figure 6.4: Cue presentation screen for four cues (numerical condition)

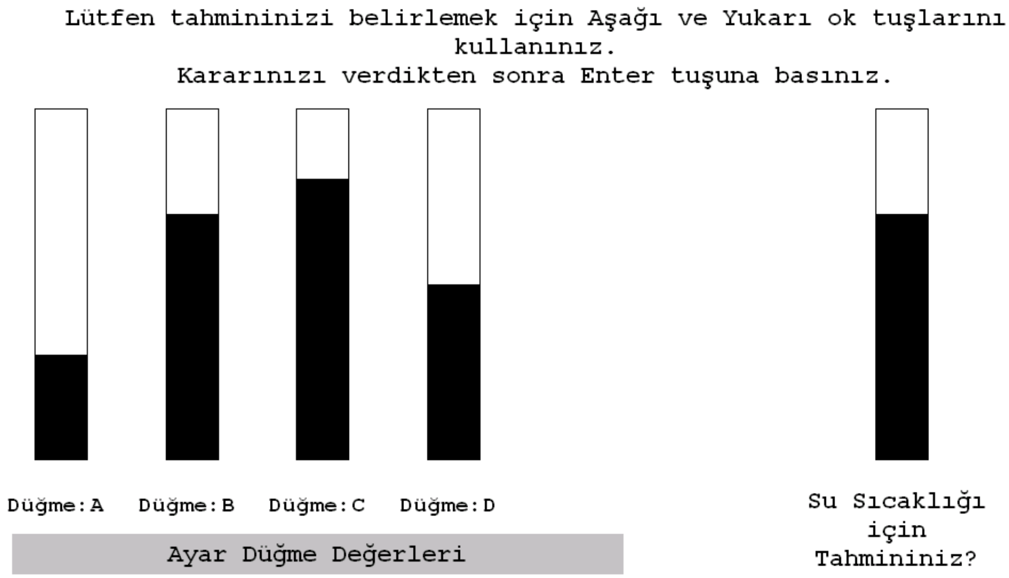



Figure 6.5: Cue presentation screen for four cues (graphical condition)

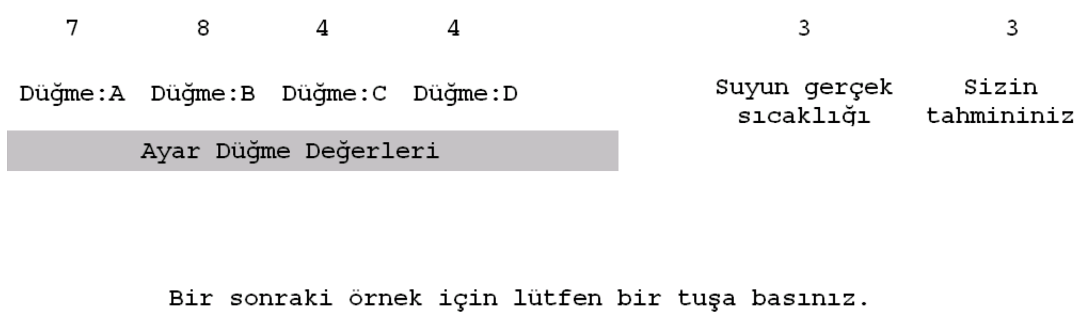



Figure 6.6: Feedback presentation screen for four cues (numerical condition)

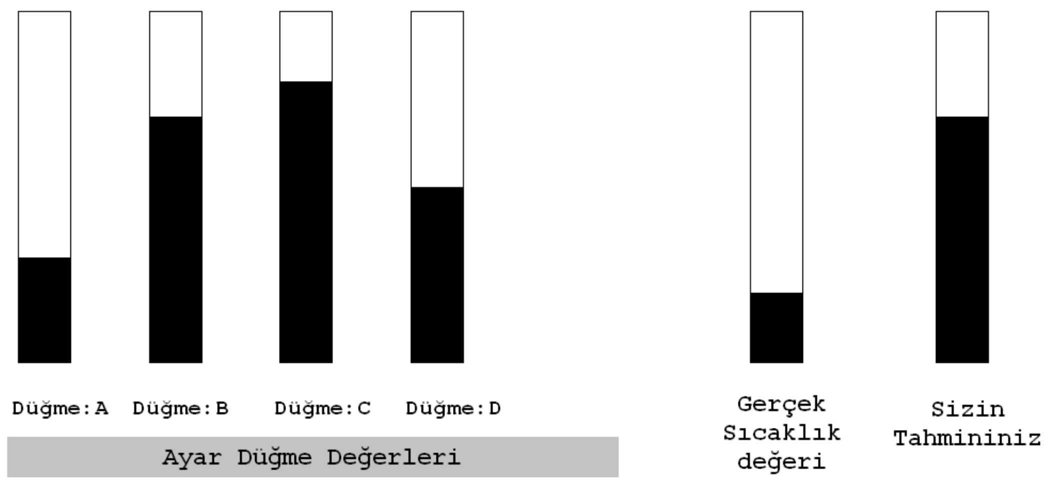



Figure 6.7: Feedback presentation screen for four cues (graphical condition)

## 6.3 Design

Independent variables used for this experiment was MCPL task modality (i.e. numerical and graphical presentation and response mode). The dependent variables were the achievements (correlation of criterion with the judgment) for the blocks (of the size 50) and overall achievement. The experiment used between-subjects design so that participants were randomly allocated to one of the two MCPL tasks.

## 6.4 Procedure

The same procedure (see Section 5.4) used in the Experiment 3 was used in this experiment without any modifications.

## 6.5 Results

### 6.5.1 Data Preparation

The same data preparation process, in the Experiment-1, was applied on the test data. Correlation values are transformed Fisher transformation and these new variables are used in statistical analyses. The achievement and WMC measurement scores are shown in Table B.8 and Table B.9 in Appendix B.

### 6.5.2 Analysis

The mean values of achievement scores for each block is depicted together for numerical and graphical modalities in Figure 6.8. In graphical condition, as compared to numerical condition, the mean values of learning performances were higher for all six blocks. The increase in mean values as the trials increased was an evidence of learning for both conditions. In this experiment, the amount of performance for predicting the criterion value decreased considerably, for both conditions. Actually the mean value of overall achievement was 0.7 in the third experiment, but it decreased to 0.22 in this experiment.

In order to understand the effect of numerical vs. graphical modality in case of new criterion function, a one way ANOVA analysis was conducted as in the other two experiments. There was a significant effect of MCPL presentation condition on Overall Achievement, $F(1,69)=5.01$, $p<.05$. Cohen's effect size value ($d = .26$) suggested a small practical significance. The effect on Block-6 Achievement was not significant, $F(1,64)=1.45$, $p=.232$. Cohen's effect size value ($d = .15$) suggested a low practical significance. The achievement scores were higher for graphical presentation condition as compared to numerical presentation condition. The ANOVA result of statistical analysis tool is shown in Table 6.1. Figure 6.9 shows the visual presentation of mean values of the two groups for Overall and Block-6 achievement. Although it

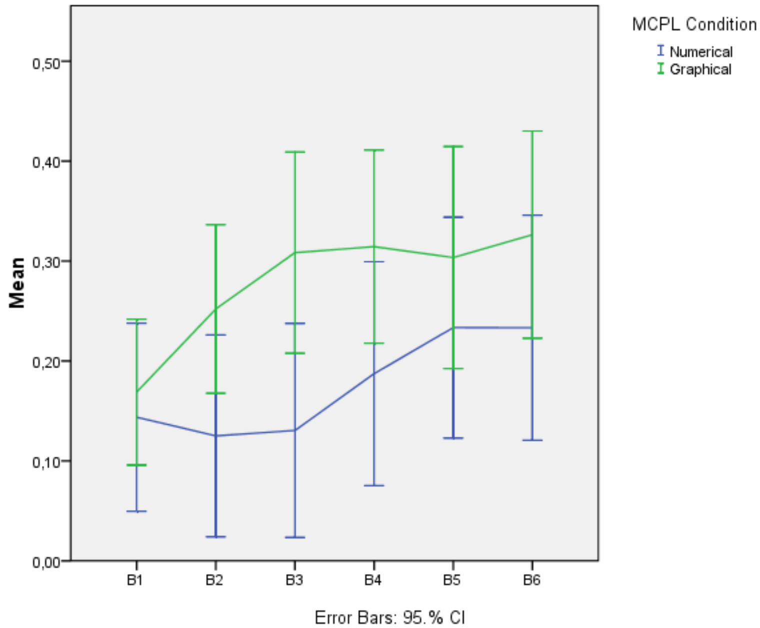


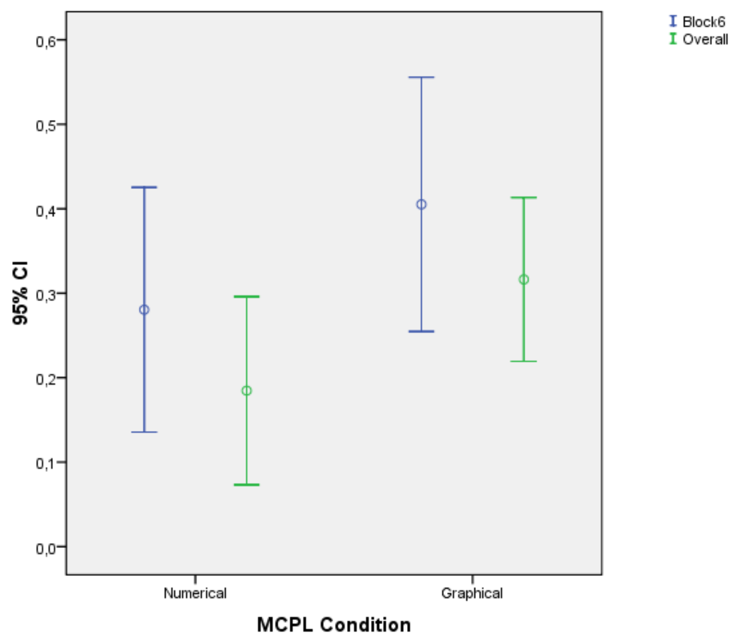

Figure 6.8: Mean achievements for each Block

is not possible quantitatively interpret this plot, we may say that non overlapping or slightly overlapping error bars indicate there are between group differences for overall achievement.

Table 6.1: One Way ANOVA conducted for the dependent variables, FTAchv and FTB6 (Experiment-4)

**ANOVA**

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| FTB6 | Between Groups | ,251 | 1 | ,251 | 1,454 | ,232 |
| | Within Groups | 10,886 | 63 | ,173 | | |
| | Total | 11,138 | 64 | | | |
| FTAchv | Between Groups | ,406 | 1 | ,406 | 5,010 | ,028 |
| | Within Groups | 5,506 | 68 | ,081 | | |
| | Total | 5,911 | 69 | | | |




FTB6=Fisher transformed Block 6 achievement. FTAch=Fisher transformed overall achievement.

Figure 6.9: Error plot for the block-6 and overall achievements (Experiment-4)

A correlation analysis was conducted to find the relation between the achievement values (Block-6 and Overall) and working memory capacity measures, Backward Digit Span Score (BDS), Corsi Score (CBT). It was found that BDS score significantly correlates with both achievement values, although the correlations are non-significant for CBT score. Actually, BDS was positively and significantly correlated with Block-6 Achievement, r=0.316, p<.05, and Overall Achievement, r=0.342, p<.01. CBT score was positively and but non-significantly correlated with Block-6 Achievement, r=0.231, p=.06, and Overall Achievement, r=0.149, p=.22. The correlation table for this analysis is given in Table 6.2.

Table 6.2: Correlation analysis for overall data (Experiment-4)

**Correlations**

| | | FTB6 | FTAchv | BDS | CBT |
|---|---|---|---|---|---|
| FTB6 | Pearson Correlation | 1 | ,887** | ,316* | ,231 |
| | Sig. (2-tailed) | | ,000 | ,010 | ,064 |
| | N | 65 | 65 | 65 | 65 |
| FTAchv | Pearson Correlation | ,887** | 1 | ,342** | ,149 |
| | Sig. (2-tailed) | ,000 | | ,004 | ,220 |
| | N | 65 | 70 | 70 | 70 |
| BDS | Pearson Correlation | ,316* | ,342** | 1 | ,208 |
| | Sig. (2-tailed) | ,010 | ,004 | | ,085 |
| | N | 65 | 70 | 70 | 70 |
| CBT | Pearson Correlation | ,231 | ,149 | ,208 | 1 |
| | Sig. (2-tailed) | ,064 | ,220 | ,085 | |
| | N | 65 | 70 | 70 | 70 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Correlation analysis was repeated by grouping the data according to modalities. The correlation tables are given in Table 6.3 and Table 6.4. In summary, none of the WMC scores was significantly correlated with any of the Achievements, for numerical mode of presentation of MCPL task. For graphical modality group, in parallel with previous findings, BDS was significantly and positively correlated with both Block-6 Achievement and Overall Achievement (for Block-6 Achievement, $r=0.448$, $p<.01$, for Overall Achievement, $r=0.456$, $p<.01$). Similarly, the visuo-spatial working memory capacity measure, CBT score, was also significantly and positively correlated with both Block-6 Achievement and Overall Achievement (for Block-6 Achievement, $r=0.408$, $p<.05$, for Overall Achievement, $r=0.365$, $p<.05$).

Table 6.3: Correlation analysis for graphical condition (Experiment-4)

**Correlations**[a]

| | | FTB6 | FTAchv | BDS | CBT |
|---|---|---|---|---|---|
| FTB6 | Pearson Correlation | 1 | ,896** | ,448** | ,408* |
| | Sig. (2-tailed) | | ,000 | ,007 | ,015 |
| | N | 35 | 35 | 35 | 35 |
| FTAchv | Pearson Correlation | ,896** | 1 | ,456** | ,365* |
| | Sig. (2-tailed) | ,000 | | ,005 | ,029 |
| | N | 35 | 36 | 36 | 36 |
| BDS | Pearson Correlation | ,448** | ,456** | 1 | ,287 |
| | Sig. (2-tailed) | ,007 | ,005 | | ,090 |
| | N | 35 | 36 | 36 | 36 |
| CBT | Pearson Correlation | ,408* | ,365* | ,287 | 1 |
| | Sig. (2-tailed) | ,015 | ,029 | ,090 | |
| | N | 35 | 36 | 36 | 36 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

a. MCPL Condition = Graphical

Table 6.4: Correlation analysis for numerical condition (Experiment-4)

**Correlations**[a]

| | | FTB6 | FTAchv | BDS | CBT |
|---|---|---|---|---|---|
| FTB6 | Pearson Correlation | 1 | ,881** | ,086 | -,046 |
| | Sig. (2-tailed) | | ,000 | ,652 | ,808 |
| | N | 30 | 30 | 30 | 30 |
| FTAchv | Pearson Correlation | ,881** | 1 | ,145 | -,123 |
| | Sig. (2-tailed) | ,000 | | ,414 | ,487 |
| | N | 30 | 34 | 34 | 34 |
| BDS | Pearson Correlation | ,086 | ,145 | 1 | ,097 |
| | Sig. (2-tailed) | ,652 | ,414 | | ,583 |
| | N | 30 | 34 | 34 | 34 |
| CBT | Pearson Correlation | -,046 | -,123 | ,097 | 1 |
| | Sig. (2-tailed) | ,808 | ,487 | ,583 | |
| | N | 30 | 34 | 34 | 34 |

**. Correlation is significant at the 0.01 level (2-tailed).

a. MCPL Condition = Numerical

The relationship between learning performance (overall achievement) and working memory measures (BDS and CBT) are depicted in Figure 6.10 and 6.11 for visual interpretation. As in the Experiment 3, there is a linear relationship between learning performance and BDS for graphical modality (see Figure 6.10). For numerical modality, although there seems to be a tendency of a linear relationship between BDS and learning performance, it is very weak. The scatter plots for CBT scores shows results similar to BDS (see Figure 6.11. In case of graphical modality a moderate linear correlation between learning performance and CBT scores is observed as it can be seen in Figure 6.11. However, for numerical modality, the relationship between BDS and learning performance is very weak although its seems linear.

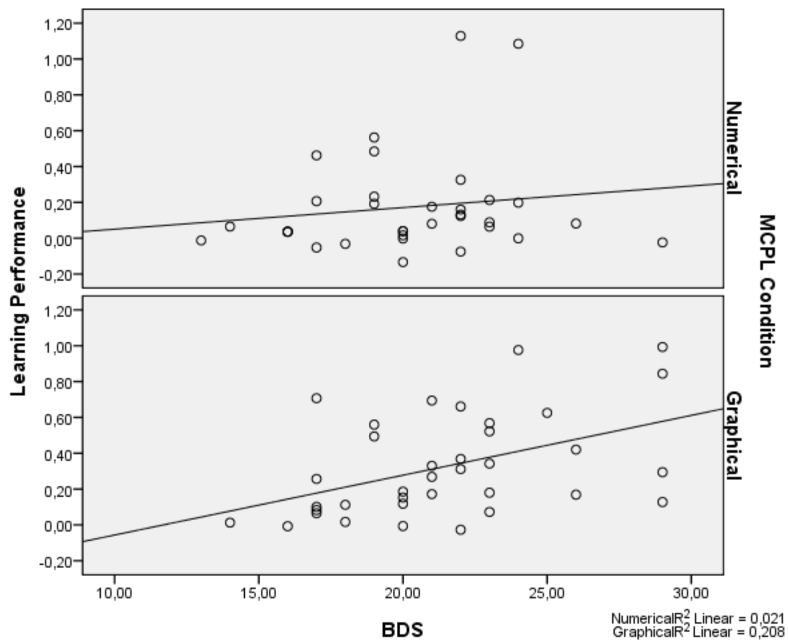



Figure 6.10: Scatter plots of learning performance (overall achievement) and BDS for numerical and graphical conditions (Experiment-4)

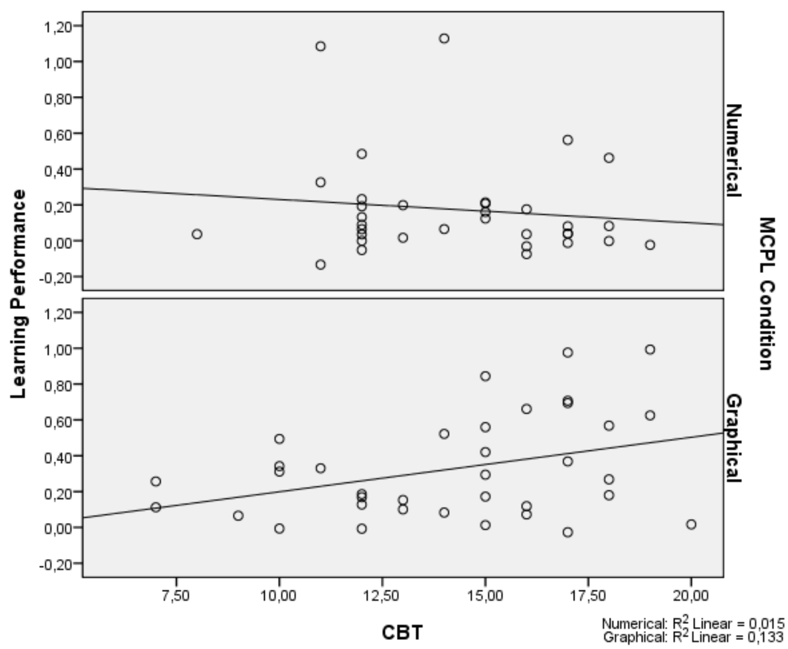



Figure 6.11: Scatter plots of learning performance (overall achievement) and CBT for numerical and graphical conditions (Experiment-4)

A three-way ANOVA was conducted for checking interactions between the factors, graphical vs. numerical modality, low and high CBT score and low and high BDS score. The low and high groups were determined by using median split. As a result, two new variables were generated NBDS and NCBT. These new variables could get either 1 or 2. One (1) representing the low rank, two (2) representing the high rank for BDS score or CBT Score. Summary table of three-way ANOVA is given in Figure 6.5.

Table 6.5: Three Way ANOVA conducted for the dependent variable Learning Performance (FTAchv) and the Factors MCPL Condition, NBDS and NCBT (Experiment-4)

**Tests of Between-Subjects Effects**

Dependent Variable:Total Achievement

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 1,526[a] | 7 | ,218 | 3,083 | ,007 |
| Intercept | 3,638 | 1 | 3,638 | 51,431 | ,000 |
| COND | ,238 | 1 | ,238 | 3,372 | ,071 |
| NCBT | ,006 | 1 | ,006 | ,078 | ,781 |
| NBDS | ,330 | 1 | ,330 | 4,659 | ,035 |
| COND * NCBT | ,302 | 1 | ,302 | 4,274 | ,043 |
| COND * NBDS | ,014 | 1 | ,014 | ,202 | ,655 |
| NCBT * NBDS | ,089 | 1 | ,089 | 1,252 | ,268 |
| COND * NCBT * NBDS | ,134 | 1 | ,134 | 1,897 | ,173 |
| Error | 4,385 | 62 | ,071 | | |
| Total | 10,386 | 70 | | | |
| Corrected Total | 5,911 | 69 | | | |

a. R Squared = ,258 (Adjusted R Squared = ,174)

The analysis showed no significant main effect for the numerical vs. graphical modalities factor, F(1,62)=3.37, p=.07. There was a significant main effect of the of BDS on Overall Achievement, F(1,62)=4.66, p<.05. Individuals with higher BDS scores obtained better achievement scores. There was a non significant main effect of Corsi on Overall Achievement, F(1,62)=.078, p=.78.

There was a significant interaction between numerical/graphical modality and CBT score, F(1,62)=4.27, p<.05. Individuals with higher visuo-spatial capacity as indicated by CBT score, achieved better in graphical modality, but, individuals with lower visuo-spatial capacity achieved equally in both graphical and numerical modality. The interaction plot is given in Figure 6.12. According to this plot, individuals with higher CBT scores performs better in graphical modality as compared to numerical modality. Individuals with lower visuo-spatial WMC, on the other hand, performs slightly lower when the modality is graphical as compared to modality is numerical.

The interaction between numerical/graphical modality and BDS score was not significant, F(1,62)=0.202, p=.66. This means that being high and being low in verbal working memory capacity affected the achievements in numerical and graphical modality in the same way. The plot for the interaction between BDS and numerical/graphical modality is given in Figure 6.13. As seen from this plot, verbal WMC, effects performance in numerical or graphical modality in the same way, meaning that there is no interaction between modality and BDS.

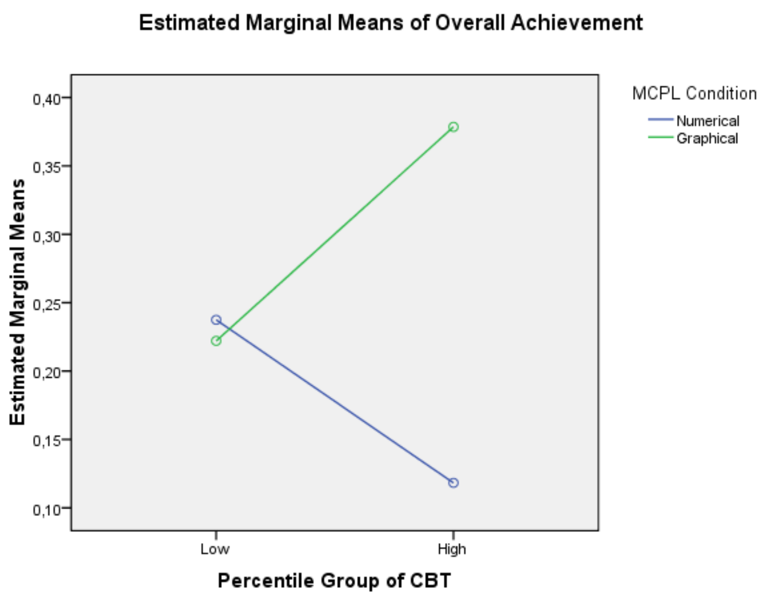



Figure 6.12: Interaction Graph for Corsi Block Tapping-Achievement Scores

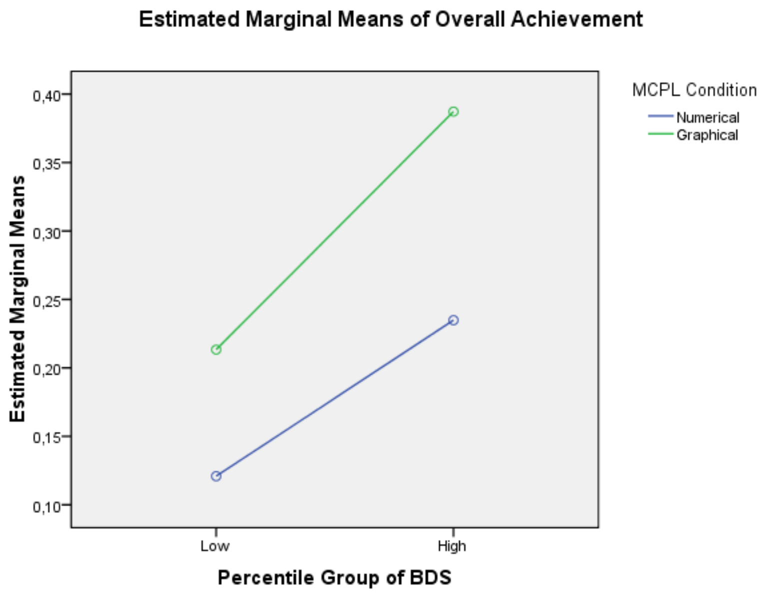



Figure 6.13: Interaction Graph for Backward Digit Span-Achievement Scores

## 6.6 Discussion

In this experiment, as distinct from the Experiment 3, the criterion function have been changed in order to force employment of working memory components. Number of cues in the criterion function was increased to 4 and number of negatively polarized cues was increased to 2. These changes made the task more complex as compared to the previous function used in the first three experiments. The complexity of the task was reflected by the difference between learning performance scores obtained in Experiment 3 and Experiment 4. Actually, independent groups t-test suggested that the group that learned the MCPL task with three cues images performed significantly better ($M = 0.73$, $SD = 0.35$) than the group that learned the MCPL task with four cues ($M = 0.25$, $SD = 0.30$), $t(166) = 9.36$, $p < .01$. A similar conclusion can be drawn from the response time analysis. When we compare the response times of Experiment 3 and Experiment 4 we see that the task in Experiment 4 took longer ($M=45$, $SD=15.13$) than the task in Experiment 3 ($M=35.37$, $SD=13.66$), $t(166)=-9.82$, $p < .01$. This results suggests that the MCPL task in the Experiment 4 is more complex as compared to the task in Experiment 3, because its mean learning performance score is significantly lower than the mean learning performance score of Experiment 3. Furthermore, the mean value of duration spent on the MCPL task in Experiment 4 significantly higher than the duration spent on the MCPL task in Experiment 3. Therefore, as an indicator of the complexity of task, individuals spent more time on the MCPL task when the number of cues is four and 2 of the cues are positively and 2 of the cues are negatively polarized.

With this settings, the effect of numerical/graphical modality on the achievement scores was observed in parallel with previous results, meaning that graphical modality in MCPL results in higher achievement scores. The difference can be quantified by means of effect size calculation; the effect size was 0.31 for Experiment 3, but it was 0.26 in this experiment. The decrease in the effect may be because of the increase in the complexity of the task. In other words, as the complexity of MCPL task increases the effect of graphical modality on learning performance may decrease, as opposed to consideration that graphical representations makes the task easier.

Some of the previously found relationships between the working memory components were retained in this experiment. Backward Digit Span score as a measure of verbal working memory capacity was significantly correlated with the achievement values in the graphical modality, although it was non-significantly correlated in case of numerical modality. Similarly, the visuo-spatial working memory component as measured by Corsi Block Tapping test, was significantly correlated with the achievement values in graphical modality and non significantly correlated with the achievement values in numerical modality.

The significant interaction between visuo-spatial WMC and numerical/graphical modality supports our fourth hypothesis which proposes the visuo-spatial working memory unrelated to achievement in numerical modality and related to graphical modality such that being high in visuo-spatial WMC means a better learning performance. But the non-significant interaction between verbal WMC and numerical/graphical modality points our third hypothesis which claims verbal WMC is not related to graphical modality but related to numerical modality is not supported by the findings. These two findings about the interaction effects, imply the single dissociation between the achievement in numerical modality and achievement in graphical modality. The possible reasons behind not observing a double dissociation is addressed in Section 7.1 in Chapter 7.

# CHAPTER 7

# GENERAL DISCUSSION

In this dissertation, we aimed to examine the factors affecting the performance in Multi Cue Probability Learning (MCPL). We specifically investigated two MCPL task modes: numerical and graphical presentation/response modes. The two tasks differed in the way cues, outcome feedback values and response collection are presented, as being either numerical or graphical. By using several "Working Memory Capacity" measures, we also examined the relevance of working memory components to numerical and graphical MCPL task modes.

In Section 7.1 the results obtained in the conducted four experiments are summarized and discussed in detail in the scope of our hypotheses. In Section 7.2 the limitations of the study in terms data analysis methodology, sampling etc. are provided. Section 7.3 gives the consequences this dissertation. The dissertation is summarized in Section 7.4 for generalizing the result obtained in the four experiments.

## 7.1 Summary of the Results and Discussion

In four experiments we measured performance in MCPL on seven different MCPL task conditions, including the numerical/graphical task modes. The properties of the tasks used in the experiments are summarized in the Table 7.1. When preparing the computer screens used in the numerical and graphical modes, two different presentation styles were applied as presented in Section 3.3.1 and Section 4.2.1.

The basic differences between them were colored/monochrome cue/feedback displays, presenting/not presenting cues and vertically/horizontally positioned cue values. In Experiment 1, colored cue/feedback depictions, vertically positioned cues were used and cues were not presented in the feedback screen. In the other experiments, monochrome cue/feedback depictions, horizontally positioned cues were used and cues were also presented in the feedback screen. These two different design are referred as Type1 in Type2 in Table 7.1. Three different criterion functions were employed in the experiments. With each criterion function two different tasks were generated by making the presentation/response mode, numerical and graphical. Exceptionally, in Experiment 3, the second criterion function with all-positive cue polarization, was only measured with graphical mode. By expecting to make the task more complex, in the criterion function used in Experiment 4, we have increased the number of negative cues from one to two and did not change the number of positive cues.

In parallel with our expectations given in our first hypothesis ($H_1$), in all experiments, we have found a significant difference between the learning performances measured in graphical and numerical task modes. The verbal working memory capacity as measured by AOSPAN task was only significantly correlated with learning in graphical mode in the first experiment but was not correlated in the other experiment that this task has been used. AOSPAN did not correlate with performance in numerical mode in any of the two experiments it has been used. The measurement of verbal WM as obtained by the Backward Digit Span task, on the other hand, was significantly correlated with the performance in graphical task mode but not with the numerical task mode, in all of the experiments it has been employed. This results shows capability of BDS on predicting the performance in graphical task mode. Same conclusion is true for the visuo-spatial WM capacity as measured by Corsi Block Tapping (CBT) task, because CBT scores, were significantly correlated with the learning in graphical task mode. Although BDS score did not correlate with the achievement in numerical task mode, the factorial ANOVA showed that, regardless of the task modality, it has a main affect on learning performance in MCPL task. This results are partially in line with our second hypothesis ($H_2$) about the working memory capacity which was stating that WMC could be positive predictor of MCPL tasks. We had thought that being a basic cognitive ability effective in judgment and decision making tasks, WMC could predict performance in MCPL tasks. This expectation was only supported by the BDS measure. Our third and fourth hypotheses was constructing a double dissociation between the performances in numerical and graphical modes as indicated by the Working Memory Capacity measures. We have found a single dissociation between learning performance in graphical modality and learning performance in numerical modality as indicated by the visuo-spatial WMC. There was not a double dissociation because we couldn't find an interaction between the task modality and verbal WMC as measured by BDS task. In the remaining part this section, these findings will be discussed.

Table 7.1: Properties of the MCPL Tasks used in the Experiments

<table>
<tr><th>Task Property</th><th>Exp. 1</th><th>Exp. 2</th><th>Exp. 3</th><th>Exp. 4</th></tr>
<tr><td>Number of cues</td><td colspan="3">3</td><td>4</td></tr>
<tr><td>Task Mode Type</td><td>Type1</td><td colspan="3">Type2</td></tr>
<tr><td rowspan="2">Cue Polarization</td><td colspan="2" rowspan="2">Mixed</td><td>Mixed</td><td rowspan="2">Mixed</td></tr>
<tr><td>All Positive</td></tr>
<tr><td rowspan="2">Criterion Function</td><td colspan="2" rowspan="2">$.63A + .40B - .60C$</td><td>$.63A + .40B - .60C$</td><td rowspan="2">$-.25A + .5B - .6C + .8D$</td></tr>
<tr><td>$.36A + .65B + .43C$</td></tr>
<tr><td rowspan="2">Negative Cues</td><td colspan="2" rowspan="2">1</td><td>1</td><td rowspan="2">2</td></tr>
<tr><td>None</td></tr>
</table>

The results obtained from the analysis of the experiment data can be summarized with Table 7.2. In this table, leftmost column contains the analysis applied and the other columns shows the results[1] of the corresponding analysis. In the following paragraphs the status of our hypotheses will be discussed.

[1] The dash means analysis is not applicable because no suitable data exist in the specific experiment.

Table 7.2: Summary of the Experiment Results

Sig.= Significant; NS= Not Significant; CBT=Corsi Block Tapping; BDS=Backward Digit Span; -=Not Applicable

| ***Analysis*** | ***Exp. 1*** | ***Exp. 2*** | ***Exp. 3*** | ***Exp. 4*** |
|---|---|---|---|---|
| Effect of MCPL Modality | Sig. | Sig. | Sig. | Sig. |
| Effect of Cue Polarization | - | - | Sig. | - |
| Correlation - AOSPAN - Numerical | NS | NS | - | - |
| Correlation - BDS - Numerical | - | NS | NS | NS |
| Correlation - CBT - Numerical | - | - | NS | NS |
| Correlation - AOSPAN - Graphical | Sig. | NS | - | - |
| Correlation - BDS - Graphical | - | Sig. | Sig. | Sig. |
| Correlation - CBT - Graphical | - | - | Sig. | Sig. |
| Correlation - BDS - Positive Polarity | - | - | NS | - |
| Correlation - CBT - Positive Polarity | - | - | NS | - |
| ANOVA - AOSPAN | NS | NS | - | - |
| ANOVA - BDS | - | Sig. | Sig. | Sig. |
| ANOVA - CBT | - | NS | NS | NS |
| ANOVA - AOSPAN * MODE | NS | NS | - | - |
| ANOVA - BDS * MODE | - | NS | NS | NS |
| ANOVA - CBT * MODE | - | NS | NS | Sig. |

*$H_1$ : Graphical presentation/response mode has a superior effect on learning performance as compared to Numerical Mode of presentation/response.*

As the support of our first hypothesis, we have found that, the effect of MCPL task mode was significant in all experiments. In MCPL literature, although there exist some studies that compare numerical and graphical presentation of cue profiles or cognitive feedback (e.g. Blatzer et.al., 1982), we were unable to find empirical studies investigating the effect of graphical and numerical display of cue and outcome feedback presentation together with response mode. So, to our knowledge this is the first study that investigate these variables cumulatively. What we have found matches to our initial prediction. Although in their study investigating the effect of presentation style of cognitive feedback, Blatzer et.al. (1982) found that presentation format didn't have a significant effect, we have found a significant difference between learning performance in the numerical mode and learning performance in graphical mode. In Experiment 4, the complexity of the task has been increased by adding an additional negative cue to the criterion function. By comparing the results of the Experiment 3 and Experiment 4, we see that the effect size decreased in Experiment 4. This result contradicts with out initial considerations, because we were expecting to see a larger effect size due to the advantages of the graphical presentations.

Related to first hypothesis it is better to compare effect sizes, because it is a good indicator of effectiveness of graphical MCPL mode. In the four experiments the effect size of the differences in achievements in numerical and graphical modes were changing. The biggest difference in the effect size was between the Experiment 1 and Experiment 2 (compare d=0.5 in Experiment 1 with d=0.29 in Experiment 2). There was an important difference between MCPL tasks of these two experiments. The style that used in presentation was changed. Although we did not systematically measure, we think that the difference may come from this change, because colorized bar graphs were turned to monochrome. This may have caused the decrease in learning performance in graphical MCPL mode. However this interference needs to be examined for as it has some practical implications, if it is true.

In our experiments participants were from several universities (Bilkent, METU and ATILIM University). In order to reveal the effect of using different participant groups we have conducted an extra analysis based on the measured cognitive abilities (AOSPAN, BDS and CBT). We have grouped the participants according to universities and experiments and looked at the inter-group differences of measured WM scores. As a result no significant effect have been found. Similarly, gender did not affect any of the WMC measures. In our experiments we also collected the department of the participants as an indicator of background knowledge. The department information was categorized into social and physical sciences. The analysis with this new independent variable showed that background did not also have a significant effect on WMC measures.

*$H_2$: WMC measures are positive predictors of learning in MCPL tasks.*

In the related literature, working memory has been considered as a basic faculty effective in most of the higher level cognitive processes, such as reasoning, problem solving and judgment and decision making (Conway et al., 2005). Being a judgment task, MCPL should have no difference. Therefore, in the second hypothesis, we initially expected that WMC capacity would predict the performance in MCPL. The results obtained in the experiments supported this expectation, because we have found that BDS measure has a main effect on the learning performance of individuals regardless of the task modality. This finding is in parallel with the Rolison et al. (2011)'s study in which they had found that working memory capacity measured by operational span task is related with the performance in MCPL tasks, when one of the cues is negatively related to criterion value. As opposed to Rolison et al. (2011)'s findings, in our study, we didn't find a relationship between learning performance and WMC, when WMC was measured by AOSPAN task. As it was mentioned in Section 3.3.2, AOSPAN task is the automated version of the operational span task and one would expect to observe a significant correlation between AOSPAN scores and learning performance. One reason for not observing that relationship can arise from the MCPL task itself, because we have used a totally different MCPL task. Specifically, in our task we have used 9 point scale (ranging from 1 to 9) whereas Rolison et al. (2011) used 5 point scale (ranging from 0 to 5). Also, the weights used in their task were integer numbers like -1, 0 and 1, however we have employed decimal numbers.

Our findings revealed that, although they are strongly correlated with each other, within the scope of our MCPL task, AOPSAN and BDS were not related to learning performance in the same way. As it is given in literature review, there is not a consensus about which working memory components were measured by BDS task. Some researchers (Kessels et al., 2008) claimed it measures short term memory whereas some others suggested it is related to working memory (Oberauer, 2000). This conflict is mainly dependent to the procedure of the BDS task which does not follow the classical interfering secondary task procedure used in most of the working memory capacity span tasks. In fact, BDS task includes a mental ordering stage which can be related to working memory's executive processing components. Our findings support the idea that what BDS measures is different than what classical WMC tasks like AOSPAN measure. We may not say that this is because, BDS measures the short term memory (i.e. slave components in Baddeley's model). However, we can state that BDS is related to a working memory component which is mainly used in MCPL tasks. Furthermore, this measured working memory component is both active in numerical and graphical modalities. Our third and fourth hypotheses based on the assumption that the performance difference in graphical and numerical modalities is related to working memory sub components. We will extend this discussion by considering the working memory sub components, while discussing our other hypotheses.

Concerning the Corsi block tapping WMC measure, in our factorial ANOVA analyses, it was found that, CBT measure did not have a main effect in any of the experiments, while significantly correlating with in the performance in graphical modality. This finding reveals that CBT do not predict the learning performance independent from task modality. This could be interpreted as the visuo-spatial working memory ability measured by CBT is not related to components that are effective when modality is numerical. In Experiment 3 and Experiment 4 the correlation analysis have indicated strong correlations between CBT and BDS scores. This finding contrasts with the results of Kessels et al. (2008) study, because they found weak correlation between the two span scores. However (Vandierendonck et al., 2004) have found that in forward and backward version of the CBT, recall was disrupted by visuo-spatial and executive interference. BDS also contains executive components as empirically shown by Kessels et al. (2008). Therefore the correlation between BDS and CBT scores can be caused by the employment of executive functions in these span tasks.

As another WMC related finding we can state that, our results support the idea that existence of negative cues in MCPL task starts employment of working memory during task execution. Remember in Experiment 3, we have added an extra condition, graphical modality with all-positive cue task. In this case the correlation between BDS and performance in graphical modality disappeared. This supports the previous findings that claim relationship between working memory and MCPL performance is dependent to polarity of the cues.

*$H_3$: Verbal WMC interacts with mode of presentation so that, learners with high Verbal WMC outperform the learners with low Verbal WMC in case of numerical mode of presentation, but learning in graphical mode is unrelated to verbal WM performance.*

*$H_4$: Visual (spatial) WMC interacts with mode of presentation so that, learners with high visual (spatial) WMC outperform the learners with low Visual WMC in case of graphical mode of presentation, learning in numerical mode is unrelated to visual (spatial) WM performance.*

While hypothesizing the superiority of the graphical modality we have considered that, if a performance difference is found, this could be a sign of allocation of different cognitive constructs, specifically, related to Working Memory Capacity. In other words we thought that some abilities (related with WMC) of the decision maker may be becoming congruent with the task mode so that a performance is observed. Consequently, by considering the experimental results and emphasizing the component based nature (Baddeley, 2000) of the Working Memory, we have thought that if we can measure different components of Working Memory capacity we may observe the interaction of this components with the performance in numerical and graphical modes of MCPL task. The expected interaction was observed after changing the task settings by increasing the number of negative cues in the criterion function. This finding is in parallel with the previous research (Rolison et al., 2011). In literature the first study that dealt with the role of working memory capacity in MCPL tasks was published in 2011. According to results of this study Rolison et al. (2011) found a difference in the relation of WMC with learning performance when the polarity of the cues are mixed as compared to all-positive. They have observed that in case of existence of negative cue, WMC correlates with learning performance; whereas if the polarity of the cues are all positive no significant correlations exist. What they have claimed was; adding negative cues increases the complexity of task and as the complexity increased an engagement to controlled processing occurs.

Rolison et al. (2011) explained the findings in the scope of dual processing accounts of reasoning. This account of reasoning claims the existence two separate processes, one being unconscious, rapid, automatic, and high capacity, and the other being conscious, slow, and deliberative (Evans, 2008). According to this idea, involvement of WMC may be the sign of controlled processing. However, to explain this finding dual processing account may not be needed, because the task itself may be causing us not to observe the effects of working memory. That is to say, all-positive cue polarity makes the task such that it is easy to remember the relationships/values and high capacity in working memory is not needed anymore. They actually discussed this issue in their study and supported their claims by the transfer effects found in their study. Although our results do support Rolison et al. (2011) indirectly, we will not go into details of dual processing theories of reasoning and try to relate our findings with that account, because it is not in the scope of this dissertation. However, some extra analysis that will take duration values into account may help relating our results with dual processing theories.

We briefly mentioned about the employed WMC measurements and their correspondence to Baddeley's working memory components, in the related section in Chapter 2. According to current state of the WM related studies (St Clair-Thompson, 2010; Kessels et al., 2008), CBT is a measure of short term memory, measuring the slave components related to visio-spatial ability (Kessels et al., 2008). The status of the BDS measure, however, is not so clear, because; beside verbal WM components, there is a possibility of involvement of central executive component in BDS measure(Oberauer, 2000).

What we have found supports our initial expectations, stated in our third and fourth hypotheses, in the scope of visuo-spatial working memory components. This is because, we have observed an interaction between the visuo-spatial WMC and the MCPL task mode in the fourth experiment. This interaction means that individuals with higher visuo-spatial working memory abilities perform better in graphical

MCPL task, whereas their ability is not related with performance in numerical MCPL task. As discussed previously this finding is obtained in the task setting used in the fourth experiment. Remember if validated, our third and fourth hypotheses would demonstrate the double dissociation between learning performances in numerical and graphical modalities of MCPL task. The evidence supporting the fourth hypothesis demonstrate the single dissociation. So what might have been changed between Experiment 3 and Experiment 4 so that the interaction between CBT and learning performance became evident? As mentioned before, in Experiment 3 and Experiment 4 we have found strong correlation between CBT and BDS scores. If we assume CBT and BDS are strongly correlated because they measure executive components, we may say that the cognitive demand for the executive components as indicated by CBT score has decreased in case of numerical modality. This, consequently caused learning performance in case of numerical modality became unrelated to CBT scores.

Our third hypothesis was not supported by the results obtained in Experiment 3 and Experiment 4. In other word, the interaction between the BDS score and task modality was not observed. In the remaining paragraphs we have discussed this finding.

As stated while discussing the second hypothesis, BDS may be measuring a construct that is very effective in both numerical and graphical MCPL modes. This very effective component prevent us observing the interactions that can be caused by the other working memory components that is used in numerical mode but not employed in graphical mode. For example, if lets say, central executive is highly involved (Over, 2005) in working memory capacity as measured by the BDS and furthermore if this component is very effective in our current MCPL task settings, this may suppress observing allocation of verbal WM components in numerical mode and not using them in graphical mode. As an alternative explanation, the common component that numerical and graphical modalites rely on, can be the verbal components measured by the BDS score. This means that even when the graphical representations activated in memory, decision maker relies on the verbal capacities during MCPL task execution.

From a intuitive processing point of view, the results related to numerical modality may be interpreted as a sign of intuitive processing in numerical MCPL mode, as opposed the previous research (Bastick, 1982). This is because neither of the working memory capacity measures (BDS and CBT) are related to the performance in numerical MCPL mode. On the other hand, from a analytical processing point of view, MCPL task execution probably consists of several sub-processes executed serially or concurrently. The working memory is involved somewhere in the internal processes. The processing needs during the execution in numerical MCPL mode could be different than the execution in graphical MCPL mode. For example, numerical representations can be easier to remember so that a little capacity may be enough to meet the need for verbal working memory demand occurring in numerical mode. But in graphical mode, because the need for visual working memory resources may be very high we may observe the relation between the visuo-spatial WM and performance in MCPL. This explanation is inline with the numerosity concept (Dehaene, 1999). According to this view there is a sense of number (called as numerosity) even in non-human animals and this may be causing storing the numerical values easily during a numerical task.

We have designed the fourth experiment, aiming to involve working memory by increasing the complexity of the MCPL task. However, we couldn't observe the involvement of verbal working memory with this new setting (i.e. criterion function with 2 negatively and 2 positively polarization cues). One important observation, in the fourth experiment, was that, the mean level of achievement of the participants attended to this experiment was very low as compared to other experiments. Decreased level of performance may be a sign of intuitive processing. This intuitive processing consequently may be causing not employing the working memory. There could be several reasons of intuitive processing. For example the task settings may be too difficult to learn. Motivation of the individuals is important at this step. In other words, if the capacity of the individuals may not be enough to achieve, they must be motivated to engage to explicit conscious effort for learning. Stanovich & West (2008) states that if the decision maker is not aware of the need for an explicit conscious effort, the measured performance values may become unrelated to capacity measures. As related to this issue, in MCPL learning literature, there are findings about the problematic nature of outcome feedback. Specifically, when the number of cues are high or the criterion function is nonlinear, outcome feedback do not contribute to learning

(Goldstein, 2005;Newell et al., 2007; Hammond et al., 1975). Furthermore for complex tasks it even negatively effects the performance (Harvey, 2012). That is, in case of non existence of outcome feedback performance becomes higher as compared to when it exists. To overcome the problems that may be caused by outcome feedback, the cognitive feedback, such as task information or functional validity information can be given to decision maker (Harvey, 2012). The effectiveness of these types of feedback is empirically evident (Balzer et al., 1994). Therefore, although there is not a predetermined limit at which the infectiveness of outcome feedback is reached, this may have been the case in Experiment 4 where we did continue to give the outcome feedback.

## 7.2 Limitations of the Study

MCPL is the application of Brunswik's ideas into probabilistic learning. Representative Design[2] is an important aspect of probabilistic functionalism. Without a design representative of the real environment (in terms of task and judges), it is merely impossible to generalize the results obtained. This dissertation was initially aimed at study the real decision makers in their real environments. But due to difficulties studying the judges -pilots- in the targeted environment -cockpit- we focused on laboratory tasks imitating the real environment to some extend. Therefore we see this imitation as a limitation of the study, preventing us to make generalizations about the real environment. However, starting with artificial tasks and using a non expert group is a very logical first step. Experimenting with real decision makers would result in wasting resources. Although the environment may be laboratory, MCPL paradigm can be used to observe behavior of the experts. So linking the results to real domains could be a follow up study.

Another limitation may again arise from MCPL environment. The results obtained may be dependent to the MCPL task settings. For example we set inter-cue correlations as very low (near to zero), so we may not assume that, the behavior will be

[2] Note that Brunswik used the term ecological validity to refer the correlations between cues and criterion and the term Representative Design to refer to relevance to real environment.

same when there exists some cue correlations as it is in the real world. So we need to interpret the results from the scope of task setting. We may not generalize all results without generalizing the task settings.

Another methodological problem is that, we did not counterbalance the tasks executed within an experiment. This has been done in order to administer experiments more easily. However this non counterbalanced experimenting may have some drawbacks such as fatigue and boredom, which directly affect the results obtained.

The correspondence between WMC measures and working memory components are not clear and there is an ongoing research on this subject. Therefore while relating the working memory capacity to MCPL performances, the used working memory capacity measure must be taken into consideration.

The number of participants who attended to experiments was not so high so that this may have prevented us getting significant results when effect sizes are small.

## 7.3 Future Work

We still think that the verbal working memory capacity is related with numerical modality in MCPL task. We briefly discussed the possible reasons for not observing the dissociation of task modes based on the verbal working memory component. As a consequence of that discussion, some new experiments can be designed. To check the effect of central executive, another verbal memory measure, preferably measuring the verbal short term memory, can be employed. Digit span task and n-back task are two candidate capacity measurement tasks. In working memory related literature these two task were assumed to be measuring short term memory capacity rather that working memory capacity (Conway et al., 2005). The level of complexity of the MCPL task in numerical mode can be increased in order to investigate whether not observing the interaction caused by less demand for WM capacity. And finally, to motivate the participant to engage in conscious processing, task information can be provided as cognitive feedback.

In this study novice users are used in the experiments conducted. As a next step using the real decision makers in the laboratory setting would be informative. From a practical point of view, to give recommendation about the instrument design or extend some basic findings to cockpit environment, what we need to do is to experiment with the targeted decision maker group. The other steps would be experimenting in simulated environments like, flight simulators. Some designed tasks can be produced and analyzed through MCPL methods. In such an environment the application of already learned rules may be measured. Additionally by dynamically changing some relations, the effect of previous belief (coming from already learned weights) can be studied.

### 7.4 Summary and Concluding Remarks

With four experiments, this study, aimed to find answers to specific questions related to MCPL and interaction of individual difference measures with performance in MCPL tasks. At the MCPL task side, we were specifically interested in numerical and graphical modes of the task in terms of presentation of cues, presentation of outcome feedback and collecting judgment response. At the decision maker side we mainly focused on Individual Differences in Working Memory Capacity (WMC).

As predicted in our first hypothesis ($H_1$), we empirically showed that performance of an individual is different and significantly higher when MCPL task mode is graphical as compared to numerical task mode. From the Individual Differences point of view, verbal working memory indicated by Backward Digit Span task, regardless of the task mode, predicts the performance in our MCPL task settings. This finding partially supported our second hypothesis ($H_2$). Furthermore, visuo-spatial working memory as assessed by Corsi Block Tapping test, interacts with task mode, indicating the single dissociation between performance in numerical mode and performance in graphical mode. In parallel with our fourth hypothesis ($H_4$), this last finding recommend us a single dissociation between the learning performances in numerical and graphical modality as indicated by visual working memory capacity measured by Corsi Block Tapping test. We couldn't find a double dissociation because we couldn't find the opposite interaction between learning performances as initially predicted in our third hypothesis ($H_3$).

To our knowledge, this is the first study that examine the effect of numerical and graphical modalities in MCPL task cumulatively. We have found that graphical modality is superior to numerical one in terms of facilitating the learning. Furthermore, although some previous studies explored the effect of numerical and graphical presentation modalities in MCPL paradigm, as opposed to them (e.g. Kerkar, 1984), we have found graphical modality is more effective in increasing the learning performance.

Another uniqueness is in investigation of individual differences in working memory capacity in MCPL tasks. At the time this study initiated there was no published study in the literature examining the relationship between WMC and learning performance in MCPL. The only such study existing in literature which was publised by Rolison et al., has appeared at the end of the 2011. Our study supports the the findings of Rolison et al. (2011), such that the working memory is effective in MCPL task, if there are negative cues in the criterion function. However we have observed this relationship for the backward digit span measure but not for the AOPSAN measure which is similar to the WMC measure used in Rolison et al. (2011). We think that these results fill some part of the existing gap in the literature which is about how working memory and its sub-components are related to performance in MCPL tasks.

Since to our best knowledge, no other study investigated the interaction between working memory components and different presentation modalities in MCPL, the findings imply a specific contribution for cognitive study of MCPL, as this study reveals the dissociation between learning performances in graphical and numerical modalities.

This and follow up studies have promising implications. For example studying the effect of individual differences provides the opportunity for creating user interfaces adaptive according to its user, so that the best possible interaction can be generated. This may be extended to adaptation according to the properties of the task. In other words, for specific task modes the interaction that would result in a better performance can be created. Similarly, tasking according to the nature of the duty may be another practical implication of the study. If the relevancy to real environment could be assessed , artificially generated laboratory tasks can be used to train and evaluate the real world decision makers.

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# APPENDICES

# APPENDIX A: EXPERIMENT MATERIALS

## A.1 Story in Turkish

Buhar Kazanı suyu buhara çevirmek için kullanılan alettir. Şekilde bir tür buhar kazanı gösterilmektedir. Kazan içerisindeki suyun sıcaklığı üç kontrol düğmesi tarafından kontrol edilmektedir. Kontrol düğmelerinin ayar değerleri kendi renklerindeki üç gösterge ile ifade edilmektedir. Suyun sıcaklığı bu ayar değerlerine bağlı olsa da kazanın güvenlik mekanizmasından dolayı gerçek sıcaklık tam olarak hesaplanamamaktadır.

## A.2 Information Consent Form

**Gönüllü Katılım Formu**

Bu çalışma birkaç parametreye bağlı bir değişkenin, katılımcılar tarafından tahmin edilebilirliğini analiz etmeye yönelik bir çalışmadır. Çalışmanın amacı zamanlama, doğruluk gibi ölçümleri toplayarak sayısal ve görsel geri bildirimdeki öğrenebilirlik farklılıklarını ortaya çıkarmaktır.

Çalışmaya katılım gönüllülük temelindedir. Çalışmada, sizden kimlik belirleyici hiçbir bilgi istenmemektedir. Cevaplarınız tamamiyle gizli tutulacak ve sadece araştırmacılar tarafından değerlendirilecektir; elde edilecek bilgiler kimliğinizi belirleyecek bir bilgi olmaksızın bilimsel yayımlarda kullanılacaktır.

Çalışma 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 uygulayıcı kişiye, devam etmek istemediğinizi söylemek yeterli olacaktır. Bilgi toplama sonunda, bu çalışmayla ilgili sorularınız cevaplanacaktır. Bu çalışmaya katıldığınız için şimdiden teşekkür ederiz.

Çalışma hakkında daha fazla bilgi almak için Bilişsel Bilimler Bölümü öğretim üyelerinden Yrd. Doç. Dr. Bilge SAY (Tel: 210 37 48; E-posta: bsay@ii.metu.edu.tr) ya da Mustafa BAYINDIR (Tel: 266 37 65; E-posta: bayindir.mustafa@gmail.com) ile iletişim kurabilirsiniz.

***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 |
|---|---|---|
| | ----/----/----- | |

Figure A.1: Information Consent Form (Approved)

## A.3 Debriefing Form

**KATILIM SONRASI BİLGİ FORMU**

Bu çalışma ODTÜ Enformatik Enstitüsü Bilişsel Bilimler Bölümü bünyesinde aynı bölüm öğretim üyesi Y. Doç. Dr. Bilge Say ve Bilkent Üniversitesi Psikoloji Bölümü öğretim üyelerinden Doç. Dr. Fergus Bolger eş danışmanlığında yürütülmekte olan bir doktora tez çalışması kapsamındadır. Çalışmada amaç görsel ve sayısal geri bildirimde ortaya çıkan öğrenme farklılıklarının ortaya çıkarılmasıdır. Çalışma kapsamında toplanan veriler istatistiksel yöntemlerle analiz edilecek ve çeşitli parametrelere göre farklılıklar incelenecektir.

Bu çalışmadan elde edilecek verilerle yapılacak analizlerin Aralık 2010 sonunda sonuçlandırılması amaçlanmaktadır. Elde edilen bilgiler sadece bilimsel araştırma ve yazılarda kullanılacaktır. Çalışmanın sonuçlarını öğrenmek ya da bu araştırma hakkında daha fazla bilgi almak için aşağıdaki isimlere başvurabilirsiniz. Bu araştırmaya katıldığınız için tekrar teşekkür ederiz.

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Tez Danışmanı, Fergus BOLGER (E-posta: fergus@bilkent.edu.tr)

Figure A.2: Debriefing Form (Approved)

## A.4 Ethics Committee Approval Form

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
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14 Şubat 2013

Gönderilen: Prof.Dr.Kürşat Çağıltay
Bilgisayar ve Öğretim Teknolojileri
Eğitimi Bölümü

Gönderen : Prof. Dr. Canan Özgen
IAK Başkan Yardımcısı

İlgi : Etik Onayı

Danışmanlığını yapmış olduğunuz Bilişsel Bilimler Bölümü doktora öğrencisi Mustafa Bayındır'ın "Individual Differences in Performance on Perceptual Multiple Cue Probability Learning Tasks" isimli araştırması İnsan Araştırmaları Komitesi" tarafından uygun görülerek gerekli onay verilmiştir.

Bilgilerinize saygılarımla sunarım.

Etik Komite Onayı

Uygundur

14/02/2013

**Prof.Dr. Canan ÖZGEN**
**Uygulamalı Etik Araştırma Merkezi**
**( UEAM ) Başkanı**
**ODTÜ 06531 ANKARA**

# APPENDIX B: EXPERIMENT DATA AND ANALYSIS RESULTS

This chapter contains the data collected with experiments and the results of the analyses done using the this data.

## B.1 Experiment-1

Table B.1: Graphical Condition Achievement Scores and Completion Time (Experiment-1).

B1, B2, B3, B4, B5, B6=Achievements for Block1, Block2, Block3, Block4, Block5, Block6. Ach=Overall Achievement. Time=Completion duration in minutes. AOSPAN=AOSPAN absolute score.

| *Ref.* | *B1* | *B2* | *B3* | *B4* | *B5* | *B6* | *Time* | *Ach.* | *AOSPAN* |
|---|---|---|---|---|---|---|---|---|---|
| 100 | 0.68 | 0.61 | 0.46 | 0.49 | 0.60 | 0.67 | 25 | 0.59 | 37 |
| 99 | 0.66 | 0.64 | 0.88 | 0.91 | 0.87 | 0.64 | 28 | 0.77 | 75 |
| 98 | 0.74 | 0.86 | 0.85 | 0.68 | 0.73 | 0.85 | 22 | 0.78 | 50 |
| 97 | 0.81 | 0.58 | 0.66 | 0.75 | 0.72 | 0.75 | 31 | 0.71 | 33 |
| 96 | 0.48 | 0.55 | 0.74 | 0.71 | 0.69 | 0.68 | 28 | 0.64 | 37 |
| 95 | 0.72 | 0.73 | 0.62 | 0.48 | 0.68 | 0.68 | 18 | 0.64 | 54 |
| 94 | 0.65 | 0.53 | 0.59 | 0.62 | 0.74 | 0.48 | 41 | 0.61 | 28 |

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Table B.1 – *Continued from previous page*

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***AOSPAN*** |
|---|---|---|---|---|---|---|---|---|---|
| 93 | 0.54 | 0.68 | 0.59 | 0.53 | 0.59 | 0.62 | 25 | 0.58 | 42 |
| 92 | 0.70 | 0.77 | 0.78 | 0.73 | 0.75 | 0.90 | 46 | 0.77 | 39 |
| 91 | 0.81 | 0.83 | 0.83 | 0.83 | 0.84 | 0.87 | 28 | 0.82 | 62 |
| 79 | 0.72 | 0.85 | 0.84 | 0.92 | 0.96 | 0.96 | 50 | 0.87 | 51 |
| 78 | 0.61 | 0.66 | 0.70 | 0.66 | 0.68 | 0.71 | 17 | 0.65 | 28 |
| 77 | 0.16 | 0.65 | 0.76 | 0.77 | 0.64 | 0.87 | 28 | 0.67 | 29 |
| 76 | 0.54 | 0.68 | 0.86 | 0.91 | 0.89 | 0.93 | 42 | 0.82 | 68 |
| 74 | 0.76 | 0.82 | 0.80 | 0.92 | 0.93 | 0.93 | 61 | 0.86 | 60 |
| 73 | 0.11 | 0.62 | 0.78 | 0.68 | 0.80 | 0.77 | 64 | 0.60 | 51 |
| 64 | 0.66 | 0.63 | 0.52 | 0.79 | 0.71 | 0.74 | 30 | 0.68 | 46 |
| 63 | 0.73 | 0.81 | 0.78 | 0.74 | 0.77 | 0.74 | 20 | 0.74 | 3 |
| 62 | 0.76 | 0.71 | 0.85 | 0.68 | 0.62 | 0.76 | 26 | 0.73 | 38 |
| 61 | 0.14 | 0.25 | 0.25 | 0.56 | 0.32 | 0.61 | 22 | 0.35 | 47 |
| 60 | 0.84 | 0.91 | 0.97 | 0.97 | 0.94 | 0.94 | 71 | 0.93 | 75 |
| 59 | 0.38 | 0.57 | 0.70 | 0.67 | 0.70 | 0.64 | 25 | 0.59 | 22 |
| 55 | 0.19 | 0.60 | 0.66 | 0.62 | 0.63 | 0.71 | 22 | 0.56 | 50 |
| 48 | 0.73 | 0.66 | 0.63 | 0.75 | 0.84 | 0.86 | 50 | 0.74 | 37 |
| 47 | 0.31 | 0.57 | 0.83 | 0.86 | 0.73 | 0.76 | 43 | 0.67 | 46 |
| 46 | 0.69 | 0.67 | 0.69 | 0.53 | 0.82 | 0.61 | 18 | 0.66 | 55 |

Table B.2: Numerical Condition Achievement Scores and Completion Time (Experiment-1).

B1, B2, B3, B4, B5, B6=Achievements for Block1, Block2, Block3, Block4, Block5, Block6. Ach=Overall Achievement. Time=Completion duration in minutes. AOSPAN=AOSPAN absolute score.

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***AOSPAN*** |
|---|---|---|---|---|---|---|---|---|---|
| 90 | 0.94 | 0.89 | 0.87 | 0.85 | 0.80 | 0.83 | 31 | 0.86 | 40 |
| 89 | 0.36 | 0.59 | 0.35 | 0.29 | 0.37 | 0.46 | 19 | 0.42 | 62 |
| 88 | 0.04 | 0.20 | 0.55 | 0.32 | 0.43 | 0.34 | 35 | 0.32 | 75 |
| 87 | 0.53 | 0.73 | 0.84 | 0.82 | 0.82 | 0.85 | 32 | 0.76 | 44 |
| 86 | 0.62 | 0.49 | 0.68 | 0.61 | 0.62 | 0.68 | 39 | 0.61 | 37 |
| 85 | 0.49 | 0.32 | 0.32 | 0.43 | 0.17 | 0.26 | 30 | 0.34 | 42 |
| 84 | 0.43 | 0.57 | 0.53 | 0.46 | 0.74 | 0.76 | 23 | 0.60 | 48 |
| 83 | 0.58 | 0.31 | 0.50 | 0.54 | 0.38 | 0.49 | 42 | 0.47 | 43 |
| 82 | 0.67 | 0.56 | 0.39 | 0.46 | 0.66 | 0.49 | 46 | 0.54 | 48 |
| 81 | 0.45 | 0.50 | 0.62 | 0.64 | 0.48 | 0.46 | 40 | 0.50 | 28 |
| 80 | 0.71 | 0.74 | 0.73 | 0.62 | 0.55 | 0.70 | 50 | 0.68 | 32 |
| 72 | 0.50 | 0.57 | 0.35 | 0.49 | 0.47 | 0.63 | 17 | 0.50 | 19 |
| 70 | 0.56 | 0.35 | 0.70 | 0.04 | 0.38 | 0.41 | 18 | 0.43 | 53 |
| 68 | 0.67 | 0.48 | 0.30 | 0.29 | 0.45 | 0.50 | 25 | 0.42 | 42 |
| 67 | 0.14 | 0.28 | 0.19 | -0.11 | 0.21 | 0.49 | 32 | 0.21 | 47 |
| 66 | 0.51 | 0.64 | 0.62 | 0.57 | 0.63 | 0.73 | 23 | 0.61 | 25 |
| 65 | 0.59 | 0.55 | 0.63 | 0.68 | 0.57 | 0.53 | 21 | 0.59 | 61 |
| 57 | 0.65 | 0.35 | 0.41 | 0.33 | 0.28 | 0.69 | 18 | 0.45 | 46 |
| 56 | 0.34 | 0.59 | 0.79 | 0.87 | 0.83 | 0.81 | 26 | 0.71 | 38 |
| 54 | 0.72 | 0.69 | 0.51 | 0.70 | 0.13 | 0.17 | 26 | 0.45 | 36 |
| 53 | 0.73 | 0.29 | 0.47 | 0.60 | 0.59 | 0.52 | 14 | 0.55 | 50 |
| 52 | 0.48 | 0.30 | 0.34 | 0.51 | 0.83 | 0.77 | 43 | 0.54 | 55 |
| 50 | 0.63 | 0.50 | 0.62 | 0.72 | 0.61 | 0.83 | 46 | 0.66 | 37 |

## B.2 Experiment-2

Table B.3: Graphical Condition Achievement Scores and Completion Time (Experiment-2)

B1, B2, B3, B4, B5, B6=Achievements for Block1, Block2, Block3, Block4, Block5, Block6. Ach=Overall Achievement. Time=Completion duration in minutes. AOSPAN=AOSPAN absolute score. BDS=BDS absolute score.

| *Ref.* | *B1* | *B2* | *B3* | *B4* | *B5* | *B6* | *Time* | *Ach.* | *AOSPAN* | *BDS* |
|---|---|---|---|---|---|---|---|---|---|---|
| 46 | 0.83 | 0.75 | 0.61 | 0.67 | 0.61 | 0.64 | 26.8 | 0.68 | 19 | 20 |
| 43 | 0.46 | 0.64 | 0.23 | 0.58 | 0.42 | 0.52 | 24.38 | 0.48 | 24 | 20 |
| 249 | 0.73 | 0.24 | 0.5 | 0.61 | 0.56 | 0.45 | 48.95 | 0.52 | 36 | 21 |
| 500 | 0.67 | 0.69 | 0.82 | 0.54 | 0.65 | 0.77 | 43.24 | 0.69 | 59 | 25 |
| 501 | 0.64 | 0.81 | 0.46 | 0.54 | 0.67 | 0.74 | 27.1 | 0.64 | 57 | 23 |
| 502 | 0.71 | 0.66 | 0.81 | 0.65 | 0.75 | 0.54 | 36.79 | 0.69 | 45 | 23 |
| 503 | 0.41 | 0.57 | 0.63 | 0.45 | 0.64 | 0.8 | 24.82 | 0.58 | 48 | 21 |
| 504 | 0.12 | 0.23 | 0.21 | 0.12 | 0 | 0.23 | 28.41 | 0.13 | 51 | 19 |
| 612 | 0.4 | 0.49 | 0.61 | 0.61 | 0.71 | 0.63 | 35.37 | 0.58 | - | 22 |
| 808 | 0.54 | 0.28 | 0.36 | 0.28 | -0.1 | 0.55 | 58.51 | 0.31 | 26 | 13 |
| 812 | 0.52 | 0.64 | 0.57 | 0.63 | 0.7 | 0.54 | 57.93 | 0.59 | 57 | 21 |
| 813 | 0.68 | 0.77 | 0.93 | 0.85 | 0.9 | 0.85 | 47.03 | 0.83 | 43 | 19 |
| 150 | 0.77 | 0.75 | 0.88 | 0.75 | 0.8 | 0.84 | 42.37 | 0.79 | 50 | 22 |
| 149 | 0.47 | 0.47 | 0.44 | 0.5 | 0.49 | 0.56 | 31.31 | 0.49 | 62 | 25 |
| 148 | 0.75 | 0.65 | 0.59 | 0.75 | 0.65 | 0.79 | 25.69 | 0.7 | 37 | 24 |
| 147 | 0.5 | 0.33 | 0.59 | 0.54 | 0.56 | 0.66 | 36.21 | 0.53 | 69 | 23 |
| 146 | 0.42 | 0.25 | 0.28 | 0.38 | 0.48 | 0.63 | 22.55 | 0.4 | 27 | 24 |
| 143 | 0.82 | 0.9 | 0.88 | 0.69 | 0.92 | 0.93 | 200.46 | 0.87 | 53 | 24 |
| 137 | 0.82 | 0.65 | 0.63 | 0.58 | 0.7 | 0.53 | 64.15 | 0.65 | 34 | 19 |
| 136 | 0.61 | 0.24 | 0.5 | 0.53 | 0.61 | 0.59 | 12.87 | 0.53 | 34 | 19 |
| 250 | 0.6 | 0.31 | 0.28 | 0.62 | 0.53 | 0.53 | 44.4 | 0.48 | 31 | 22 |
| 301 | 0.77 | 0.71 | 0.86 | 0.73 | 0.76 | 0.78 | 37.04 | 0.77 | 51 | 25 |
| 302 | 0.6 | 0.59 | 0.66 | 0.57 | 0.43 | 0.77 | 31.94 | 0.61 | 28 | 18 |

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Table B.3 – *Continued from previous page*

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***AOSPAN*** | ***BDS*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 804 | 0.47 | 0.56 | 0.65 | 0.63 | 0.6 | 0.71 | 54.8 | 0.6 | 34 | 16 |
| 805 | 0.47 | 0.77 | 0.71 | 0.7 | 0.75 | 0.47 | 45.33 | 0.66 | 42 | 20 |
| 806 | 0.42 | 0.38 | 0.5 | 0.44 | 0.37 | 0.04 | 45.45 | 0.36 | 43 | 20 |
| 807 | 0.61 | 0.73 | 0.66 | 0.59 | 0.65 | 0.77 | 32.92 | 0.65 | 36 | 24 |
| 816 | -0.1 | 0.75 | 0.79 | 0.76 | 0.75 | 0.68 | 27.05 | 0.59 | 68 | 23 |

Table B.4: Numerical Condition Achievement Scores and Completion Time (Experiment-2)

B1, B2, B3, B4, B5, B6=Achievements for Block1, Block2, Block3, Block4, Block5, Block6. Ach=Overall Achievement. Time=Completion duration in minutes. AOSPAN=AOSPAN absolute score. BDS=BDS absolute score.

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***AOSPAN*** | ***BDS*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 138 | 0.31 | 0.33 | 0.59 | 0.41 | 0.75 | 0.9 | 31.33 | 0.55 | 49 | 22 |
| 50 | 0.73 | 0.61 | 0.69 | 0.74 | 0.74 | 0.67 | 33.2 | 0.68 | 34 | 22 |
| 47 | 0.7 | 0.56 | 0.44 | 0.56 | 0.63 | 0.64 | 18.31 | 0.58 | 27 | 19 |
| 45 | 0.61 | 0.63 | 0.4 | 0.33 | 0.29 | 0.65 | 16.13 | 0.5 | 19 | 17 |
| 44 | 0.61 | 0.65 | 0.68 | 0.62 | 0.49 | 0.65 | 23.04 | 0.59 | 37 | 18 |
| 42 | 0.45 | 0.46 | 0.4 | 0.42 | 0.49 | 0.57 | 45.2 | 0.46 | 61 | 26 |
| 247 | 0.68 | 0.59 | 0.31 | 0.59 | 0.51 | 0.45 | 18.55 | 0.52 | 38 | 19 |
| 400 | 0.72 | 0.7 | 0.37 | 0.66 | 0.63 | 0.57 | 37.99 | 0.62 | 28 | 14 |
| 401 | 0.31 | 0.09 | 0.52 | 0.35 | 0.7 | 0.55 | 30.54 | 0.42 | 68 | 27 |
| 402 | 0.6 | 0.65 | 0.52 | 0.66 | 0.51 | 0.65 | 32.6 | 0.58 | 19 | 13 |
| 505 | 0.72 | 0.62 | 0.71 | 0.58 | 0.58 | 0.76 | 14.9 | 0.62 | 56 | 20 |
| 600 | 0.52 | 0.56 | 0.53 | 0.49 | 0.47 | 0.7 | 26.43 | 0.54 | - | 13 |
| 809 | 0.57 | 0.8 | 0.78 | 0.79 | 0.75 | 0.84 | 23.02 | 0.74 | 56 | 18 |
| 810 | 0.79 | 0.72 | 0.75 | 0.62 | 0.31 | 0.21 | 25.31 | 0.59 | 37 | 15 |

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Table B.4 – *Continued from previous page*

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***AOSPAN*** | ***BDS*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 814 | 0.56 | 0.48 | 0.62 | 0.62 | 0.59 | 0.56 | 19.5 | 0.56 | 68 | 20 |
| 815 | 0.81 | 0.82 | 0.66 | 0.64 | 0.54 | 0.73 | 54.03 | 0.71 | 39 | 14 |
| 144 | 0.56 | 0.8 | 0.94 | 0.92 | 0.95 | 0.96 | 86.38 | 0.86 | 48 | 28 |
| 145 | 0.94 | 0.89 | 0.93 | 0.88 | 0.95 | 0.93 | 37.88 | 0.92 | 37 | 24 |
| 142 | 0.85 | 0.95 | 0.9 | 0.9 | 0.94 | 0.97 | 52.94 | 0.92 | 55 | 29 |
| 141 | 0.63 | 0.65 | 0.92 | 0.81 | 0.93 | 0.95 | 38.7 | 0.82 | 44 | 27 |
| 134 | 0.12 | 0.5 | 0.75 | 0.54 | 0.7 | 0.83 | 29.81 | 0.61 | 40 | 26 |
| 48 | 0.52 | 0.72 | 0.72 | 0.66 | 0.83 | 0.91 | 18.52 | 0.73 | 46 | 23 |
| 248 | 0.79 | 0.88 | 0.92 | 0.89 | 0.88 | 0.89 | 79.79 | 0.86 | 63 | 19 |
| 601 | 0.55 | 0.22 | 0.13 | 0.66 | 0.66 | 0.51 | 14.81 | 0.47 | 28 | 17 |
| 604 | 0.45 | 0.56 | 0.61 | 0.67 | 0.71 | 0.73 | 46.66 | 0.61 | - | 21 |
| 610 | 0.68 | 0.67 | 0.72 | 0.65 | 0.85 | 0.83 | 24.1 | 0.73 | 62 | 25 |
| 801 | 0.46 | 0.68 | 0.61 | 0.71 | 0.71 | 0.77 | 31.27 | 0.66 | 56 | 29 |
| 802 | 0.74 | 0.81 | 0.84 | 0.81 | 0.81 | 0.8 | 33.65 | 0.8 | 68 | 21 |
| 803 | 0.45 | 0.6 | 0.63 | 0.59 | 0.73 | 0.75 | 23.35 | 0.62 | 44 | 27 |
| 811 | 0.67 | 0.72 | 0.78 | 0.75 | 0.72 | 0.75 | 31.54 | 0.73 | 63 | 24 |

## B.3 Experiment-3

Table B.5: Graphical Condition Achievement Scores and Completion Time (Experiment-3)

B1, B2, B3, B4, B5, B6=Achievements for Block1, Block2, Block3, Block4, Block5, Block6. Ach=Overall Achievement. Time=Completion duration in minutes. BDS=BDS absolute score. CBT=CBT absolute score.

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***BDS*** | ***CBT*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 50 | 0.49 | 0.40 | 0.56 | 0.59 | 0.75 | 0.75 | 45.82 | 0.57 | 19 | 03 |
| 51 | 0.54 | 0.77 | 0.68 | 0.76 | 0.72 | 0.72 | 34.01 | 0.66 | 21 | 13 |
| 52 | 0.57 | 0.6 | 0.57 | 0.42 | 0.7 | 0.35 | 29.22 | 0.54 | 18 | 12 |
| 53 | 0.69 | 0.75 | 0.87 | 0.83 | 0.84 | 0.82 | 51.5 | 0.78 | 24 | 10 |
| 54 | 0.66 | 0.8 | 0.8 | 0.82 | 0.72 | 0.81 | 22.66 | 0.77 | 17 | 10 |
| 55 | 0.53 | 0.75 | 0.71 | 0.74 | 0.82 | 0.77 | 32.13 | 0.72 | 18 | 13 |
| 56 | 0.71 | 0.57 | 0.74 | 0.82 | 0.85 | 0.82 | 49.02 | 0.76 | 15 | 12 |
| 57 | 0.71 | 0.81 | 0.66 | 0.67 | 0.71 | 0.81 | 39.22 | 0.72 | 22 | 13 |
| 58 | 0.52 | 0.48 | 0.91 | 0.95 | 0.91 | 0.95 | 62.27 | 0.78 | 27 | 18 |
| 59 | 0.56 | 0.5 | 0.74 | 0.53 | 0.65 | 0.73 | 42.57 | 0.63 | 25 | 13 |
| 60 | 0.72 | 0.9 | 0.81 | 0.87 | 0.89 | 0.95 | 31.18 | 0.86 | 21 | 19 |
| 61 | 0.69 | 0.53 | 0.53 | 0.47 | 0.64 | 0.46 | 15.83 | 0.54 | 17 | 9 |
| 62 | 0.52 | 0.3 | 0.43 | 0.35 | 0.32 | 0.38 | 19.57 | 0.38 | 20 | 14 |
| 63 | 0.6 | 0.53 | 0.55 | 0.46 | 0.45 | 0.6 | 30.45 | 0.53 | 21 | 15 |
| 64 | 0.74 | 0.53 | 0.75 | 0.84 | 0.71 | 0.57 | 30.22 | 0.7 | 20 | 11 |
| 65 | 0.82 | 0.92 | 0.91 | 0.88 | 0.91 | 0.88 | 45.71 | 0.88 | 24 | 12 |
| 66 | 0.65 | 0.81 | 0.92 | 0.91 | 0.9 | 0.88 | 44.04 | 0.84 | 21 | 13 |
| 67 | 0.48 | 0.64 | 0.6 | 0.73 | 0.64 | 0.8 | 29.96 | 0.66 | 29 | 17 |
| 68 | 0.58 | 0.68 | 0.6 | 0.56 | 0.74 | 0.79 | 26.51 | 0.66 | 17 | 16 |
| 69 | 0.52 | 0.59 | 0.72 | 0.63 | 0.69 | 0.7 | 25.66 | 0.63 | 20 | 13 |
| 70 | 0.44 | 0.62 | 0.24 | 0.11 | 0.46 | 0.18 | 27.16 | 0.37 | 19 | 11 |
| 71 | 0.38 | 0.57 | 0.56 | 0.23 | 0.23 | 0.79 | 60.32 | 0.66 | 18 | 13 |
| 72 | 0.67 | 0.56 | 0.46 | 0.23 | 0.6 | 0.56 | 27.21 | 0.55 | 18 | 15 |

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Table B.5 – *Continued from previous page*

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***BDS*** | ***CBT*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 73 | 0.73 | 0.69 | 0.78 | 0.84 | 0.72 | 0.75 | 28.87 | 0.75 | 19 | 18 |
| 74 | 0.5 | 0.74 | 0.09 | 0.58 | 0.71 | 0.46 | 47.95 | 0.55 | 21 | 14 |
| 75 | 0.52 | 0.79 | 0.82 | 0.88 | 0.87 | 0.89 | 31.98 | 0.8 | 22 | 17 |
| 76 | 0.8 | 0.74 | 0.73 | 0.74 | 0.69 | 0.85 | 20.52 | 0.76 | 26 | 18 |
| 77 | 0.85 | 0.93 | 0.97 | 0.97 | 0.98 | 0.94 | 58.53 | 0.94 | 22 | 17 |
| 78 | 0.86 | 0.89 | 0.96 | 0.98 | 0.96 | 0.96 | 76.72 | 0.93 | 25 | 17 |
| 79 | 0.62 | 0.65 | 0.73 | 0.65 | 0.73 | 0.78 | 22.52 | 0.69 | 25 | 17 |
| 80 | 0.59 | 0.33 | 0.11 | 0.28 | 0.44 | 0.42 | 24.89 | 0.39 | 15 | 6 |
| 81 | 0.45 | 0.76 | 0.75 | 0.86 | 0.91 | 0.87 | 38.57 | 0.77 | 25 | 20 |
| 82 | 0.73 | 0.78 | 0.74 | 0.58 | 0.53 | 0.75 | 29.02 | 0.69 | 26 | 23 |
| 83 | 0.52 | 0.52 | 0.68 | 0.68 | 0.65 | 0.51 | 33.51 | 0.6 | 25 | 16 |
| 84 | 0.65 | 0.81 | 0.74 | 0.75 | 0.63 | 0.66 | 44.84 | 0.71 | 27 | 14 |
| 85 | 0.45 | 0.68 | 0.71 | 0.78 | 0.64 | 0.74 | 56.35 | 0.65 | 21 | 16 |
| 86 | 0.53 | 0.35 | 0.05 | 0.44 | 0.12 | 0.22 | 52.99 | 0.26 | 23 | 15 |
| 87 | 0.81 | 0.76 | 0.86 | 0.73 | 0.8 | 0.78 | 27.56 | 0.79 | 15 | 12 |
| 88 | 0.58 | 0.74 | 0.66 | 0.67 | 0.51 | 0.76 | 20.85 | 0.66 | 23 | 15 |
| 89 | 0.24 | 0.8 | 0.68 | 0.84 | 0.75 | 0.66 | 37.76 | 0.67 | 23 | 16 |
| 90 | 0.26 | 0.33 | 0.51 | 0.46 | 0.27 | 0.3 | 19.66 | 0.33 | 15 | 12 |
| 91 | 0.76 | 0.8 | 0.81 | 0.84 | 0.87 | 0.89 | 25.46 | 0.82 | 23 | 16 |
| 92 | 0.3 | 0.25 | 0.5 | 0.04 | 0.29 | 0.59 | 28.63 | 0.32 | 18 | 14 |
| 93 | 0.65 | 0.77 | 0.83 | 0.67 | 0.74 | 0.74 | 19.44 | 0.73 | 23 | 9 |
| 94 | 0.73 | 0.26 | 0.22 | 0.4 | 0.46 | 0.3 | 21.34 | 0.44 | 18 | 11 |
| 95 | 0.8 | 0.85 | 0.8 | 0.88 | 0.81 | 0.88 | 37.22 | 0.83 | 23 | 18 |
| 96 | 0.84 | 0.79 | 0.76 | 0.62 | 0.78 | 0.82 | 43.1 | 0.77 | 20 | 13 |
| 97 | 0.79 | 0.91 | 0.92 | 0.81 | 0.89 | 0.74 | 39.31 | 0.82 | 18 | 14 |
| 98 | 0.7 | 0.79 | 0.85 | 0.86 | 0.91 | 0.89 | 46.32 | 0.83 | 27 | 16 |

Table B.6: Numerical Condition Achievement Scores and Completion Time (Experiment-3)

B1, B2, B3, B4, B5, B6=Achievements for Block1, Block2, Block3, Block4, Block5, Block6. Ach=Overall Achievement. Time=Completion duration in minutes. BDS=BDS absolute score. CBT=CBT absolute score.

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***BDS*** | ***CBT*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.68 | 0.39 | 0.62 | 0.51 | 0.32 | 0.46 | 38.01 | 0.48 | 20 | 11 |
| 2 | 0.26 | 0.36 | 0.21 | 0.15 | 0.02 | 0.03 | 48.11 | 0.13 | 17 | 9 |
| 3 | 0.71 | 0.64 | 0.32 | 0.58 | 0.54 | 0.59 | 61.79 | 0.57 | 16 | 10 |
| 4 | 0.27 | 0.02 | 0.02 | 0.59 | 0.26 | 0.35 | 46.73 | 0.25 | 20 | 17 |
| 5 | 0.57 | 0.74 | 0.66 | 0.75 | 0.76 | 0.79 | 31.12 | 0.69 | 22 | 16 |
| 6 | 0.3 | 0.35 | 0.26 | 0.06 | 0.11 | 0.06 | 32.83 | 0.17 | 23 | 15 |
| 7 | 0.19 | 0.11 | 0.27 | 0.45 | 0 | 0.03 | 27.38 | 0.17 | 21 | 10 |
| 8 | 0.55 | 0.62 | 0.61 | 0.42 | 0.29 | 0.68 | 46.61 | 0.53 | 17 | 12 |
| 9 | 0.57 | 0.55 | 0.59 | 0.47 | 0.48 | 0.46 | 27.55 | 0.52 | 18 | 15 |
| 10 | 0.27 | 0.79 | 0.13 | 0.66 | 0.77 | 0.72 | 28.51 | 0.54 | 16 | 8 |
| 11 | 0.45 | 0.34 | 0.54 | 0.54 | 0.43 | 0.7 | 24.95 | 0.51 | 24 | 18 |
| 12 | 0.59 | 0.53 | 0.57 | 0.28 | 0.65 | 0.43 | 30.43 | 0.5 | 20 | 8 |
| 13 | 0.06 | 0.26 | 0.05 | 0.13 | 0.28 | 0.04 | 26.2 | 0.15 | 21 | 13 |
| 14 | 0.32 | 0.11 | 0.15 | 0.71 | 0.37 | 0.5 | 28.21 | 0.32 | 21 | 11 |
| 15 | 0.63 | 0.32 | 0.37 | 0.38 | 0.59 | 0.55 | 30.53 | 0.48 | 20 | 8 |
| 16 | 0.22 | 0.35 | 0.34 | 0.65 | 0.52 | 0.54 | 26.04 | 0.42 | 17 | 18 |
| 17 | 0.67 | 0.63 | 0.66 | 0.85 | 0.69 | 0.66 | 33.77 | 0.69 | 19 | 7 |
| 18 | 0.46 | 0.44 | 0.56 | 0.04 | 0.39 | 0.64 | 12.82 | 0.42 | 20 | 12 |
| 19 | 0.64 | 0.7 | 0.63 | 0.7 | 0.64 | 0.78 | 20.69 | 0.67 | 30 | 18 |
| 20 | 0.51 | 0.32 | 0.38 | 0.59 | 0.6 | 0.47 | 43.31 | 0.48 | 19 | 14 |
| 21 | 0.56 | 0.34 | 0.04 | 0.11 | 0.21 | 0.1 | 16.37 | 0.22 | 20 | 17 |
| 22 | 0.32 | 0.21 | 0.32 | 0.15 | 0.22 | 0.13 | 15.8 | 0.18 | 21 | 14 |
| 23 | 0.36 | 0.15 | 0.59 | 0.28 | 0.33 | 0.28 | 55.35 | 0.32 | 23 | 11 |
| 24 | 0.42 | 0.4 | 0.3 | 0.42 | 0.45 | 0.69 | 73.36 | 0.41 | 20 | 7 |

*Continued on next page*

Table B.6 – *Continued from previous page*

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***BDS*** | ***CBT*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 25 | 0.5 | 0.55 | 0.52 | 0.24 | 0.71 | 0.75 | 61.51 | 0.54 | 21 | 18 |
| 26 | 0.66 | 0.56 | 0.71 | 0.66 | 0.68 | 0.73 | 29.88 | 0.67 | 18 | 10 |
| 27 | 0.67 | 0.73 | 0.45 | 0.47 | 0.57 | 0.24 | 28.91 | 0.55 | 19 | 12 |
| 28 | 0.8 | 0.73 | 0.62 | 0.74 | 0.57 | 0.67 | 50.28 | 0.69 | 18 | 11 |
| 29 | 0.67 | 0.62 | 0.49 | 0.53 | 0.55 | 0.71 | 18.98 | 0.59 | 20 | 12 |
| 30 | 0.45 | 0.38 | 0.55 | 0.52 | 0.24 | 0.36 | 46.26 | 0.39 | 17 | 13 |
| 31 | 0.37 | 0.58 | 0.47 | 0.48 | 0.23 | 0.66 | 14.88 | 0.48 | 17 | 14 |
| 32 | 0.71 | 0.62 | 0.53 | 0.2 | 0.4 | 0.15 | 38.89 | 0.43 | 18 | 16 |
| 33 | 0.74 | 0.78 | 0.61 | 0.63 | 0.72 | 0.1 | 40.93 | 0.6 | 25 | 17 |
| 34 | 0.73 | 0.74 | 0.86 | 0.61 | 0.78 | 0.84 | 42.99 | 0.75 | 21 | 18 |
| 35 | 0.55 | 0.24 | 0.4 | 0.25 | 0.3 | 0.2 | 23.01 | 0.32 | 17 | 17 |
| 36 | 0.52 | 0.71 | 0.68 | 0.48 | 0.51 | 0.71 | 39.81 | 0.6 | 17 | 11 |
| 37 | 0.55 | 0.6 | 0.44 | 0.58 | 0.57 | 0.73 | 23.28 | 0.56 | 24 | 19 |
| 38 | 0.45 | 0.37 | 0.42 | 0.46 | 0.58 | 0.61 | 33.54 | 0.47 | 25 | 14 |
| 39 | 0.62 | 0.63 | 0.56 | 0.59 | 0.69 | 0.82 | 41.69 | 0.66 | 15 | 14 |
| 40 | 0.59 | 0.78 | 0.73 | 0.68 | 0.71 | 0.78 | 36.63 | 0.71 | 22 | 14 |
| 41 | 0.72 | 0.84 | 0.76 | 0.67 | 0.75 | 0.84 | 31.02 | 0.76 | 24 | 13 |
| 42 | 0.07 | 0.39 | 0.31 | 0.13 | 0.11 | 0.03 | 30.77 | 0.1 | 18 | 16 |
| 43 | 0.58 | 0.9 | 0.94 | 0.97 | 0.95 | 0.93 | 39.99 | 0.89 | 25 | 12 |
| 44 | 0.77 | 0.8 | 0.75 | 0.83 | 0.77 | 0.86 | 15.47 | 0.8 | 28 | 22 |
| 45 | 0.14 | 0.01 | 0.08 | 0.14 | 0.06 | 0.43 | 20.94 | 0.12 | 16 | 7 |
| 46 | 0.74 | 0.82 | 0.92 | 0.87 | 0.93 | 0.88 | 48.11 | 0.85 | 23 | 19 |
| 47 | 0.34 | 0.49 | 0.93 | 0.94 | 0.95 | 0.91 | 46.34 | 0.78 | 21 | 14 |
| 48 | 0.87 | 0.86 | 0.86 | 0.95 | 0.95 | 0.97 | 64.73 | 0.91 | 18 | 16 |
| 49 | 0.47 | 0.54 | 0.31 | 0.44 | 0.52 | 0.41 | 15.47 | 0.41 | 24 | 12 |

Table B.7: Graphical and All Positive Polarization Condition Achievement Scores and Completion Time (Experiment-3)

B1, B2, B3, B4, B5, B6=Achievements for Block1, Block2, Block3, Block4, Block5, Block6. Ach=Overall Achievement. Time=Completion duration in minutes. BDS=BDS absolute score. CBT=CBT absolute score.

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***BDS*** | ***CBT*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 1-2 | 0,82 | 0,9 | 0,8 | 0,76 | 0,77 | 0,73 | 0,8 | 29,68 | 24 | 14 |
| 1-3 | 0,83 | 0,79 | 0,87 | 0,85 | 0,91 | 0,85 | 0,85 | 30,47 | 27 | 21 |
| 1-4 | 0,71 | 0,79 | 0,65 | 0,76 | 0,6 | 0,74 | 0,69 | 17,61 | 26 | 17 |
| 1-5 | 0,71 | 0,78 | 0,85 | 0,81 | 0,69 | 0,8 | 0,78 | 42,04 | 19 | 17 |
| 2-3 | 0 | 0,32 | 0,14 | 0,14 | 0,37 | 0,4 | 0,25 | 27,49 | 18 | 12 |
| 2-4 | 0,74 | 0,62 | 0,87 | 0,77 | 0,64 | 0,82 | 0,74 | 26,64 | 17 | 11 |
| 2-5 | 0,7 | 0,79 | 0,77 | 0,65 | 0,71 | 0,73 | 0,72 | 31,29 | 17 | 14 |
| 3-2 | 0,67 | 0,63 | 0,62 | 0,52 | 0,54 | 0,53 | 0,57 | 32,5 | 16 | 11 |
| 3-3 | 0,7 | 0,69 | 0,76 | 0,78 | 0,82 | 0,85 | 0,76 | 36,52 | 22 | 11 |
| 3-4 | 0,82 | 0,9 | 0,89 | 0,83 | 0,79 | 0,85 | 0,82 | 35,6 | 16 | 14 |
| 4-2 | 0,67 | 0,53 | 0,73 | 0,46 | 0,63 | 0,67 | 0,61 | 14,25 | 24 | 15 |
| 4-3 | 0,69 | 0,58 | 0,87 | 0,82 | 0,72 | 0,83 | 0,75 | 40,7 | 21 | 12 |
| 4-4 | 0,47 | 0,35 | 0,89 | 0,82 | 0,85 | 0,74 | 0,65 | 54,44 | 24 | 18 |
| 4-5 | 0,82 | 0,84 | 0,86 | 0,83 | 0,81 | 0,91 | 0,84 | 50,04 | 22 | 9 |
| 5-2 | 0,68 | 0,73 | 0,72 | 0,75 | 0,73 | 0,83 | 0,73 | 23,1 | 18 | 9 |
| 5-4 | 0,8 | 0,63 | 0,86 | 0,81 | 0,76 | 0,85 | 0,79 | 27,55 | 19 | 14 |
| 5-5 | 0,67 | 0,76 | 0,75 | 0,71 | 0,82 | 0,83 | 0,76 | 30,79 | 26 | 16 |
| 6-3 | 0,82 | 0,85 | 0,73 | 0,59 | 0,71 | 0,85 | 0,77 | 29,54 | 20 | 15 |
| 6-4 | 0,88 | 0,8 | 0,86 | 0,88 | 0,86 | 0,91 | 0,86 | 43,66 | 25 | 10 |
| 6-5 | 0,77 | 0,58 | 0,8 | 0,66 | 0,73 | 0,82 | 0,72 | 24,72 | 25 | 15 |
| 7-3 | 0,15 | 0,27 | 0,36 | 0,22 | 0,05 | 0,02 | 0,19 | 22,52 | 17 | 13 |
| 7-4 | 0,94 | 0,95 | 0,92 | 0,91 | 0,89 | 0,61 | 0,86 | 47,14 | 24 | 13 |
| 7-5 | 0,85 | 0,82 | 0,71 | 0,74 | 0,89 | 0,85 | 0,79 | 25,81 | 15 | 15 |
| 8-3 | 0,81 | 0,65 | 0,84 | 0,79 | 0,84 | 0,9 | 0,8 | 36,11 | 22 | 12 |

*Continued on next page*

Table B.7 – *Continued from previous page*

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***BDS*** | ***CBT*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 8-4 | 0,83 | 0,71 | 0,75 | 0,63 | 0,75 | 0,86 | 0,76 | 24,27 | 15 | 17 |
| 8-5 | 0,74 | 0,84 | 0,7 | 0,6 | 0,6 | 0,64 | 0,69 | 22,14 | 22 | 12 |
| 9-3 | 0,64 | 0,65 | 0,65 | 0,59 | 0,47 | 0,25 | 0,55 | 20,27 | 18 | 13 |
| 9-4 | 0,67 | 0,83 | 0,87 | 0,86 | 0,88 | 0,93 | 0,83 | 28,14 | 19 | 18 |
| 9-5 | 0,72 | 0,91 | 0,92 | 0,86 | 0,91 | 0,88 | 0,87 | 36,7 | 20 | 14 |
| 10-4 | 0,55 | 0,87 | 0,81 | 0,92 | 0,83 | 0,89 | 0,81 | 33,94 | 19 | 15 |
| 10-5 | 0,78 | 0,75 | 0,67 | 0,58 | 0,72 | 0,73 | 0,7 | 47,91 | 16 | 15 |
| 12-4 | 0,71 | 0,74 | 0,79 | 0,59 | 0,69 | 0,53 | 0,67 | 22,87 | 16 | 7 |
| 12-5 | 0,84 | 0,63 | 0,75 | 0,74 | 0,47 | 0,68 | 0,68 | 21,84 | 19 | 15 |
| 13-5 | 0,81 | 0,57 | 0,73 | 0,52 | 0,49 | 0,6 | 0,61 | 21,17 | 22 | 12 |
| 1-6 | 0,7 | 0,76 | 0,61 | 0,58 | 0,76 | 0,81 | 0,69 | 17,64 | 17 | 9 |
| 1-7 | 0,94 | 0,9 | 0,94 | 0,91 | 0,95 | 0,89 | 0,92 | 17,14 | 21 | 21 |
| 1-9 | 0,82 | 0,75 | 0,61 | 0,67 | 0,66 | 0,72 | 0,7 | 18,56 | 17 | 12 |
| 2-6 | 0,69 | 0,77 | 0,6 | 0,79 | 0,74 | 0,75 | 0,72 | 29,91 | 18 | 7 |
| 2-7 | 0,78 | 0,81 | 0,82 | 0,83 | 0,76 | 0,8 | 0,8 | 36,21 | 23 | 14 |
| 2-8 | 0,37 | 0,68 | 0,67 | 0,7 | 0,59 | 0,74 | 0,61 | 14,93 | 21 | 10 |
| 2-9 | 0,78 | 0,76 | 0,85 | 0,8 | 0,79 | 0,72 | 0,78 | 32,49 | 26 | 15 |
| 3-8 | 0,88 | 0,85 | 0,87 | 0,78 | 0,81 | 0,89 | 0,85 | 32,49 | 20 | 15 |
| 4-7 | 0,79 | 0,87 | 0,81 | 0,64 | 0,52 | 0,68 | 0,73 | 18,84 | 22 | 15 |
| 4-8 | 0,85 | 0,9 | 0,82 | 0,86 | 0,83 | 0,73 | 0,84 | 21,78 | 26 | 19 |
| 4-11 | 0,74 | 0,8 | 0,68 | 0,93 | 0,89 | 0,88 | 0,8 | 68,69 | 20 | 13 |
| 5-7 | 0,84 | 0,79 | 0,67 | 0,59 | 0,82 | 0,75 | 0,75 | 24,93 | 24 | 11 |
| 5-8 | 0,75 | 0,87 | 0,85 | 0,75 | 0,84 | 0,84 | 0,82 | 26,3 | 22 | 11 |
| 6-6 | 0,81 | 0,91 | 0,89 | 0,86 | 0,83 | 0,9 | 0,87 | 36,4 | 21 | 8 |
| 6-7 | 0,77 | 0,64 | 0,69 | 0,83 | 0,84 | 0,83 | 0,75 | 34,85 | 25 | 16 |
| 6-9 | 0,85 | 0,83 | 0,53 | 0,85 | 0,77 | 0,82 | 0,77 | 23,66 | 22 | 20 |
| 7-6 | 0,74 | 0,69 | 0,79 | 0,86 | 0,7 | 0,75 | 0,75 | 29,84 | 17 | 12 |
| 7-7 | 0,79 | 0,94 | 0,89 | 0,9 | 0,91 | 0,92 | 0,88 | 47,02 | 18 | 18 |
| 7-8 | 0,75 | 0,51 | 0,76 | 0,68 | 0,65 | 0,69 | 0,67 | 22,4 | 23 | 14 |

*Continued on next page*

Table B.7 – *Continued from previous page*

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***BDS*** | ***CBT*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 8-7 | 0,8 | 0,8 | 0,82 | 0,83 | 0,77 | 0,82 | 0,79 | 51,72 | 22 | 15 |
| 8-8 | 0,77 | 0,56 | 0,74 | 0,63 | 0,51 | 0,79 | 0,65 | 18,71 | 19 | 14 |
| 9-7 | 0,78 | 0,82 | 0,79 | 0,75 | 0,69 | 0,82 | 0,79 | 28,83 | 12 | 13 |
| 9-8 | 0,71 | 0,83 | 0,65 | 0,69 | 0,76 | 0,59 | 0,7 | 21,42 | 16 | 17 |
| 10-6 | 0,64 | 0,83 | 0,77 | 0,87 | 0,72 | 0,76 | 0,75 | 28,94 | 17 | 19 |
| 10-7 | 0,71 | 0,72 | 0,59 | 0,85 | 0,66 | 0,7 | 0,68 | 24,82 | 20 | 18 |
| 10-8 | 0,78 | 0,8 | 0,8 | 0,72 | 0,8 | 0,62 | 0,76 | 22,31 | 20 | 22 |
| 12-6 | 0,5 | 0,63 | 0,81 | 0,82 | 0,62 | 0,8 | 0,69 | 22,17 | 21 | 11 |
| 12-7 | 0,84 | 0,8 | 0,8 | 0,94 | 0,79 | 0,91 | 0,84 | 32,54 | 15 | 12 |
| 12-8 | 0,77 | 0,79 | 0,77 | 0,75 | 0,68 | 0,84 | 0,76 | 26,36 | 21 | 17 |
| 13-7 | 0,53 | 0,4 | 0,22 | 0,59 | 0,53 | 0,47 | 0,43 | 26,03 | 14 | 11 |
| 13-8 | 0,77 | 0,65 | 0,83 | 0,85 | 0,77 | 0,66 | 0,76 | 22,99 | 20 | 17 |

## B.4 Experiment-4

Table B.8: Graphical Condition Achievement Scores and Completion Time (Experiment-4)

B1, B2, B3, B4, B5, B6=Achievements for Block1, Block2, Block3, Block4, Block5, Block6. Ach=Overall Achievement. Time=Completion duration in mins. BDS=BDS score. CBT=CBT score.

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***BDS*** | ***CBT*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 1-7 | -0,14 | -0,08 | 0,08 | -0,19 | 0,04 | 0,16 | -0,01 | 0,00 | 16 | 12 |
| 7-7 | 0,23 | 0,47 | 0,47 | 0,45 | 0,63 | 0,38 | 0,46 | 0,00 | 19 | 10 |
| 1-10 | -0,06 | 0,05 | 0,14 | 0,17 | 0,12 | 0,1 | 0,07 | 0,00 | 23 | 16 |
| 3-10 | 0,36 | 0,25 | 0,46 | 0,34 | 0,36 | 0,31 | 0,35 | 0,00 | 22 | 17 |
| 1-11 | 0,12 | 0,51 | 0,7 | 0,76 | 0,71 | 0,44 | 0,55 | 0,00 | 25 | 19 |
| 3-11 | 0,07 | 0,25 | 0,18 | 0,12 | 0,12 | 0,28 | 0,17 | 0,00 | 21 | 15 |
| 6-11 | 0,13 | 0,37 | 0,43 | 0,38 | 0,53 | 0,12 | 0,33 | 0,00 | 23 | 10 |
| 7-11 | 0,21 | 0,51 | 0,74 | 0,71 | 0,7 | 0,8 | 0,61 | 0,00 | 17 | 17 |
| 11-11 | 0,02 | -0,04 | 0,16 | 0,2 | 0,16 | 0,37 | 0,17 | 0,00 | 26 | 12 |
| 1-14 | -0,12 | 0,37 | 0,53 | 0,49 | 0,11 | 0,36 | 0,29 | 0,00 | 29 | 15 |
| 6-14 | 0,15 | 0,16 | -0,25 | -0,09 | -0,04 | -0,03 | 0,02 | 0,00 | 18 | 20 |
| 7-14 | 0,35 | -0,05 | 0,04 | 0,12 | -0,05 | -0,01 | 0,08 | 0,00 | 17 | 14 |
| 11-14 | 0,26 | 0,76 | 0,79 | 0,72 | 0,85 | 0,85 | 0,69 | 0,00 | 29 | 15 |
| 13-14 | 0,12 | 0,27 | 0,38 | 0,69 | 0,76 | 0,74 | 0,51 | 0,00 | 23 | 18 |
| 1-15 | 0 | 0 | 0 | 0 | 0 | 0 | 0,6 | 0,00 | 21 | 17 |
| 6-15 | 0,01 | -0,06 | -0,15 | 0,06 | 0,05 | 0,16 | 0,01 | 0,00 | 14 | 15 |
| 7-15 | 0,43 | 0,3 | 0,42 | 0,25 | 0,28 | 0,22 | 0,32 | 0,00 | 21 | 11 |
| 11-15 | -0,13 | 0,17 | -0,23 | 0,08 | -0,21 | 0,13 | -0,03 | 0,00 | 22 | 17 |
| 13-15 | 0,26 | 0,57 | 0,51 | 0,47 | 0,51 | 0,7 | 0,48 | 0,00 | 23 | 14 |
| 5-16 | 0,15 | 0,2 | 0,15 | 0,16 | 0,38 | 0,64 | 0,26 | 0,00 | 21 | 18 |
| 6-16 | 0,64 | 0,55 | 0,67 | 0,86 | 0,9 | 0,94 | 0,75 | 0,00 | 24 | 17 |
| 7-16 | 0,63 | 0,75 | 0,77 | 0,77 | 0,86 | 0,83 | 0,76 | 0,00 | 29 | 19 |
| 9-16 | 0,51 | 0,54 | 0,54 | 0,46 | 0,71 | 0,67 | 0,58 | 0,00 | 22 | 16 |
| 1-17 | 0,28 | 0,21 | 0,26 | 0,25 | 0,13 | 0,2 | 0,18 | 0,00 | 20 | 12 |

*Continued on next page*

Table B.8 – *Continued from previous page*

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***BDS*** | ***CBT*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 6-17 | 0,14 | 0,13 | 0,14 | 0,34 | 0 | -0,21 | 0,11 | 0,00 | 18 | 7 |
| 7-17 | 0,05 | 0,2 | 0,04 | 0,03 | 0,27 | 0,29 | 0,15 | 0,00 | 20 | 13 |
| 11-17 | 0,24 | 0,1 | 0,41 | 0,56 | -0,12 | 0,22 | 0,25 | 0,00 | 17 | 7 |
| 13-17 | 0,28 | -0,16 | 0,55 | 0,14 | 0,33 | 0,51 | 0,3 | 0,00 | 22 | 10 |
| 1-19 | -0,03 | 0,12 | 0,31 | 0,27 | 0,02 | 0,2 | 0,13 | 0,00 | 29 | 12 |
| 6-19 | 0,24 | -0,09 | 0,26 | 0,19 | 0,35 | 0,08 | 0,18 | 0,00 | 23 | 18 |
| 7-19 | 0,06 | 0,65 | 0,79 | 0,51 | 0,61 | 0,52 | 0,51 | 0,00 | 19 | 15 |
| 11-19 | -0,06 | 0,32 | 0,27 | 0,2 | 0,21 | -0,01 | 0,12 | 0,00 | 20 | 16 |
| 13-19 | 0,2 | 0,11 | -0,08 | -0,05 | 0,04 | 0,1 | 0,07 | 0,00 | 17 | 9 |
| 14-19 | -0,32 | 0,28 | 0,32 | 0,21 | 0 | -0,13 | 0,1 | 0,00 | 17 | 13 |
| 3-27 | 0,33 | 0,17 | 0,05 | 0,61 | 0,48 | 0,52 | 0,4 | 0,00 | 26 | 15 |
| 4-27 | 0,28 | -0,03 | -0,06 | -0,22 | -0,17 | -0,01 | -0,01 | 0,00 | 20 | 10 |

Table B.9: Numerical Condition Achievement Scores and Completion Time (Experiment-4)

B1, B2, B3, B4, B5, B6=Achievements for Block1, Block2, Block3, Block4, Block5, Block6. Ach=Overall Achievement. Time=Completion duration in mins. BDS=BDS score. CBT=CBT score.

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***BDS*** | ***CBT*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 3-7 | 0,09 | 0 | 0,18 | -0,32 | 0,4 | 0,3 | 0,12 | 0,00 | 22 | 15 |
| 5-7 | 0,06 | 0,02 | -0,07 | 0,2 | 0,37 | 0,39 | 0,13 | 0,00 | 22 | 12 |
| 9-7 | -0,18 | 0,11 | -0,09 | -0,03 | 0,09 | 0,1 | -0,03 | 0,00 | 18 | 16 |
| 3-8 | - | - | - | - | - | - | 0,23 | 0,00 | 19 | 12 |
| 4-10 | 0,27 | 0 | 0,29 | 0,3 | 0,39 | 0,38 | 0,31 | 0,00 | 22 | 11 |
| 5-10 | 0,75 | 0,76 | 0,74 | 0,9 | 0,81 | 0,82 | 0,79 | 0,00 | 24 | 11 |
| 4-11 | 0,09 | -0,06 | 0,04 | 0,18 | -0,2 | -0,18 | 0 | 0,00 | 24 | 12 |
| 5-11 | -0,11 | -0,05 | -0,1 | 0,11 | 0,44 | 0,44 | 0,04 | 0,00 | 20 | 17 |

*Continued on next page*

Table B.9 – *Continued from previous page*

| ***Ref.*** | ***B1*** | ***B2*** | ***B3*** | ***B4*** | ***B5*** | ***B6*** | ***Time*** | ***Ach.*** | ***BDS*** | ***CBT*** |
|---|---|---|---|---|---|---|---|---|---|---|
| 9-11 | 0,12 | 0,04 | -0,15 | -0,11 | 0,06 | 0,03 | 0,03 | 0,00 | 16 | 12 |
| 10-11 | 0,1 | -0,14 | 0 | 0,03 | -0,06 | -0,05 | -0,01 | 0,00 | 13 | 17 |
| 13-11 | - | - | - | - | - | - | -0,05 | 0,00 | 17 | 12 |
| 3-14 | 0,47 | 0,07 | 0,06 | 0,21 | 0,09 | 0,29 | 0,16 | 0,00 | 22 | 15 |
| 4-14 | -0,19 | 0,1 | 0,15 | 0,31 | 0,32 | 0,35 | 0,2 | 0,00 | 17 | 15 |
| 5-14 | 0,05 | 0,1 | 0,27 | 0,36 | 0,36 | 0,34 | 0,2 | 0,00 | 24 | 13 |
| 9-14 | -0,02 | 0,05 | -0,14 | 0,24 | -0,1 | -0,11 | 0,08 | 0,00 | 21 | 17 |
| 10-14 | - | - | - | - | - | - | 0,17 | 0,00 | 21 | 16 |
| 3-15 | 0,18 | 0,41 | 0,23 | 0,41 | 0,04 | 0,05 | 0,19 | 0,00 | 19 | 12 |
| 4-15 | 0,33 | 0,06 | 0,02 | 0,09 | 0,32 | 0,33 | 0,21 | 0,00 | 23 | 15 |
| 5-15 | 0,25 | 0,01 | -0,04 | -0,15 | 0,11 | 0,1 | 0,02 | 0,00 | 20 | 13 |
| 9-15 | 0,71 | 0,9 | 0,69 | 0,85 | 0,81 | 0,82 | 0,81 | 0,00 | 22 | 14 |
| 10-15 | 0,73 | 0,71 | 0,83 | 0,83 | 0,82 | 0,79 | 0,45 | 0,00 | 19 | 12 |
| 14-15 | 0,08 | 0,13 | 0,08 | 0,15 | 0,15 | 0,18 | 0,09 | 0,00 | 23 | 12 |
| 1-16 | - | - | - | - | - | - | 0,04 | 0,00 | 20 | 17 |
| 3-16 | - | - | - | - | - | - | -0,09 | 0,00 | 23 | 11 |
| 4-16 | 0,07 | 0,05 | 0,55 | 0,56 | 0,68 | 0,67 | 0,43 | 0,00 | 17 | 18 |
| 3-17 | 0,04 | -0,17 | 0,07 | 0,17 | -0,05 | -0,1 | 0 | 0,00 | 20 | 18 |
| 4-17 | -0,1 | 0,18 | -0,07 | -0,04 | 0,06 | -0,03 | 0,04 | 0,00 | 16 | 16 |
| 5-17 | -0,1 | -0,19 | 0,14 | 0,04 | 0,04 | 0,04 | -0,02 | 0,00 | 29 | 19 |
| 9-17 | -0,02 | -0,03 | -0,42 | -0,01 | 0,09 | 0,08 | -0,13 | 0,00 | 20 | 11 |
| 10-17 | 0,08 | -0,02 | -0,07 | 0,36 | 0,33 | 0,35 | 0,08 | 0,00 | 26 | 18 |
| 3-19 | 0,39 | 0,53 | 0,53 | 0,3 | 0,64 | 0,68 | 0,51 | 0,00 | 19 | 17 |
| 4-19 | -0,1 | 0,18 | -0,07 | -0,04 | 0,06 | -0,03 | 0,04 | 0,00 | 16 | 8 |
| 5-19 | 0,11 | 0,01 | 0,09 | 0,04 | 0,23 | 0,25 | 0,06 | 0,00 | 14 | 14 |
| 9-19 | 0,08 | -0,08 | -0,02 | -0,23 | -0,2 | -0,2 | -0,07 | 0,00 | 22 | 16 |
| 10-19 | 0,13 | 0,05 | 0,18 | -0,08 | -0,09 | -0,1 | 0,06 | 0,00 | 23 | 12 |

**TEZ FOTOKOPİ İZİN FORMU**

**ENSTİTÜ**

Fen Bilimleri Enstitüsü ☐

Sosyal Bilimler Enstitüsü ☐

Uygulamalı Matematik Enstitüsü ☐

Enformatik Enstitüsü ☒

Deniz Bilimleri Enstitüsü ☐

**YAZARIN**

Soyadı : BAYINDIR
Adı : MUSTAFA
Bölümü : BİLİŞSEL BİLİMLER

**TEZİN ADI** (İngilizce) : INDIVIDUAL DIFFERENCES IN PERFORMANCE ON PERCEPTUAL MULTIPLE CUE PROBABILITY LEARNING TASKS

**TEZİN TÜRÜ** : Yüksek Lisans ☐ Doktora ☒

1. Tezimin tamamı dünya çapında erişime açılsın ve kaynak gösterilmek şartıyla tezimin bir kısmı veya tamamının fotokopisi alınsın. ☒
2. Tezimin tamamı yalnızca Orta Doğu Teknik Üniversitesi kullanıcılarının erişimine açılsın. (Bu seçenekle tezinizin fotokopisi ya da elektronik kopyası Kütüphane aracılığı ile ODTÜ dışına dağıtılmayacaktır.) ☐
3. Tezim bir (1) yıl süreyle erişime kapalı olsun. (Bu seçenekle tezinizin fotokopisi ya da elektronik kopyası Kütüphane aracılığı ile ODTÜ dışına dağıtılmayacaktır.) ☐

Yazarın imzası ............................ Tarih 29.01.2013