THE RELATIONSHIP BETWEEN WORKING MEMORY, ENGLISH (L2) AND ACADEMIC ACHIEVEMENT OF 12-14 YEAR-OLD TURKISH STUDENTS: THE EFFECT OF AGE AND GENDER

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

BY

GAMZE ÇALIŞKANEL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF ARTS
IN
THE DEPARTMENT OF ENGLISH LANGUAGE TEACHING

JANUARY 2013

Approval of the Graduate School of Social Sciences

Prof. Dr. Meliha Altunışık
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Arts.

Prof. Dr. Gölge Seferoğlu
Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Arts.

Assoc. Prof. Dr. Gülay Cedden Edipoğlu
Supervisor

Examining Committee Members

Assoc. Prof. Dr. Gülay Cedden Edipoğlu (METU, FLE)

Assoc. Prof. Dr. Çiğdem Sağın Şimşek (METU, FLE)

Yrd. Doç. Dr. Korkut Uluç İşısağ (Gazi University, FLE)

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

Name, Last name: Gamze Çalışkanel

Signature:

ABSTRACT

THE RELATIONSHIP BETWEEN WORKING MEMORY, ENGLISH (L2) AND ACADEMIC ACHIEVEMENT IN 12-14 YEAR-OLD TURKISH STUDENTS: THE EFFECT OF AGE AND GENDER

Çalışkanel, Gamze
M.A., Department of English Language Teaching
Supervisor: Assoc. Prof. Dr. Gülay Cedden Edipoğlu

January, 2013, 97 pages

The aim of this thesis is to investigate the relationship between working memory, English as a second language and academic achievement of secondary school students between the ages of 12-14. The study also examines the effects of age and gender factors on working memory capacity and its relation with academic attainments. Data were collected from 12-14 year-old children (N=54) in two state secondary schools in Kırşehir, Turkey. Verbal working memory was assessed by a reading span (RS) test and a backward digit span (BDS) test. Academic achievement was determined by performance on basic secondary school courses which were English (foreign language), Turkish (mother tongue), Social Sciences, Mathematics and Science. The study examined the predictive role of working memory capacity on success on each course. The results revealed that verbal working memory tests significantly correlated with the tests of both general academic achievement (for RS: r=42, for BDS: r=43) and specific courses (.001≤ p <.01). The results also indicated that verbal working memory capacity had a far more predictive role on school success for females than males.

Keywords: Working Memory, Academic Achievement, Age, Gender, Reading Span

ÖZ

12-14 YAŞINDAKİ TÜRK ÖĞRENCİLERDE İŞLER BELLEK, İNGİLİZCE VE AKADEMİK BAŞARI ARASINDAKİ İLİŞKİ: YAŞIN VE CİNSİYETİN ETKİLERİ

Çalışkanel, Gamze
Yüksek Lisans, İngiliz Dili Öğretimi Bölümü
Tez Yöneticisi: Assoc. Prof. Dr. Gülay Cedden Edipoğlu

Ocak, 2013, 97 Sayfa

Bu çalışmanın amacı, 12-14 yaş aralığındaki ortaokul öğrencilerinin akademik başarıları ve İngilizce ile işler bellekleri arasındaki ilişkiyi araştırmaktır. Çalışma, ayrıca, yaş ve cinsiyet faktörlerinin işler bellek kapasitesi ve onun akademik başarı ile ilişkisi üzerinde etkilerini de inceler. Veriler Kırşehir, Türkiye'de iki devlet ortaokulundaki 12-14 yaşında çocuklardan (N=54) toplanmıştır. Sözel işler bellek, okuma aralığı testi ve geriye doğru rakam aralığı testi ile ölçülmüştür. Akademik başarı, İngilizce (yabancı dil), Türkçe (ana dil), sosyal bilimler, matematik ve fen bilimlerinden oluşan temel ortaokul derslerindeki performanslarına göre belirlenmiştir. Çalışma, işler bellek kapasitesinin, her bir dersteki başarı üzerindeki tahminsel rolünü incelemiştir. Sonuçlar, sözel işler bellek kapasitesinin hem genel akademik başarı (okuma aralığı testi için: $r=.42$, rakam aralığı testi için: $r=.43$) hem de belirli derslerin testleriyle ($.001 \leq p < .01$) önemli ölçüde korelasyon sağladığını ortaya çıkarmıştır. Ayrıca, sonuçlar göstermiştir ki sözel işler bellek kapasitesinin okul başarısı üzerindeki tahminsel rolü bayanlarda erkeklere kıyasla çok daha fazladır.

Anahtar Kelimeler: İşler Bellek, Akademik Başarı, Yaş, Cinsiyet, Okuma Aralığı

In memory of

my beloved Sister

&

To my family

for their infinite love and trust

ACKNOWLEDGMENTS

I wish to thank, first and foremost, my supervisor Gülay Cedden Edipoğlu who introduced me to "Brain functions, memory and learning relations" and whose enthusiasm for my research topic had motivational effect. I am sincerely and heartily grateful to her for the support and guidance she showed me throughout this effortful thesis writing process. This thesis would not have been possible without her help.

I share the credit of my work with my parents who generously tolerated the many absences of body and mind, and never failed to give me encouragement when it was needed. They have given me the opportunity of an education from the institutions I wished to study at and the support throughout my life. They have always stood by me and remained the source of my lasting motivation and success.

I am deeply indebted to my dear friends who supported me throughout this stressful and exhausting thesis writing process by placing reliance and belief on my research skills.

This thesis is dedicated to my beloved sister, with my great admiration to her even in her absence of body. She is the one whom I will all the time think of beside me, drawing my strength in every moment of my life from her eternal spirit and infinite love.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF ABBREVIATIONS

AAS	Academic Achievement Score
BDS	Backward Digit Span
BDST	Backward Digit Span Test
DS	Digit Span
DST	Digit Span Test
EYS	End-of-Year Score
RS	Reading Span
RST	Reading Span Test
L1	First Language
L2	Second Language
LTM	Long-Term Memory
PTS	Preparatory Test Score
SM	Sensory Memory
SPSS	Statistical Package for the Social Sciences
STM	Short-Term Memory
TEYS	Total End-of-Year Scores
TPTS	Total Preparatory Test Scores
WM	Working Memory
WMC	Working Memory Capacity

CHAPTER 1

INTRODUCTION

1.0. Presentation

This chapter presents the background of the study, its significance and the research questions to be answered.

1.1. Background of the study

Human cognition entails the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered, and used (Neisser, 1967). The concept that many of these cognition processes are intimately associated with is working memory (WM), therefore, it has been acknowledged as the cornerstone of cognitive psychology (Andrade, 2001) and a dynamic and evolving area of psychological research (Towse & Cowan, 2005).

Over the last 30 years, the concept of working memory has been increasingly widely used, extending from its origin in cognitive psychology to many areas of cognitive science and neuroscience, and been applied within areas ranging from education, to psychiatry (Baddeley, 2010).

Working memory was assumed to play a central role in a wide range of cognitive activities (Kane & Engle, 2002; Alloway et al., 2004) and in all forms of complex thinking (Just & Carpenter, 1992), such as reasoning, problem solving, and language comprehension. On account of the presumed role of working memory in many cognitive tasks, there has been considerable interest in the extent to which individual differences in working memory capacity may explain individual differences in other cognitive domains (Waters & Caplan, 2003), involving children's ability to acquire knowledge and new skills (Cowan & Alloway, 2008).

The explored functions of working memory and its acceptance as a bottleneck for learning (Alloway et al., 2006) form the basis of this study which proposes that working memory and academic attainments are to be related. This relation detected in childhood is significant not only for cognitive theory, but also for educational practice (Gathercole & Alloway, 2008).

There is growing concern for the relationship between working memory and academic attainment. However, as Baddeley et al. (2006) remark, assessing the contribution of working memory to the performance of complex tasks has only recently gained in popularity and requires further exploration.

1.2. Significance of the study

Given the theoretical properties attributed to WM, it is likely to be fundamental in understanding intellectual performance, not just in the experimental laboratory but also in everyday situations (Richardson, 1996). WM is also of crucial importance in explaining learning variations among individuals.

Although numerous studies have been conducted on the role of working memory in several domains of learning, this thesis lends a fresh perspective to the field with regard to following aspects:

- There are still contra-arguments on whether working memory capacity (WMC) is capable of predicting school achievement and to what extent WM can explain the individual differences in learning. Thus, this issue needs further investigation.

- Primary target population in most of the working memory studies is educated adults such as college students (Just & Carpenter, 1992). It remains unclear that

WM as a construct is fully understood outside L1 college-age and intellectual-level participants (Baddeley, 2000b). This research is going to contribute to the field in that the participants consist of 12-14 year-old children (N=54) from state secondary schools.

- Most of the studies in literature emphasize on just one or two components or skills of learning (Iuculano et al., 2011; Nevo & Breznitz, 2011; Zheng et al., 2011), whereas this study comprises both verbal and logical/mathematical abilities as the research components. In this research, academic achievement involves all the key subjects in Turkish secondary education system and a wide range of tasks are employed to assess the attainments in each of these subjects.

- To the best of my knowledge, although age differences have been dealt in studies, gender issue has been neglected. With this respect, the effect of gender differences on the relation between working memory and learning needs further investigation This study provides significant results to the research area of both cognitive psychology and education regarding the gender issue.

- Significance of WM in learning has been recognized and investigation of this relation has drawn attention among American, European, and Asian scientists in recent years, whereas few empirical evidence have been presented in Turkish literature and just one or two of them is in the field of education.

In that regard, the main purpose of this thesis is to investigate the extent to which verbal working memory capacity relates to secondary school students' achievements in key scholastic domains of curriculum such as language, mathematics, social sciences and science. This relation has, further, been investigated with regard to age and gender factors.

This research is significant in that it confirms the link between verbal working memory capacity and general achievement as well as several specific abilities in national curriculum. It reveals, further, significant results in regard to the effect of gender difference in relations of working memory and achievement scores.

1.3. Research Questions:

The aim of the current study is to answer the following research questions:

1. Is there a relationship between working memory capacity (WMC) and overall academic achievement of secondary school students? Do children with high levels of WMC success better levels on academic abilities?

2. Is there a relationship between working memory capacity and achievement in key subjects of curriculum which require verbal/ linguistic abilities?
   - WM & Turkish (L1)
   - WM & English (L2)
   - WM & Social Sciences

3. Is there a relationship between working memory capacity and achievement in key subjects of curriculum which require logical/ mathematical abilities?
   - WM & Science
   - WM & Mathematics

4. Is there a difference in working memory - achievement correlations between male and female learners?

   4.1. Does WMC differ in males and females?

5. Is there a difference in working memory - achievement correlations between age groups (12, 13, and 14 year olds)?

   5.1. Does WMC differ in three age groups (12, 13, and 14 year olds)?

CHAPTER 2

REVIEW of LITERATURE

2.0. Presentation

The first section sets about briefly introducing the subsystems of memory. In the second section, the landmarks in the development of working memory and emergence of working memory as a complex subsystem of memory are introduced. The chapter proceeds with clarification of the current understanding of working memory, an introduction to working memory models frequently referred in literature and the assessment techniques for working memory capacity. The following section argues the role of working memory on complex cognitive activities, learning, and specifically academic attainments such as L1, L2, Maths and Science. As no empirical study, which specifically investigated the role of WM in learning of social sciences, exists in literature, no title has been reserved for the issue. The chapter concludes with analyses regarding the effect of age and gender on the relationship between WMC and sub-skills in academic achievement.

2.1. Subsystems of Human Memory

Human memory is a modular system comprising functionally separate subsystems (Hitch, 1984). Research within this framework attempts to identify the various memory subsystems (see Figure 1) by specifying their properties and functions, and seeks also to characterize interrelationships among them.

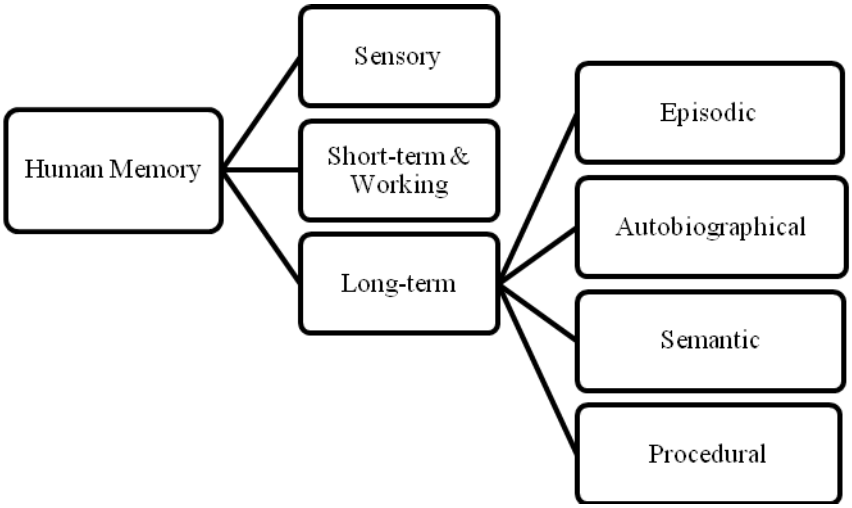

Figure 1. Subsystems of Human Memory
Source: Gathercole & Alloway, 2008

2.1.1. Sensory Memory

Humans have five main senses: sight, hearing, taste, smell, and touch. During every moment of a person's life, sensory information is being taken in by these sensory receptors and processed by the nervous system. Sensory memory (SM) allows individuals to retain impressions of sensory information after the original stimulus has ceased.

SM is considered to be outside of cognitive control and is instead an automatic response. The information represented in SM is the "raw data" which provides a snapshot of a person's overall sensory experience (Cowan & Winkler, 2005). The function of sensory memory is to store the information people received just long enough to be transferred to short-term memory (Carlson, 2009).

2.1.2. Short-Term and Working Memory

Short-term memory ("primary" or "active memory") is the capacity for holding a small amount of information in mind in an active, readily available state for a short period of time.

The duration of short-term memory (when rehearsal or active maintenance is prevented) is believed to be in the order of seconds. A commonly cited capacity is 7 ± 2 elements (Miller, 1956). Remembering an unknown telephone number is an example of short-term memory.

Working memory (WM) is a larger system of which short-term memory (STM) is a part. It refers to structures and processes used for temporarily storing and manipulating information. Activities that tax the central executive (in combination with at least one of the short-term memory stores) are described as working memory tasks. These are more complex activities that involve not only the storage of information, but also either its mental transformation or being engaged in some other effortful mental process.

Working memory is, further, presented as having a vital role in holding information in our short-term memory long enough to act on it and in both the storage and retrieval of information from our long-term memory (Kelly and Phillips, 2011). This is demonstrated in the input-output model (see Figure 2) of Kelly & Philips (2011).

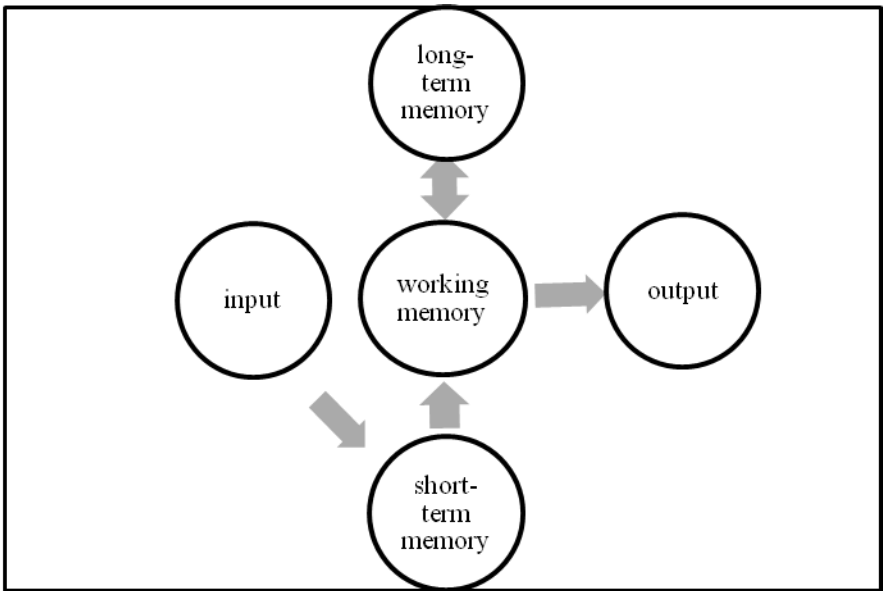

Figure 2. Input-Output Model of Memory
Source: Kelly and Phillips, 2011

The distinction between short-term and working memory will be examined in detail in the section 2.2.

2.1.3. Long-Term Memory

In contrast to short-term memory, long-term memory (LTM) indefinitely stores a seemingly unlimited amount of information. WM is used to keep information active for a few seconds, while long-term memory can keep it stored for years on end.

The term 'long-term memory' is reserved for memory of experiences that occurred at a point in time prior to the immediate past or near present, and also for knowledge that had been acquired over long periods of time (Gathercole & Alloway, 2008).

There are several kinds of long-term memory, and the characteristics of the four main kinds (episodic, autobiographical, semantic and procedural) are summarised in Table 1.

Table 1. Characteristics of different kinds of memories
Source: Gathercole & Alloway, 2008

Kind of memory	Duration	Type of information	Example
short-term	Seconds	verbal or non-verbal	remembering an unfamiliar phone number
working	Seconds	any kind	following lengthy directions of how to reach a location
episodic	hours to days	details of particular information	remembering what you had for breakfast this morning
autobiographical	lifetime	basic facts and conceptual knowledge	remembering your wedding day
semantic	lifetime, with regular exposure	knowledge, including personal facts	knowing that Paris is the capital of France
procedural	lifetime once skill is established	any kind of skill that can be used automatically	knowing how to drive a car

WM is employed when somebody is to remember the place of the car parked, whereas STM is employed when somebody is trying to keep a new phone number in mind until noting it on a piece of paper.

2.2. Early Development of Working Memory

In early studies in literature, memory was investigated under two basic categories: short-term and long-term memories. Evidence which came from patients with brain injury led the researchers to put a new subsystem, working memory, forward as a consequence of questions regarding the brain functions not being able to be answered through the existing concept of memory and its sub-division. The complex nature of brain resulted in emergence of several terms employed for the function of working memory. Researchers have not reached a consensus, so far, on several issues regarding working memory although the term ‘working memory’ has frequently been referred in recent literature.

2.2.1. WM as Contemplation

One of the earliest recorded references to a concept akin to working memory was in the writings of the seventeenth-century British philosopher John Locke (1690, as cited in Logie, 1996). Locke explicitly distinguished between a temporary workspace for the “idea in view” and a more permanent “storehouse of ideas”.

2.2.2. WM as Primary Memory

In his writings, William James (1905) coined the expression “primary memory” to refer to “the specious present”, as distinct from the storehouse of “secondary memory”. James (1918) distinguished between primary memory, i.e., our continued awareness of what has just happened or the ‘feeling of the specious present’, and secondary memory, i.e., ‘knowledge of a former state of mind after it has already once dropped from consciousness’.

Hebb (1949) suggested a neural mechanism for this binary memory system, primary memory being the result of temporarily reverberating electrical circuits in the brain and secondary memory reflecting permanent synaptic changes.

Waugh and Norman (1965) revived these terms in an influential paper by specifying the characteristics of primary memory in more detail. Primary memory was limited in its capacity and information could be maintained by verbal rehearsal. Rehearsal was also a mechanism for copying information from primary memory to secondary memory.

2.2.3. WM as Immediate Memory

Another term in early use, “immediate memory”, referred to memory in situations in which recall was requested soon after the stimulus sequence ended. One limitation of the term was that it implied that the memory faculty included only items just presented (Cowan, 2005). If information was recalled from secondary memory back into primary memory, that did not fall within the definition of immediate memory.

2.2.4. WM as Executive Control System

Miller, Galanter, and Pribram (1960) were accepted to be the first researchers who employed the term ‘working memory’, assigning it a central role in their analysis of organization and human actions which was acknowledged to be a milestone in the early development of cognitive psychology.

Miller and colleagues questioned the presence of a particular component of the human information-processing system that was implicated in the executive control and behaviour and also served as a form of short-term storage.

They interpreted WM as a distinct component of the human information-processing system from the long-term store, and even located its anatomical sustrate within the frontal lobes.

2.2.5. WM as Short-Term Memory

Atkinson and Shiffrin (1968) revised and considerably extended the ideas behind Waugh and Norman's primary memory. They referred to short-term memory as a combination of storage and control processes. They suggested a flexible system of limited capacity that could function for storage or processing, and the capacity limitation entailed a trade-off between the two functions. They proposed that information came in from the environment into a temporary short-term storage system which served as an antechamber to the more durable long-term memory. This temporary system also served as a working memory, a workspace necessary not only for long-term learning, but also for many other complex activities.

Anderson (1983) referred to working memory, as well, as "the temporary knowledge structures currently being attended and the active parts of long-term memory".

Evidence for this two-component model derived from studies of brain-damaged patients who had severe difficulty in learning new information but could recall information that they had learnt prior to their injury (Logie, 1996). Their short-term buffer also appeared to be unimpaired in that they could store sequences of digits and maintain the sequence by verbal rehearsal. As soon as rehearsal was prevented, the sequence was forgotten.

2.2.6. WM as Multiple Components

The view put forward by Atkinson and Shiffrin (1968) that working memory acted as a "gateway" between sensory input and long-term memory was challenged by data from patients with impairments of short-term storage, but with normal long-term memory function.

Shallice and Warrington (1970) reported patients who could learn new information despite having a severe impairment in short-term memory. If the short-term memory system functioned as a working memory, then such patients ought to have had problems not only in long-term memory, but also in a wide range of complex cognitive tasks (Baddeley, 2003). Such cases provided evidence for the several working memory subsystems, not all of which were damaged in such patients.

Baddeley & Hitch (1974) argued that Atkinson & Shiffrin's (1968) short-term memory focused too much on the storage functions and not enough on the processing functions. Thus, they preferred the name 'working memory' and argued for the importance of both storage and processing in a functional analysis of their working memory system.

Figure 3 illustrates the multi-component working memory model, developed by Baddeley and Hitch in 1974.

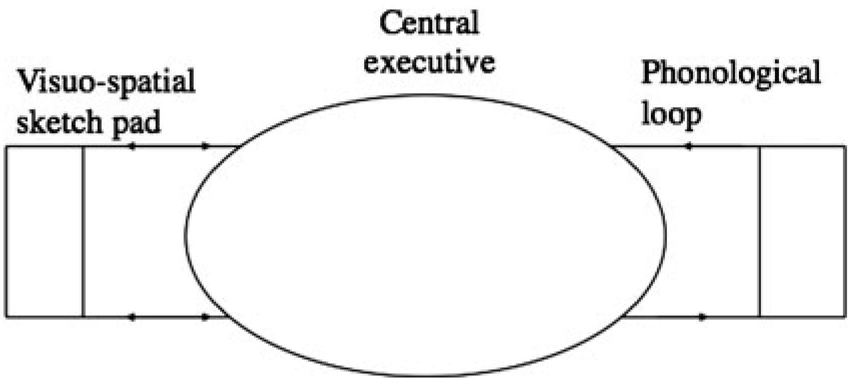

Figure 3. The original Baddeley & Hitch (1974) Working Memory Model

Source: Baddeley & Hitch, 1974

Baddeley & Hitch (1974) claimed that most cognitive tasks required the use of a working memory system that not only stored small amounts of information for brief periods of time, as the older short-term memory system had been thought to do, but also simultaneously processed information.

2.3. Current Concept of Working Memory

While short-term memory traditionally was conceived of as a passive storage buffer, the term working memory developed as a way to refer to a more active part of the human processing system (Newell, 1973). Miyake & Shah (1999) referred to working memory as a mental workspace that was involved in controlling, regulating, and actively maintaining relevant information to accomplish complex cognitive tasks.

Working memory represented the immediate memory processes involved in simultaneous storage and processing of information in real-time (Harrington & Sawyer, 1992). It was characterized as a “computational arena” wherein partial products of comprehension were stored for brief periods while incoming information was decoded and integrated into the ongoing text interpretation (Just & Carpenter, 1989).

Baddeley (1986) defined WM as a brain system that provided temporary storage and manipulation of the information necessary for complex cognitive tasks as language comprehension, learning and reasoning. Examples of everyday activities that employ WM (Gathercole & Alloway, 2008):

- Mental arithmetic: to multiply the numbers 43 and 56 without using a calculator or a pen and paper.

- Following directions: ‘When you pass the park on the left, take the first turn to the right and then take the second left.’

- Remembering to measure and combine the correct amounts of ingredients (‘rub in 50g of margarine and 100g of flour, then add 75g of sugar’), when the recipe is no longer in view on TV.

- Hearing an unfamiliar word in a foreign language and attempting to repeat it several seconds later.

2.3.1. Information Loss from WM

The information in WM can be lost within a few seconds either because attention is distracted or it is displaced by other information (Gathercole & Alloway, 2008). Once information has been lost from WM, it cannot be recovered.

- **Distraction.** Some distractors may lead to the loss of contents of WM such as an unrelated thought springing to mind, an interruption by someone else, a telephone ringing or a child crying.

- **Processing a simultaneous activity.** Activities that require attention to be switched to another effortful activity may cause the loss of information. These attention-demanding processes may be a part of the ongoing activity as in the case of using the stored mathematical knowledge when engaged in mental arithmetic.

2.4. Models of Working Memory

The model of working memory evolved considerably over time, gradually becoming more and more specific and elaborated (Towse & Cowan, 2005). Several ideas about working memory developed in the absence of formally specified model. Nonetheless, Baddeley and Hitch (1974) laid important foundations for subsequent research. Their work welded together a number of important concepts connected with immediate memory. One of these was the realization that immediate memory is fragile and limited to a small number of independent items (Miller, 1956). This model's capability to account for a wide range of data with a few, albeit broad concepts led to widespread use in several fields of cognitive psychology.

2.4.1. Baddeley's Multi-component Working Memory Model

The model defined working memory as a domain-general component responsible for the control of attention and processing that was involved in a range of regulatory functions, including the retrieval of information from long-term memory (Baddeley, 2000a).

The model included two domain-specific stores responsible for the temporary storage of verbal and visuo-spatial information and was supported in studies of children (Alloway et al., 2006; Alloway et al., 2004; Bayliss et al., 2003), adults (Kane et al. 2004), neuroimaging research (Jonides et al., 2005; Vallar & Papagno, 2003) and neuropsychological patients (Baddeley, 1996).

The model originally consisted of three components (Baddeley & Hitch, 1974): A superordinate controlling system, the so-called central executive, and two subsidiary slave systems, the phonological loop and the visuo-spatial sketchpad. The concept was extended with the presentation of a fourth component, the episodic buffer (Baddeley, 2000).

2.4.1.1. The Phonological Loop

The phonological loop was the verbal storage system which was composed of a short-term phonological store subject to rapid decay plus subvocal rehearsal process that could be used to restore decaying representations within the store (Baddeley, 1986).

The loop was assumed to have developed on the basis of processes initially evolved for speech perception (the phonological store) and production (the articulatory rehearsal component) (Baddeley, 2000a). The function of the articulatory rehearsal process was to retrieve and re-articulate the contents held in this phonological store and in this way to refresh the memory trace. Further, while speech input entered the phonological store automatically, information from other modalities entered the phonological store only through recoding into phonological form, a process performed by articulatory rehearsal. As the articulation operated in real time, the capacity of the phonological store was limited by the number of items that could be articulated in the time available before their memory trace faded away (Baddeley & Repovs, 2006).

The capacity of phonological loop was typically assessed by serial recall tasks involving digits or words. The phonological loop had been suggested to play a key role in vocabulary acquisition, particularly in the early childhood years (Baddeley et al., 1998).

2.4.1.2. The Visuospatial Sketchpad

While the phonological loop was specialized to hold verbal information, the visuospatial sketchpad was assumed to be capable of maintaining and manipulating visual and spatial information, a process that was crucial for performing a range of cognitive tasks (Baddeley & Repovs, 2006). This subsystem of working memory served the function of integrating spatial, visual, and possibly kinaesthetic information into a unified representation (Baddeley, 2003).

The empirical evidence suggested that visuospatial working memory could be further divided into visual and spatial subcomponents, each with separate and independent passive storage, representations, mechanisms of maintenance, and manipulation. While visual working memory was closely related to perception and visual imagery, spatial working memory showed closer connection to attention and action (Baddeley Repovs, 2006).

2.4.1.3. The Central Executive

Baddeley and Repovs (2006) put forward that in the realm of working memory tasks, executive processes seemed to be involved whenever information within the stores needed to be manipulated.

In complex cognitive abilities, the central executive seemed to be mostly involved as a source of attentional control, enabling the focusing of attention, the division of attention between concurrent tasks and as one component of attentional switching.

Baddeley (1996) assumed four main functions of the central executive:

1. The coordination of simultaneous tasks and task switching.

2. The control of encoding and retrieval strategies of temporarily stored information (also when retrieved from the long-term store).

3. The selection of attention and inhibitory processes.

4. The retrieval and manipulation of long-term stored information.

In many of these functions central executive was supported by other components of working memory. It was supplemented by two slave systems specialised for temporary storage and manipulation of material in specific domains. The phonological loop seemed to provide one form of convenient storage of execution programs, while the visuospatial sketchpad seemed to be involved in guiding visual and spatial attention (Baddeley & Repovs, 2006).

The argument for the central executive was less contentious (Logie, 1996) than those for the other components. The alternative models of WM, such as those put forward by Just and Carpenter (1992), and by Cowan (1993), appeared to refer to a WM consisting of a central executive that operated upon the activation of long-term traces.

There was considerable amount of data on the development of the phonological loop and a growing number of findings on the development of visuospatial sketchpad. However, less effort has gone into exploration of the central executive (Zoelch et al., 2005). Although its role in WM is currently being specified in more detail, little is as yet known about the development of central executive processes.

2.4.1.4. The Episodic Buffer

The episodic buffer was fractionated from the central executive in the revision of the model by Baddeley (2000a). The revised model differed from the old principally in focussing attention on the processes of integrating information, rather than on the isolation of the subsystems. Episodic buffer was capable of binding together information from a number of different sources into chunks or episodes, hence the term ‘‘episodic’’; it was a buffer in the sense of providing a way of combining information from different modalities into a single multi-faceted code (Baddeley, 2003).

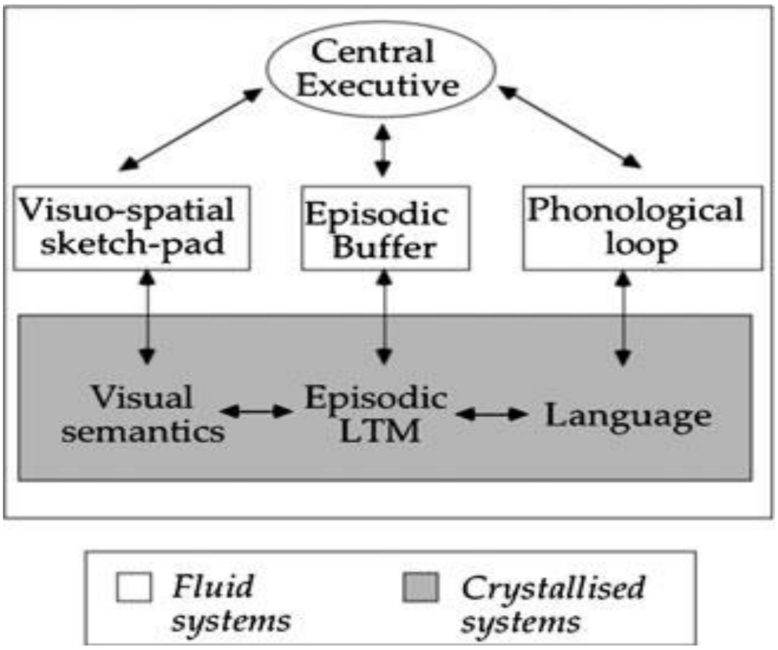

Figure 4. The model following the introduction of a fourth component, the episodic buffer, a system for integrating information from a range of sources into a multi-dimensional code.
Source: Baddeley, 2000a

The episodic buffer (see Figure 4) was assumed to be capable of storing information in a multi-dimensional code. It thus provided a temporary interface between the slave systems (the phonological loop and the visuospatial sketchpad) and LTM. It was assumed to be controlled by the central executive, which was responsible for binding information from a number of sources into coherent episodes. Such episodes were assumed to be retrievable consciously.

The buffer served as a modelling space that was separate from LTM, but which formed an important stage in long-term episodic learning. Shaded areas represent 'crystallized' cognitive systems capable of accumulating long-term knowledge, and unshaded areas represent 'fluid' capacities (such as attention and temporary storage), themselves unchanged by learning (Baddeley, 2000a).

In the revised model the episodic buffer provided direct inputs into episodic long-term memory, raising the possibility that that component of working memory too might provide an important gateway for learning (Alloway et al, 2004).

2.4.2. The Gateway Hypothesis versus the Workspace Hypothesis

There was a general assumption that information could enter one or more subcomponents of working memory either from sensory input or from long-term memory. WM was also assumed to play an important role in transferring information from sensory input to long-term memory (Baddeley et al., 1984).

The hypothesis accounted for normal long-term learning in patients with verbal short-term memory deficits by arguing that only the phonological loop was impaired, thus permitting the central executive and the visuospatial sketchpad to affect long-term learning. This assumption was supported by a large body of data (Baddeley, 1986; Logie, 1995).

An alternative view that questioned the status of WM as a gateway between sensory input and long-term memory was put forward by Logie (1996). He questioned whether WM could store and process information without prior access to stored knowledge. He proposed that WM operated not as a gateway but as a 'workspace'.

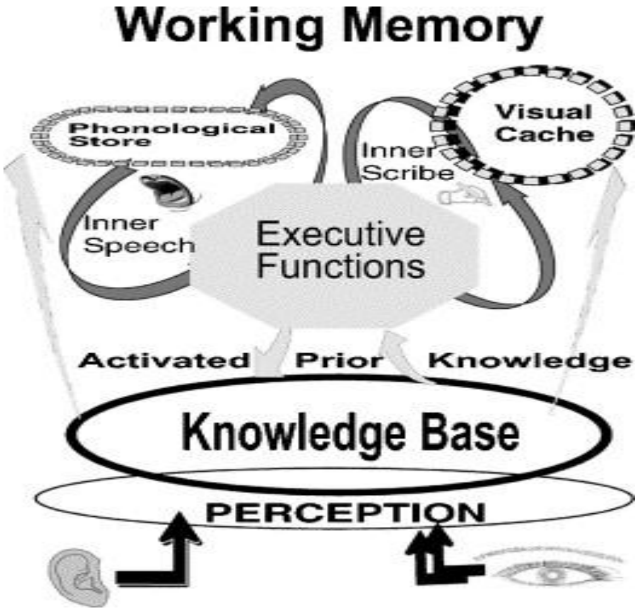

Figure 5. Working memory as a multiple component cognitive system with contents derived from activated prior knowledge.
Source: Logie, 2003

In Figure 5, the slave systems of WM are not input buffers, rather, function as ‘working buffers’. That is, information that has been recently presented to the senses may activate traces in long-term memory, which then become available to components of working memory. For example, when a word is read, this activates the phonological information about the word, and this activated information becomes available to the phonological store.

Further evidence has come from the research of Shallice and Warrington (1969) with a brain-damaged patient whose verbal learning and long-term retention appeared normal, but verbal short-term memory was reduced. They concluded that the systems responsible for short-term and long-term storage must be functionally independent.

2.4.3. Cowan’s Embedded Process Model

Cowan’s model (1999) had three levels: 1. Long-term representations, 2. Activated LTM representations, 3. The focus of attention. Cowan outlined a group of mechanisms that were subsets or super sets of each other. They therefore formed embedded processes (as illustrated in Figure 6).

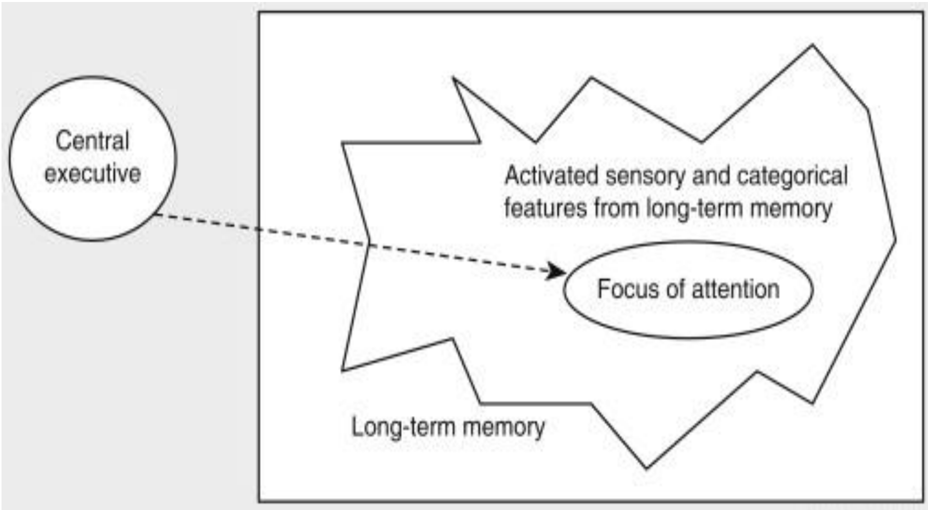

Figure 6. Cowan's model (2005), which treats working memory as the temporary activation of areas of long-term memory.
Source: Cowan, 2005

Cowan defined working memory as “cognitive processes that retain information in an unusually accessible state”. Activation occurred in long-term memory, was temporary, and faded unless maintained by verbal rehearsal or continued attention. Cowan (2005) emphasised the focus of attention, which he suggested had a limit of about four items or chunks.

Placing activation at the forefront of the model provided a contrast to Baddeley’s (2000a) model, wherein the core issues revolved around the appropriate laying down, refreshing, and decay of domain-specific memory traces (Towse & Cowan, 2005).

However, the two models have not received the same degree of empirical scrutiny (Towse & Cowan, 2005). A far greater body of research has been built on Baddeley’s framework, investigating the structural characteristics of the system components.

2.5. Theories on Working Memory Capacity

The frequently argued capacity issues are Engle's general capacity theory (1996) and inhibition-resource hypothesis (Hasher and Zacks, 1988).

2.5.1. The General Capacity Theory (Engle, 1996)

Engle (1996) who referred to WMC as a unitary structure or resource, proposed a set of ideas to specify the mechanisms that mediate the relationship between measures of WMC and higher-level cognitive tasks. The following assumptions were made:

1. The contents of WM consist of temporary or permanent knowledge units in long-term memory that are currently active above some threshold.

2. These knowledge units vary in their level of activation, and the total amount of activation in the system is limited.

3. Individuals differ in the total amount of activation available to their systems.

4. Spreading activation occurs quickly, automatically, and without conscious, controlled attention or intention.

5. Short-term memory is a subset of working memory, which is in turn a subset of long-term memory.

6. WM allows us to shift attention away from the current task, then back to the initial task, and to recover the relevant task information and the status of task variables at the time of the interruption.

2.5.2. The Inhibition-Resource Hypothesis of WMC

Many accounts of WM based upon the spread of activation also postulate the existence of inhibitory mechanisms between competing items (Richardson, 1996). These serve to prevent information that is irrelevant to the task at hand from gaining access to working memory.

Hasher and Zacks (1988) argued that inhibitory processes were crucial to the efficient operation of WM. These mechanisms served to restrict the contents of WM to information that was relevant to the task being carried out at the time. Engle (1996) suggested that the resources of the central executive were necessary to inhibit distracting information and information or thoughts that were irrelevant to the goals of the current task.

Hasher and Zacks (1988) argued that the reason that WMC apparently declines with age is a decline in the inhibitory mechanisms. As a result, in older subjects WM contains irrelevant information that would be inhibited or filtered out by younger subjects. Because WM is limited in terms of the amount of information that it can hold, there is less task-relevant information available when needed.

2.6. Assessment of Working Memory Capacity

Researchers have not reached a consensus, yet, on how to measure the limited working memory capacity (reading span task, digit span, non-word span) (Juffs, 2004). Tasks involving WM come in different shapes and guises (Towse & Cowan, 2005). Some of these incorporate elements of temporary retention of information, where the focus is very much on the number of independent memories that an individual can cope with. Other tasks focus more on the executive or control aspects of performance. Towse and Cowan (2005) suggest the incorporation of different measures into an assessment of performance because WM cannot be meaningfully rendered down to a single dimension.

Individual differences in the capacity of the central executive were commonly assessed using complex memory paradigms requiring simultaneous storage and processing of information. Within the group of verbal span measures, two subgroups can be distinguished: Simple and complex span measures.

2.6.1. Simple verbal working memory measures

Simple verbal working memory tasks such as a forward digit span tap only the storage component of working memory (Van den Noort et al., 2006). Simple digit and word spans (measured without a background task) which measure phonological short-term memory showed no correlation with reading comprehension (Turner & Engle, 1989; Harrington & Sawyer, 1992) and L2 skills (Kormos & Safar, 2008).

This led to the question of why the complex spans, but not the simple spans, predicted reading comprehension. Turner & Engle's experiment (1989) resulted that the complex span was a more accurate measure of WMC because it prevented the use of memory strategies, such as grouping and rote rehearsal. Simple span tasks such as forward digit recall (Alloway et al., 2004; Pickering & Gathercole, 2001; Harrington & Sawyer, 1992; van den Noort et al., 2006), word recall (Alloway et al., 2004; Pickering & Gathercole, 2001; Harrington & Sawyer, 1992) and nonword repetition (Alloway et al., 2004; Gathercole & Baddeley, 1996; Kormos & Safar, 2008) were all used to measure the phonological loop of working memory whereas complex span tasks were supposed to measure a more complex system, including the central executive.

2.6.2. Complex verbal working memory measures

Working memory capacity is measured by complex span tasks that require simultaneous short-term storage of information while processing additional, and sometimes unrelated, information (Alloway & Pickering, 2006; Van den Noort et al., 2006). These tasks involve some effortful mental processing, which are supported by the central executive and at least one of the two short-term stores (verbal or visuo-spatial). Some widely used complex span measures:

- **Reading span task:** One of the most widely used complex span measures is the reading span task, originally developed by Daneman and Carpenter (1980). This task requires participants to read a series of sentences aloud and recall the final words.

  RST was used in studies on the relation of working memory span and language comprehension (Juffs,2004; Service et al., 2002; Turner & Engle, 1989; Harrington & Sawyer, 1992; Waters & Caplan, 2003; Waters et. al., 2004; van den Noort et al., 2006). RST scores correlated significantly with L1 reading (Turner & Engle, 1989; Daneman & Carpenter, 1980), L2 reading (Harrington & Sawyer, 1992) and overall L2 competence (Service et al., 2002; Kormos & Sáfár, 2008).

- **Backward digit span task:** In this task, participants hear sequences of spoken digits, and are asked to repeat them in backwards order (Gathercole et al., 2004). Testing commences with two-digit sequences, with the length of the sequences increasing by one digit up to six digits.

  It was used as a complex span task which measure working memory by many researchers (Alloway & Alloway, 2010; Alloway et al., 2004; Waters & Caplan, 2003; van den Noort et al., 2006; Kormos & Safar, 2008; Lamont et al., 2005). Both the central executive and verbal short-term memory were supposed to contribute to backward digit span performance (Gathercole & Alloway, 2008).

- **Listening span task:** Listening span task has been developed as the spoken form of reading span test (Alloway & Alloway, 2010).

- **Operation span task:** Turner and Engle (1989) developed the operation span task in which a series of arithmetic problems was presented, each followed by a word to be recalled later.

- **Counting recall task:** Case et al. (1982) developed the counting span task, in which a series of screens each has a number of dots that have to be counted, and the sums of all the screens then are to be recalled in order. Alloway et al. (2004) and Pickering & Gathercole (2001) used this task as a measure for central executive.

The backward digit span and the reading and listening span tasks were frequently regarded as instruments testing more than just phonological short-term memory. They were claimed to assess the capacity of complex verbal working memory including the functioning of the central executive, which was responsible for regulating attention (Gathercole, 1999; Kormos & Sáfár, 2008).

2.6.3. Backward versus Forward Digit Recall

Forward digit recall was employed as a measure of verbal short-term memory and backward digit recall as a measure of verbal working memory (Alloway & Alloway, 2010). This decision was based on findings (Lamont et al., 2005) that in forward digit recall, the processing load is minimal given that the child immediately recalls number sequences. In contrast, in the backward digit recall task, there is an added requirement to recall the digits in reverse sequence that imposes a substantial processing load on the child, as illustrated by the finding that forward digit spans are higher than backward digit spans (Isaacs & Vargha Khadem, 1989). On average, forward digit span for an adult is around seven items, and backward digit span is either four or five. Correspondingly, short-term memory skills such as forward digit recall are much more weakly associated with general academic and cognitive performance than working memory skills as measured by backward digit recall (e.g., Daneman & Merikle, 1996).

2.6.4. Task- Dependent versus Task- Independent WMC

There were two views on whether working memory span tests measured spare capacity in connection with a specific background (or secondary) task (e.g., reading or sentence verification) or a general capacity to focus attention in the presence of distraction (Service et al. 2002). The view that WMC measures were task-specific assumed that better developed expertise at the background task freed additional WMC for the storage component of the task. Service et al. (2002) concluded that sentence processing in a language that was not completely automated consumed extra working memory resources so that the reduction in overall capacity could be detected by working memory span tasks. If the first view was right, expertise at languages could be reflected in better working memory spans when participants were tested in better-mastered languages and shorter spans when they were tested in less familiar languages (Service at al. 2002). If the second view was right, skill in the processing task could not master as long as maintenance rehearsal was interrupted. There was also the possibility that both views were correct and working memory span in a complex span task reflected both expertise at the processing task and individual capacity differences (Service et al. 2002).

2.6.4.1. A measure of a general WMC rather than just reading: RST

On one hand, a task-dependent view suggested that if the span measure was to predict individual variation in reading comprehension, the background task must have included reading (Turner & Engle, 1989) as in Daneman & Carpenter's study (1980). Daneman & Carpenter's claim was that good readers used less processing capacity in comprehending the sentences and they were able to produce more sentence final words than poor readers in their reading span test. Just & Carpenter (1992) also supported the view that the comprehension processes used in reading the sentences in reading span test might consume less of the working memory resources of high span readers who would thus have more capacity left to hold the final words of the sentences.

On the other hand, Turner & Engle (1989) evaluated the findings of Daneman & Carpenter (1980) from a task-independent view, as well. They put forward that good readers could remember more words against the background of processing sentences in the RST because they had larger capacities than poor readers, not because good readers had more efficient reading skills than poor readers. A greater working memory capacity would have been independent of the type of background task used while measuring span. That was, a good reader may have had more working memory capacity available for processing and storage than a poor reader whether performing a reading or a non-reading task. The results of their study showed that the sentence word, sentence digit, operations word and operation digit spans all predicted reading comprehension. Thus, a complex span reflecting WMC did not need to be "reading" related to generate a significant correlation with reading comprehension. The complex memory span index could be embedded in any task that required heavy processing beyond the span task and still reflected individual differences in WMC that were important in higher level functioning.

2.6.5. Measuring Working Memory Capacity of Children

Alloway et al. (2004) presented that working memory could be tested reliably from as young as 4 years of age. Because the working memory tasks such as backward digit recall and the reading span task are very simple, they can be easily understood even by young children (Gathercole & Alloway, 2008).

Alloway (2007a) developed a computer-based program for nonspecialist assessors such as classroom teachers to identify and support children with working memory impairments. It consisted of 3 tests each of: 1) verbal short term memory, 2) visuo-spatial short term memory, 3) verbal working memory, 4) visuo-spatial working memory (Gathercole & Alloway, 2008).

2.7. The Role of WM in Complex Cognition

Many scholars defined working memory as temporary maintenance of task-relevant information in the service of complex cognition (Miyake & Shah, 1999). Complex cognitive tasks were characterized as being under cognitive control, involving multiple steps of processing, involving multiple components of the memory system, and requiring fast access to large amounts of information.

Individual differences in WMC are important to cognition in a large sample of real-life situations, at least in those involving the acquisition of new information (Engle, 1996). Working memory was linked to a range of cognitive activities from reasoning tasks to verbal comprehension (Kane & Engle, 2002; Alloway et al., 2004). It was assumed to play a central role in all forms of complex thinking, such as reasoning, problem solving, language comprehension (Just & Carpenter, 1992; Gathercole & Baddeley, 1993) and mental arithmetic (Seitz & Schumann-Hengsteler, 2002).

Alloway et al. (2004) conducted a study with children aged 4 to 6 years and identified a complex structural organisation to working memory and related cognitive abilities in children. One cognitive skill that is closely associated with both short-term memory and children's abilities to acquire language skills including literacy is phonological awareness—the ability to encode, access, and manipulate the sound units of language. A further cognitive skill that is linked with children's capacities to acquire knowledge and skills is nonverbal ability, measures of which are widely interpreted as reflecting general fluid intelligence and are good predictors of indices of learning ability.

2.8. The Role of WMC in Learning

Individual differences in working memory capacity had significant consequences for children's ability to acquire knowledge and new skills (Cowan & Alloway, 2008). Language learning as well as literacy and arithmetic skills required that children maintained information in working memory while engaging in various cognitive activities (Kormos & Sáfár, 2008).

Working memory scores predicted reading achievement (Swanson et al., 2004; De Jong 1998; Swanson, 1994), maths achievement (Swanson et al., 2004; Swanson et al., 2001; Bull & Scerif, 2001) and language comprehension (Nation et al., 1999; Seigneuric et al., 2000). Alloway et al. (2009) reported that children with poor working memory capacity were more likely to perform poorly in key learning outcomes such as reading and maths and to be inattentive, forgetful and easily distracted, leading to careless mistakes, especially in writing and solving problems. Differences in working memory capacity had also strong link to learning in developmental disorders such as reading disabilities (Alloway et al., 2006), language impairments (Alloway & Archibald, 2008), and motor difficulties (Alloway, 2007b). Measures of working memory at school entry (at 4 or 5 years, in the UK) provided predictors of children's success in national assessments of scholastic abilities up to 3 years later (Brown et al., 2003). Alloway & Alloway's study (2010) that investigated 5-year-old children's working memory skills, comparing the results with their performance in literacy and numeracy 6 years later provided evidence that working memory at the start of the formal education was a more powerful predictor of academic success than IQ.

2.8.1. Capacity Constrained Comprehension Theory

Just & Carpenter (1992) explained the performance differences among individuals within a task domain with a capacity theory in which capacity limitations were presumed to affect performance only when the resource demands of the task exceeded the available supply. Their "capacity constrained comprehension theory" presumed that both storage and processing were fueled by the same commodity: activation. In that framework, capacity was expressed as the maximum amount of activation available in working memory to support either of the two functions. When the task demands exceeded the available sources, both storage and computational functions were degraded.

It was assumed that working memory capacity constrained comprehension, and it constrained comprehension more for some people than for others (Just & Carpenter, 2004). They described capacity as though it were an energy source that some people had more of than other people had. One suggestion of Alloway (2006) on the reason why WMC constrain learning is that working memory provides a resource for the individual to integrate knowledge from long-term memory with information in temporary storage. Children with weak working memory capacities are therefore limited in their ability to perform this operation in important classroom-based activities.

2.8.2. WM as a Bottleneck for Learning

Alloway et al. (2006) suggested that working memory acted like a “bottleneck for learning” in many of the individual learning episodes required to increment the acquisition of knowledge. Because low working memory children often fail to meet working memory demands of individual learning episodes, the incremental process of acquiring skill and knowledge over the school years is disrupted.

2.8.3. Which WM component is related to learning?

While in the Engle et al. (1999) model only the controlled attentional aspect of working memory capacity is predictive of learning, in the Baddeley and Hitch (1974) model links have been established between both the central executive and the specialized storage systems and academic attainment (e.g., Pickering & Gathercole, 2004).

2.9. Working Memory versus Intelligence

As intelligence has a long-standing tradition as a predictor of school achievement, some researchers have suggested that the key factor underlying the relationship between WM and school achievement might be intelligence (Alloway et al., 2004; Alloway et al., 2006). There are only a few empirical studies that reported a joint assessment of intelligence and WM (Alloway, 2009; Krumm et al., 2008). Some studies indicate that many children with poor working memory have low IQ and vice versa.

Tillman et al. (2007) investigated, in children aged 6–13 years, how different components of the working memory (WM) system (short-term storage and executive processes), within both verbal and visuospatial domains, relate to fluid intelligence. Results demonstrated that all four WM components (verbal- and visuospatial short-term storage and verbal- and visuospatial executive processes) provided significant, independent contributions to intelligence, indicating that, in children, both storage and executive processes of the WM system are relevant to intelligence. This idea was supported by Colom et al. (2007) who tested several cognitive abilities of secondary school students so as to understand which psychological construct significantly predicts academic performance. The results revealed that all basic cognitive abilities (defined by fluid intelligence, short-term memory, and working memory) predicted academic performance to a high degree.

However, there is growing consensus that WM cannot simply be equated with intelligence, despite substantial correlations between the two (Lu et al., 2011). Furthermore, numerous studies have reported much lower associations between WM and intelligence (Engle, Tuholski, Laughlin, & Conway, 1999). Conway, Kane, and Engle (2003) confirmed that WM accounted for at least one third of the variance in general intelligence, which means despite being highly associated, general intelligence and WM are not identical.

An important difference between WM and IQ was put forward by Gathercole and Alloway (2008). Intelligence tests draw on previous experiences, knowledge or skills, whereas the information to be stores and manipulated in WM tests is designed to be equally unfamiliar to all individuals. In WM tests, participants will succeed in the early parts of the test that involve low memory loads, and then start to fail as the task progresses because the memory load exceeds their working memory, and not because they have not learned something previously. The study of Alloway and

Alloway (2010) supported this idea in that children's working memory skills at 5 years of age predicted well literacy and numeracy 6 years later, even better than IQ which accounted for a smaller portion of unique variance to these learning outcomes. That is to say, working memory at the start of formal education is a more powerful predictor of subsequent academic success than IQ.

2.10. The Role of WMC in Academic Achievement

The prediction of academic performance has been an important research topic in psychological science for almost one century (Colom et al., 2007)**.** Intelligence and personality have shown significant associations with academic performance in several studies. Recently, there has been strong empirical evidence that WM is substantially related to learning abilities and school achievement (Lamont et al., 2005; Brown et al., 2003; Gathercole & Pickering, 2000; Gathercole, Pickering, Knight, & Stegmann, 2004) and academic performance (Daneman & Carpenter, 1980).

Monette et al. (2011) examined the role of executive functions (inhibition, flexibility, and working memory) in early school achievement of children, attending kindergarten. The results indicated that only working memory contributed uniquely to the variance in school achievement after all covariates (pre-academic abilities, affective variables, and family variables) were controlled. In a similar study, Brown et al., (2003) found out that measures of working memory at school entry (at 4 or 5 years) provided excellent predictors of children's success in national assessments of scholastic abilities up to 3 years later.

Gathercole and Alloway (2008) proposed that WM overload is the cause of slow academic progress across the full range of school years. The relationship between WM and academic achievement extends across life span and is present to as strong as a degree in college students as in young children just starting school (Gathercole & Alloway, 2008). This proposal was supported by the studies which reported that children with low working memory capacity were having more difficulties in academic performance (Aronen et al., 2005) and specifically in reading comprehension (Carretti et al., 2004) at school than children with good WMC.

Gathercole, Pickering, Knight, and Stegmann (2004) assert that the contribution of working memory to levels of scholastic attainment during the school years varies considerably according to curriculum area. They base this claim on the result that strong links with English assessments and working memory scores were present at 7 but not 14 years. The very high associations between scores on the mathematics and science assessments at both ages raises the possibility that it is skills or processes common to both domains, such as number processing and problem solving, that benefit from central executive support.

2.10.1. WMC and Verbal-Linguistic Abilities

The variables along which language learners differed were generally sub-divided into affective, cognitive and personality-related individual differences (Gardner, 1985). The cognitive factors that were held to be important predictors of success in language learning were intelligence, foreign language aptitude and working memory capacity (Kormos & Sáfár, 2008). Baddeley (2003) supported this idea by suggesting that working memory should have had implications for language processing assuming that it was a temporary storage system that underpinned our capacity for thinking. In addition to its role in storage, working memory was viewed as the pool of operational resources that performed the symbolic computations and thereby generated the immediate and final products (Just & Carpenter, 1992). Language comprehension was shown by Just & Carpenter (1992) as the excellent example of a task that demanded extensive storage of partial and final products in the service of complex information processing.

For that reason, complex working memory span measures were supposed to be effective predictors of performance in many complex cognitive activities including language comprehension (Just, & Carpenter, 1992), and reading (De Jong, 1998; Swanson, 1994)

Which WM component? Just & Carpenter (1992) suggested that working memory for language referred to a set of processes and resources that performed language comprehension, and the part of working memory that dealt with language comprehension corresponded approximately to the central executive in Baddeley's theory. Executive processes were identified as one of the principal factors determining individual differences in working memory span (Daneman & Carpenter, 1980) and proved to be a robust predictor of a wide range of complex cognitive skills including language comprehension (Baddeley, 2003).

Nevo and Breznitz (2011) observed the highest correlations of children's reading abilities with the phonological complex memory subsystem. Studies both on children with specific language impairment (Gathercole & Baddeley, 1989) and on normal children (Gathercole, Willis, Emslie, & Baddeley, 1992) revealed that the phonological loop had a significant role on language acquisition. Some researchers claim that phonological short-term memory plays a more general role in second language acquisition than just supporting vocabulary acquisition. Ellis (1996) argues that language learning is mostly sequence learning, and even abstract grammatical knowledge is a product of the analysis of sequences. As short-term memory is responsible for remembering sequential information, its role in language learning is far greater than previously supposed.

Though the sketchpad clearly was less central relevance to language disorders than was the phonological loop, it seemed likely that the system would be involved in everyday reading tasks by maintaining a representation of the page and its layout (Baddeley, 2003).

2.10.1.1. WMC and L1

Lu et al. (2011) found that working memory was an excellent predictor of children's school achievement on Chinese (L1) beyond intelligence. Similarly, St. Clair-Thompson and Gathercole (2009) remarked that in school-age children, reading and writing skills have been linked to WM. Their study revealed that WM was more strongly associated with school achievement than was inhibition.

Working memory capacity also appeared to be a very good predictor of text integration abilities in the L1, that was the ability to maintain coherence within and between sentences in the text (Just & Carpenter, 1989), and reading abilities such as decoding, reading comprehension, and reading time (Nevo & Breznitz, 2011).

2.10.1.1.1. Single Resource Theory

Some researchers (e.g., Just & Carpenter, 1992) argued that there was a general verbal working memory system that supported span performance, language processing, and other verbally mediated cognitive functions. This theory predicted that verbal working memory span measures should have been related to all measures of language processing comprising both offline and online language processing. That contrasted with separate resource theory, which proposed that language tasks that tapped unconscious, obligatory, online processing were not predicted to be related to verbal working memory span measures.

2.10.1.1.2. Separate Resource Theory

Waters and Caplan (1996) argued for the “separate language interpretation resource theory”, which stated that there was a domain-specific verbal working memory system that supported online language comprehension. In that view, traditional span measures, such as digit span and the Daneman and Carpenter (1980) reading span task, were not associated with all measures of language processing. According to the separate resource theory (Waters & Caplan, 1999; Waters et al., 2004), verbal working memory span measures required controlled, conscious verbal processing and were therefore predicted to be related to global measures of language processing such as text comprehension and offline measures of comprehension such as plausibility judgments, but not online language processing..

According to that theory, there were at least two specialized resources: 1. used in processes such as constructing syntactic representations and assigning thematic roles; 2. used in controlled verbally mediated tasks such as reading span task.

However, Van den Noort et al. (2006) found no significant correlations between the different simple and complex working memory spans, which was in line with the separate resource theory of Waters and Caplan (1999).

2.10.1.2. WMC and L2

One of the basic questions in second language acquisition research was what accounted for students' differential success in language learning. The individual factors that influenced language learning have been widely researched in the past 30 years (Kormos & Sáfár, 2008). WM has become a variable of intense interest among L2 researchers (Juffs, 2004). In the past ten years a number of studies have been conducted on how verbal working memory capacity influences language learning (Kormos & Sáfár, 2008), and some researchers suggested a central role for working memory capacity in accounting for individual differences in language comprehension skill (Just & Carpenter, 1989; Turner & Engle, 1989). For instance, Krumm et al. (2008) provided evidence that the verbal task of the WM component storage in the context of processing significantly accounted for individual differences in language courses.

Baddeley (2003) clarified that while a huge amount of language processing was relatively automatic, deficits within the phonological loop, and to a lesser extent, within other aspects of working memory, may seriously impair language processing.
Miyake and Friedman (1998) proposed that verbal working memory should have been equated with foreign language aptitude since it could capture the essence of the three important components of the language aptitude- a language analytic capacity, memory ability and phonetic coding ability. However, Kormos and Sáfár (2008) found it more reasonable to seek the explanation for differential success in language

learning in general cognitive abilities than to posit the existence of a construct specific to second language learning, i.e. foreign language aptitude.

Studies on the role of verbal working memory capacity in L2 learning concentrated and reported data on strong correlations between WM and various aspects of L2 learning from vocabulary learning (Kormos & Sáfár, 2008), reading skills (Harrington & Sawyer, 1992) and to overall language proficiency (Service et al., 2002). Service (1992) found out that children with good immediate verbal memory proved to be better at language learning than those with short spans, not only when measured by vocabulary, but also by acquisition of syntax. Similar results have been found for adult learners of a second language, in the case of both vocabulary and syntax (Atkins & Baddeley, 1998; Adams et al., 1999).

2.10.1.2.1. Working Memory Capacity Interaction Hypothesis

Van den Noort et al. (2006) found out that the functional working memory capacity was larger in the L1 compared to the L2 and was larger in L2 compared to L3. Differences in performance between L1 and the foreign languages were found on both simple and complex working memory tasks, supporting the working memory capacity interaction hypothesis which suggested that working memory capacity interacted with language proficiency (Service et al., 2002, Van den Noort et al., 2006). There was a measurable extra load on general working memory when a not fully automatized language had to be comprehended (Service et al.,2002) because understanding foreign language consumed more of a limited pool of working memory resources than understanding the native language did.

Contrary to this hypothesis, Harrington and Sawyer (1992) found no difference between working memory span in English as a second language and Japanese as a native language. The L1 advantage was not evident for the reading span test. Osaka & Osaka (1992) found, as well, that there was a correlation between L1 and L2 working memory.

Harrington and Sawyer (1992) suggested that development of L2 working memory capacity be studied across time. Such evidence would provide a profile of how L2 working memory capacity and L2 comprehension skill interact in the course of development.

2.10.2. WMC and Logical-Mathematical Abilities

As a construct fundamentally important to higher mental processes, WM involves the operations and nature of higher mental processes such as discrimination, attention and intelligence (Lu et al., 2011). Mathematical competence entails a variety of complex skills that encompass different conceptual content and procedures (e.g., arithmetic, algebra, and geometry); problem solving in these domains often involves the holding of partial information and the processing of new information to arrive at a solution, which ought to require working memory resources. Thus, the very nature of many mathematical tasks would seem to require or at least be supported by working memory (Raghubar et al., 2010). Gathercole, Pickering, Knight, & Stegmann (2004) found that intellectual operations required in Math and Science were constrained by the limited capacity of WM across the childhood years.

Which component? Zheng et al. (2011) conducted a research so as to determine the working memory components (executive, phonological loop, and visual–spatial sketchpad) that best predicted mathematical word problem-solving accuracy of elementary school children. Results supported the notion that all components of WM played a major role in predicting problem-solving accuracy. Iuculano et al. (2011) explored how the sub-components of working memory (phonological-loop and central executive) influence children's arithmetical development. Results showed that children were similar for phonological loop abilities, while working memory updating (the amount of information recalled after being held and manipulated in WM) demonstrated a domain-specific modulation related to the level of children's arithmetical performance. Study of De Smedth et al. (2009) also concluded that the central executive was a unique predictor of both the first- and the second-grade mathematics achievements.

2.10.2.1. WMC and Mathematics

Several studies (Raghubar et al., 2010; Bull & Scerif, 2001; Lu et al. (2011) reveal that working memory is related to mathematical performance in adults and in typically developing children and in children with difficulties in math. The study of De Smedth et al. (2009) revealed that working memory was significantly related to mathematics achievement, showing that working memory clearly predicts later mathematics achievement. WM assessed in kindergarten predicted the early school achievement in areas of maths and number knowledge (Monette et al., 2011; Fitzpatrick and Pagani, 2011). Alloway and Passolunghi's study (2011) with seven- and eight-year-old children also provided evidence for the idea that memory skills uniquely predicted mathematical skills and arithmetical abilities.

However, Raghubar, Barnes and Hecht's (2010) study also demonstrate that the relations between working memory and math are complex and likely depend on several factors including, but not limited to: age, skill level, language of instruction, the way in which mathematical problems are presented, the type of mathematical skill under consideration and whether that skill is in the process of being acquired, consolidated, or mastered.

Whether cognitive training of a domain general ability such as working memory in combination with high quality domain specific instruction in mathematics would prove to be effective particularly for younger children at risk and for older children with difficulties in math remains to be seen (Raghubar et al., 2010).

2.10.2.2. WMC and Science

While there have been extensive studies of WM's relationship with reading and mathematics achievement (Alloway, 2006; Swanson & Howell, 2003), less emphasis has been given to the connection between WM and science learning (Yuan et al., 2006).

Niaz & Logie, 1993 indicates that researchers in science education recognise the importance of information processing capacity as a constraint on the abilities and the achievements of science students. The weight of the evidence from prior research points to a strong connection between WM and science achievement (Yuan et al., 2006). For instance, Gathercole et al. (2004) found a strong relationship between WMC and science achievement for 14-year-old students. Similarly, Danili and Reid (2004) found that 15- and 16-year-old Greek students with high and low WMC differed significantly in their performance on chemistry tests. Their enquiry confirmed that both working memory space and extent of field dependency were two psychological factors affecting science performance. Krumm et al. (2008) who studied German undergraduate students reported abilities as assessed with the WM component coordination are relevant for good performances at school, especially for science courses.

2.11. Working Memory and Age

Working memory capacity is supposed to increase across childhood years as children grow older because they become more efficient at carrying out mental processes and their attention improves (Gathercole & Alloway, 2008). Alloway and Pickering (2006) investigated whether the structure of working memory was consistent across the childhood years and concluded that the developmental functions from 4 to 11 years for each aspect of memory tapped by the AWMA (verbal short-term and working memory and visuospatial short-term and working memory) were comparable, showing steady improvements in accuracy across age groups. This improvement is followed by small increases up to 15 years when adult levels are reached (Gathercole & Alloway, 2008).

However some studies reveal that the adult model of working memory is in place as early as 6 years of age (Gathercole, Pickering, Ambridge, & Wearing, 2004). A modular structure that includes an episodic buffer distinct from both the central executive and the phonological loop (Baddeley, 2000) is in place in 4- to 6-year-old children starting school (the result of the study of Gathercole et al., 2004).

Gathercole and Alloway (2008) highlight that not all children of the same age have the same WMC. In fact, differences can be very large within a particular age group. In a classroom of seven-year-olds, some children will have the WM capacities of the average five-year-old child, and others of an average eleven-year-old.

Developmental research suggested that children and adults differed in processing capacity and there was little difference in their static capacities. If adults were prevented from using special strategies and if the material was equated for familiarity, children and adult memory spans were very similar (Chi, 1976). However, children had much slower and less efficient processes.

Alloway et al., (2005) proposes that working memory plays a critical role in predicting learning outcomes when children are young because they had very few knowledge-based resources to draw on to support learning. This idea was supported by studies on WM- mathematical ability relation. The age disparity in the contribution of working memory to mathematical skills is most pronounced with respect to verbal working memory tasks (Alloway, 2006). For example, Bull and Scerif (2001) found a relationship between memory and math in 7-year olds, but this association was no longer significant in an adolescent population (Reuhkala, 2001). One possibility is that verbal working memory plays a crucial role in mathematical performance when children are younger. However, as they get older, other factors such as number knowledge and strategies play a greater role (Thevenot and Oakhill, 2005). This view is supported by recent evidence that working memory is a reliable indicator of mathematical disabilities in the first year of formal schooling (Gersten et al., 2005).

Swanson & Howell (2003) explored the contribution of two working memory (WM) systems (the phonological loop and the central executive) to reading performance in younger (9-year-old) and older (14-year-old) children. The results supported the notion that both the phonological and the executive systems are important predictors of age-related changes in reading but that these processes operate independent of each other in predicting fluent reading.

2.12. Working Memory and Gender

Previous literature provided no empirical research on gender differences in WMC. Few studies have evaluated gender differences related to WM tasks (Speck et al., 2000). Roivainen (2011) found an advantage of females in processing speed tasks involving digits and alphabets, whereas no difference was found in short-term memory tasks. On the contrary, Gathercole et al. (2008) identified no significant ($p>.10$) sex difference in their study on children with poor WM.

Results vary as to what extent the hemispheres are involved in the execution of the working memory tasks. Speck et al. (2000) examined gender differences in brain activation during four verbal working memory tasks. For all four tasks, the male subjects showed bilateral activation or right-sided dominance, whereas females showed activation predominantly in the left hemisphere. The task performance data demonstrated higher accuracy and slightly slower reaction times for the female subjects. The results showed highly significant ($p < 0.001$) gender differences in the functional organization of the brain for working memory. Authors explained these gender-specific differences in functional organization of the brain by gender-differences in problem solving strategies or the neurodevelopment.

2.14. Environmental Influences on WMC

There is emerging evidence that working memory is relatively impervious to environmental influences such as the number of years spent in preschool education (Alloway et al., 2004) and economic background (Engel et. al., 2008). One explanation for this is that working memory is a relatively pure measure of a child's learning potential and indicates a child's capacity to learn (Lamont et al., 2005). In contrast, academic attainment and even IQ tests measure knowledge that the child has already learned (Alloway & Alloway, 2010).

CHAPTER 3

METHODOLOGY

3.0. Presentation

This chapter sets forth the participants and the methods employed for the assessment of working memory and academic attainments. The procedures are presented, as well. The chapter concludes with the clarification of how the data has been analysed.

3.1. Participants

A total of 54 normally developing children (27 females and 27 males) from grades 6, 7, and 8 from two state secondary schools participated in this study. The age of children ranged from 12 to 14 years and their mean age was 13. As shown in Table 2, the sample consisted of equal number of participants (18) from each grade (6, 7, and 8), including 9 girls and 9 boys in each group. For the statistical analyses, participants were divided into three age groups: 12 year olds (n=18, 9 girls), 13 year olds (n=18, 9 girls) and 14 year olds (n=18, 9 girls).

Table 2. Age and sex distributions of the participating children

Age	N	Female	Male
12-year-olds	18	9	9
13-year-olds	18	9	9
14-year-olds	18	9	9
Total:	54	27	27

Participants were randomly recruited from two different state secondary schools, one in the suburban region and one in an inner-city area in Kırşehir, a middle-sized town located in the Central Anatolia Region of Turkey. In order to ensure sufficient number of participants, the study was conducted in two secondary schools. All children were native Turkish speakers and of Turkish nationality. They all started learning English as a foreign language at 4th grade (at the age of about 10). To reach the outcomes of the main courses such as Maths, Science and Turkish, they followed the standard nation-wide program shared in all state schools.

Among social groups, of the parents 37,7% belonged to working class, who earn little money, often being paid for the hours or days that they work, while 57,7% belonged to middle class, predominantly from police force. Where schooling was concerned, 90% of the mothers reported their highest level of education to be primary or secondary school and the remaining 10% had a high-school degree as their highest educational degree.

Recruitment of participants was initiated by obtaining verbal consent from school principals and teachers. Parental consent was obtained for each child participating in the study. Parents were informed of the study by a letter, and asked to return a written consent form. In addition, verbal consent was obtained from participating children prior to the assessment session. The study protocol was approved by the Ethics Committee of the Institute of Social Sciences.

None of the assessed children was receiving special education services or had documented brain injury; language, behavioural or developmental problems.

3.2. Measures

3.2.1. Tests of Working Memory

Two measures of verbal working memory were administered in the present study: reading span test (RST) and backward digit span test (BDST).

3.2.1.1. Reading Span Test

The test was arranged in two sets each of two, three, four and five sentences. The original test of Daneman and Carpenter (1980) included three sets and the number of sentences increased up to six sentences. Since the subjects of this study were 12-14 year-old students who could get bored easily and lose concentration, the set size was limited to two and the number of sentences increased only up to five.

The test was constructed with 28 unrelated sentences, 8-10 words in length. As in the study of Alloway and Passolunghi (2011) who translated the memory tasks into the mother tongue of the participants (Italian), in this study RST was presented in Turkish, the mother tongue of the participants.

Turkish is an agglutinative language and the sentence finals are verbs. This challenging structure of Turkish language led us to invert the word order and place the nouns to the sentence finals.

Each sentence ended in a different word. The end-words were two-syllable concrete nouns (Turner & Engle, 1989) from most common five-letter words that were used in students' Turkish course books (Juffs, 2004, also took the sentences for RST from L1 (Japanese) high school textbooks in his study).
As Harrington & Sawyer (1992) acknowledged, the attempt was made to avoid phonologically similar words in the same set.

The sentences did not cover any special knowledge domain and were of moderate difficulty. The sentences were also syntactically simple and short in length in order to avoid possible floor effects in performance due to task difficulty (Harrington & Sawyer, 1992).

Some reading span tests that were used in literature (Turner & Engle, 1989; Daneman & Carpenter, 1980; Harrington & Sawyer, 1992) included true-false component to ensure that subjects processed the entire sentence and did not just concentrate on the final words. Whether or not subjects verified the sentences correctly was ignored. The accuracy data was not used in Waters and his friends' study (Waters et al., 2004), either. It was a possible strategy if subjects had to only listen or silently read a sentence. Daneman & Carpenter (1980) emphasized that it was not a possible strategy when reading orally. Since the sentences were read aloud in the reading span test used in this study, there was no thread of any memory strategy. Thus, the test did not require a true-false component so as not to complicate the process for the participants.

3.2.1.2. Backward Digit Span Test

In backward digit recall as a verbal working memory measure, participants were required to recall a sequence of auditorily presented digits in the reverse order. On each trial, the child is required to recall a sequence of spoken digits in the reverse order.

Test trials begin with two numbers, and increase by one number in each level until six number-level. There were two trials at each span size. There were two sets of 2, 3, 4, 5 and 6 numbers. The maximum score on the backward digit span task was 40.

For the digit-span (backward) task, the experimenter read a set of numbers aloud in the language of investigation (Turkish), but in contrast with the forward digit span the participant had to repeat the number set in exactly the opposite order. For example, when the experimenter read: 2–4–5, the participant answered 5–4–2.

Table 3. Total number of items for recall in WM measures

WM Measures	Total number of items for recall
RST	28
DST	40

3.2.2. Assessment of School Achievement

The data collection session for academic attainment lasted for two educational semesters comprised of approximately 9 months so as to get as reliable and definite results as possible.

Scholastic attainments of the participants were obtained through two ways:

1. Course end-of-year grades
2. SBS prep tests

Education in Turkey is governed by a national system. Children are obliged to take 12 years of education between the ages of 6 and 18. The interest of this survey comprises the students at 6th, 7th and 8th grades with an age range of 12-14. The curriculum for these grades covers the following core subjects: Turkish, Maths, Science, Social Sciences and English.

The competence at each course is determined by the average scores of several assessment items such as exams, projects, tasks and in-class performance. At the end of the semester, an online-computer program of Ministry of Education calculates all the values entered by the teachers to the system and assesses an end-of-semester grade for each course. In this study, these grades are taken as one of the measures of attainment for each ability of interest.

When students start studying the 6th grade, they start preparing themselves for the national level placement test called ‘SBS’ (Seviye Belirleme Sınavı). At the end of 6th, 7th and 8th grade, each student take this exam and at the end of 3rd year, according to the average SBS scores, students make a list of choices from several types of high schools they would like to study at, and placed in one of them. In recent years this high school determination system is under discussion by the government and new regulations are on the way. However, general assessment tests or so-called ‘SBS preparatory tests’ continues to be employed. During the educational year, students attend a number of such tests. These tests are administered at the same time in the state and private schools which determined to take the preparatory tests from a common publication at the beginning of the semester. The test scores are accepted to demonstrate the overall success of a student in each course. It consists of multiple-choice type of questions from five main courses: Turkish, Maths, Science, Social Sciences and English.

The average of the test scores were used as the measures of attainment for each scholastic area under investigation. Each area was evaluated separately, and the total score was also used to discuss a general ability for academic learning.

3.3. Procedures

Each assessment was pilot tested once with 15 students. All participants were tested individually in a silent classroom throughout one-hour lunch breaks or after school each weekday. Testing sessions lasted 20-25 minutes for each participant.

3.3.1. Administration of RST

Since children were tested in the classroom, the tasks were presented through a laptop computer with a 15.4-inch colour monitor. Sentences in RST were displayed as a slight show at the centre of the computer screen as black letters on a white background in 40-point Arial font. Each participant was provided a recall sheet with set numbers and sentence numbers in each set and some space left for the record of the recalled last words.

The span test contained two sets of each two, three, four, and five sentences. Subjects were presented increasingly longer sets of sentences. They were informed to expect the number of sentences per set to increase during the course of the test.

Before the test began, participants were presented several practice items at the two-sentence level to prevent any possible misinterpretation regarding the test.

Subjects were asked to read a series of sentences aloud at their own pace and recall the last word of each sentence. As soon as the sentence was read, the next sentence appeared (initiated by a key press by the experimenter).

Each subject was warned to look at each sentence only for as long as it took to read it at a normal pace- approximately 5 seconds. The subject was instructed to read the sentence in a normal voice and at a normal rate of speaking, without backtracking.

The procedure was repeated until an instruction slight signalled that a trial had ended and that the subject was to recall the last word of each of the sentences and record them in the recall sheet. The last words could be recalled in any order regardless of the order they had occurred.

3.3.2. Administration of Backward DST

After a short break, testing resumed with backward digit recall. Before the test began, participants were presented several practice items at the starting two and three-digit levels. They were again tested individually in a quiet classroom.

The test administrator orally presented the numbers in a normal voice and a normal speed. Immediately after each set, the participant repeated the digits in the reverse order and meanwhile the administrator noted the digits which the participant uttered to calculate thereafter.

3.3.3. Computation of the Span Scores

An individual's working memory capacity was indexed as the number of final words correctly recalled, either in criteria terms- that is, the maximum set size in which all or a portion of the sentence-final words were correctly recalled (Daneman & Carpenter, 1980; Just & Carpenter, 1989)- or in absolute number of final words recalled (Turner & Engle, 1989).

Turner & Engle (1989) reported that both types of scores led to the same conclusions. Waters and Caplan (1996) found a correlation of .91 for those two types of measures for Daneman and Carpenter's (1980) reading span task.

Because the test was proved to be so difficult (Daneman & Carpenter, 1980), the subject was given credit for any set for which he/she recalled all sentence-final words, irrespective of the order of recall.

Backward digit span was calculated as the total number of digits the participants were able to repeat correctly in the reverse order of presentation.

3.4. Data Analysis

For statistical analysis (comprising descriptive statistics and preliminary statistics) of the data, a widely used computer application SPSS (Statistical Package for the Social Sciences) 15.0 for Windows Evaluation Version was employed.

The two scores of each course achievement (1. End-of-year score [EYS], 2. SBS preparatory test score [PTS]) were compared by *paired-samples t-test* and *bivariate correlation* in order to determine whether the average of the two scores could be employed as one score of each course achievement. Both analyses revealed exactly the same results, as shown in Table 4.

Table 4. Paired samples correlations between two types of measures of each course

		N	Correlation	Sig.
Pair 1	Turkish EYS & Turkish PTS	54	,829	,000
Pair 2	English EYS & English PTS	54	,683	,000
Pair 3	Social Sciences EYS & Social Sciences PTS	54	,630	,000
Pair 4	Maths EYS & Maths PTS	54	,786	,000
Pair 5	Science EYS & Science PTS	54	,702	,000

The perfect correlation (r = .00) indicated that one type of scoring can be determined exactly by knowing the other type of scoring. Thus, the strong significance (see Table 4) between end-of-year grades and SBS preparatory test scores has led the study to employ the average of the two measures as one achievement score for each course.

Correspondingly, the academic achievement scores (AAS) were obtained by the average of all the course scores in both measures, relying on the strong significance (r = .00) between the total scores of the two types of measures as shown in Table 5.

Table 5. Paired Samples Correlations between Total Preparatory Test Scores (TPTS) and Total End-of-Year Scores (TEYS)

	N	Correlation	Sig.
Pair 1 TPTS & TEYS	54	,830	,000

The correlation analysis was dealt with bivariate Pearson product-moment correlation coefficient which was designed to describe the strength and relation of the linear relationship between two continuous variables or one continuous variable and one dichotomous variable. Continuous variables in this study were the scores of working memory and academic achievement measures, while dichotomous variables were age and sex.

A perfect correlation of 1 or –1 indicates that the value of one variable can be determined exactly by knowing the value on the other variable. On the other hand, a correlation of 0 indicates no relationship between the two variables.

So as to compare the strength of the correlation coefficients separately for the age and gender groups, the sample was split into three groups for age (1. 12-year olds, 2. 13-year olds, 3. 14-year olds) and two groups for gender (1. Males, 2. Females). Thus, separate correlation results were obtained for each group, and this provided data for making comparisons between groups. The output of this analysis showed that a difference in correlations was observed between gender groups, whereas there seemed to be no difference between age groups. With this regard, the observed difference between age groups was further tested for the significance to determine the likelihood that the difference in the correlation noted between the two groups could have been due to chance (Pallant, 2011).

In order to test the statistical significance of the difference between correlation coefficients for the gender groups (M-F), the calculation procedures which Pallant (2011) described in the SPSS manual were followed. First, the r values which were obtained in Pearson correlation were converted into a standard score form (referred to as z scores), using a transformation table provided in the manual. Next, values were put into the following equation to calculate the observed value of z (z_{obs} value):

$$z_{obs} = \frac{z1 - z2}{\sqrt{\frac{1}{N1-3} + \frac{1}{N2-3}}}$$

If –1.96 < *zobs* < 1.96: correlation coefficients are *not* statistically significantly different.

If *zobs* ≤ –1.96 or *zobs* ≥ 1.96: coefficients are statistically significantly different (Pallant, 2005).

CHAPTER 4

RESULTS and DISCUSSION

4.0. Introduction

This chapter commences with illustrating the descriptive results entailing normality distribution analysis. It proceeds with the statistical analysis of the data outlined in accordance with the research questions. The chapter also presents the interpretations and discussion on the results.

4.1. Descriptive Results

Initially, the variables were checked for any violation of the assumptions underlying the statistical techniques that this study was going to address to answer the target research questions.

Normality of the distribution. Correlation analysis assumes that the scores are normally distributed. As a preliminary analysis for primary statistics, the normality of the distribution of entire scores in hand was assessed.

As Table 6 illustrates, the non-significant results (Significance value of more than .05) of the Kolmogorov-Smirnov statistic for scores of WM and academic achievement indicated that the distribution of scores in the current sample was reasonably normal.

Table 6. Kolmogorov-Smirnov Test of Normality

	Kolmogorov-Smirnov(a)		
	Statistic	df	Sig.
reading span score	,098	54	,200(*)
digit span score	,087	54	,200(*)
Turkish	,090	54	,200(*)
Maths	,102	54	,200(*)
Science	,083	54	,200(*)
Social	,089	54	,200(*)
English	,119	54	,053
SAS	,069	54	,200(*)

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Descriptives for WM scores. Descriptive statistics for the working memory tests are reported in Table 7. Scores were computed out of 100. Mean scores of the two measures were rather close, which might be regarded that both tests were similarly performed, and the tests were of moderate difficulty.

Table 7. Descriptive Statistics for WM Measures

	N	Minimum	Maximum	Mean	Std. Deviation
RS score	54	46,00	86,00	65,0556	10,79031
BDS score	54	43,00	100,00	66,7778	13,59615
Valid N (listwise)	54				

The sample achieved slightly better in backward digit span test and even one participant achieved the highest score by correctly repeating all the digits in reverse order. Although some studies in literature reported participants who recalled a maximum of 4 or 5 digits in backward digit span, in this study 4 students were able recall a 6-digit set correctly.

Frequencies. Among the participants, one student reached the maximum score of 100 in backward digit span test. The most frequent scores (5 students for each) were

65, 70, 73, and 78 for BDS test, and 54 (6 students), 64 (9 students), 71 (6 students), and 75 (5 students) as for RS test. The distribution of the scores closely approximates the normal curve.

59.3% of the participants scored in the average range, while 24.1% of the learners were below and 16.7% above the average in terms of their reading span. As for backward digit span, 68.8% of the participants scored in the average range, with 16.7% below and 15% above. This shows that there is enough variation in span scores of the participants to carry out meaningful analyses of the relationship of verbal working memory capacity and academic performance.

WM mean scores in age groups. Figure 7 illustrates the mean scores obtained in each age group. Mean does not follow a linear line for backward digit span, whereas for reading span increases gradually by the age.

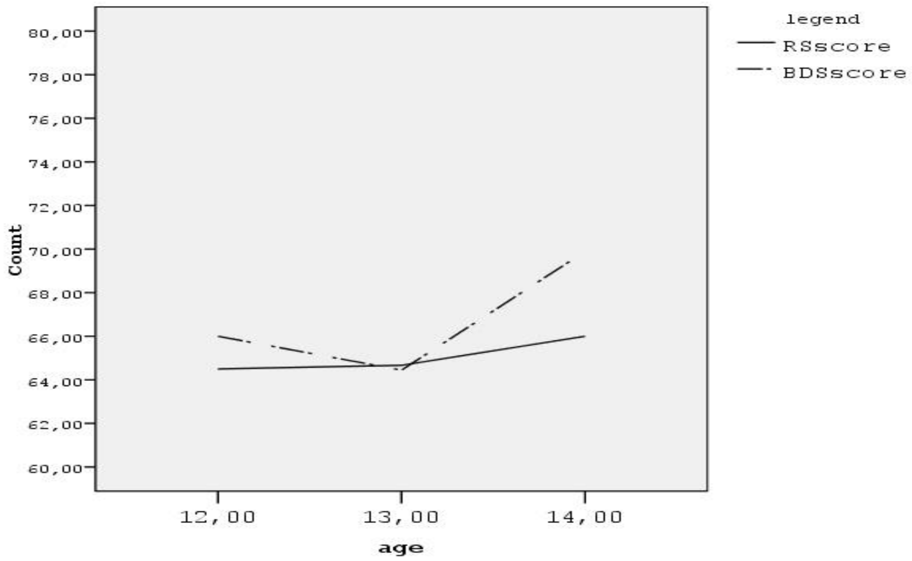

Figure 7. Mean scores of RST and BDST in age groups

The figure above is quite similar to that of Gathercole & Alloway (2008, see the figure on page 21) who identified that there was a big increase in working memory capacity between 5 and 11 years of age, followed by small increases up to 15 years when adult levels were reached.

Mean scores in gender groups. Both groups obtained higher scores in BDS test, and the mean difference between tests was higher in female group.

A slight, but linear increase in both measures of verbal working memory was observed in females when compared with scores of males. Figure 8 and 9 demonstrated that WM capacity of females was slightly higher than that of males.

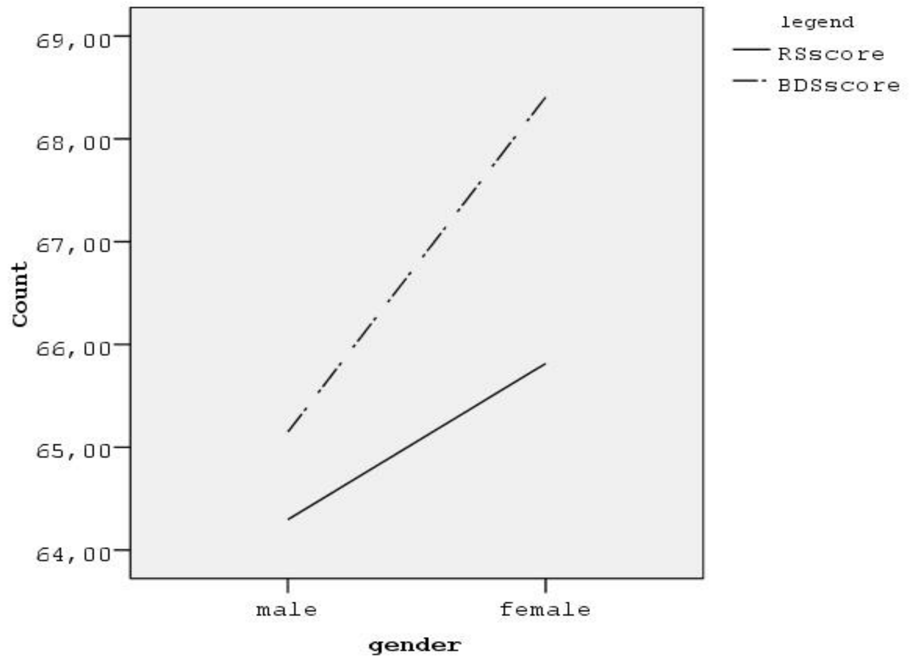

Figure 8. Mean scores of RST and BDST in gender groups

Previous literature provided no empirical research on gender differences in WMC. Gathercole & Alloway identified no difference between boys and girls in WM tests. Roivainen found an advantage of females in processing speed tasks involving digits and alphabets, whereas no difference was found in short-term memory tasks.

The results of this study suggest that females perform better than males in working memory tasks, and WMC of females seems slightly higher than that of males.

However, it is an insufficient result regarding the 2 or 3-digit increase in the scale (see Figure 8), thus further empirical study is needed to clarify the gender difference in WMC.

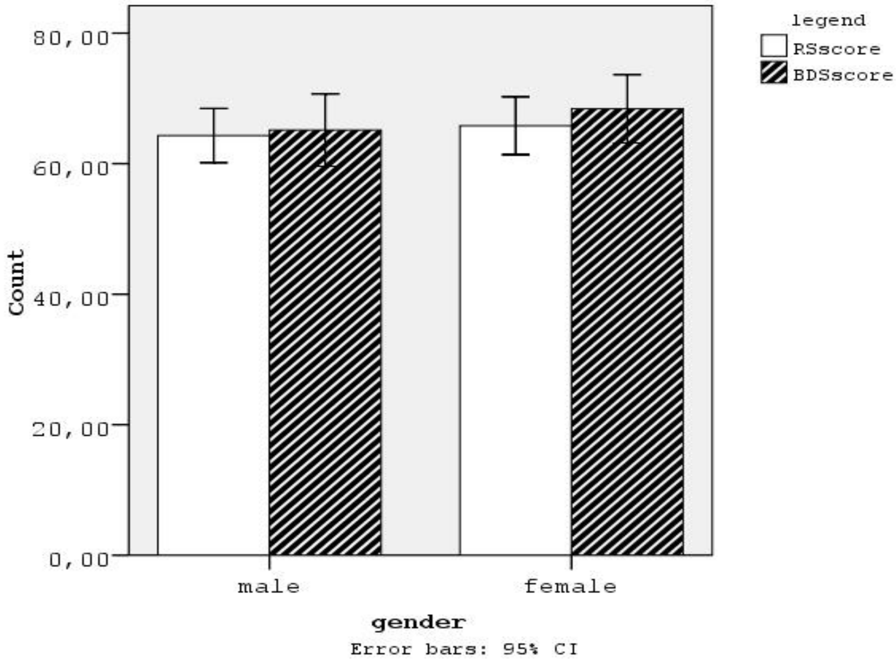

Figure 9. Mean reading span and digit span scores of males and females with error bars

Figure 9, as well, illustrates that males appear to have slightly lower levels of working memory span than females.

Descriptives for Academic Achievement Scores. Mean and standard deviation with minimum and maximum scores of achievement scores out of 100 were illustrated in Table 8. The highest mean score was detected in Turkish course (M=75), whereas the lowest mean achievement score was obtained for Mathematics (M=60). Standard deviations for all the scores were within the normal range.

Table 8. Descriptive Statistics for Academic Achievement Results

	N	Minimum	Maximum	Mean	Std. Deviation
Turkish	54	40,00	97,00	75,2963	14,17895
English	54	33,00	92,00	65,1296	15,58064
Social	54	37,00	96,00	69,5741	15,19012
Maths	54	30,00	93,00	60,5926	16,88867
Science	54	36,00	94,00	67,3333	13,83324
SAS	54	46,00	94,00	72,1111	11,97902
Valid N (listwise)	54				

Mean scores in age groups. Mean score of each school subject in each of the three groups which were split by ages of the participants was illustrated in Figure 10. Students in all groups achieved best in Turkish course, which was followed by Social Sciences and English. A gradual decline was observed in English attainment scores. Scores of Social Sciences followed a smooth route, whereas Turkish scores showed irregularity among ages.

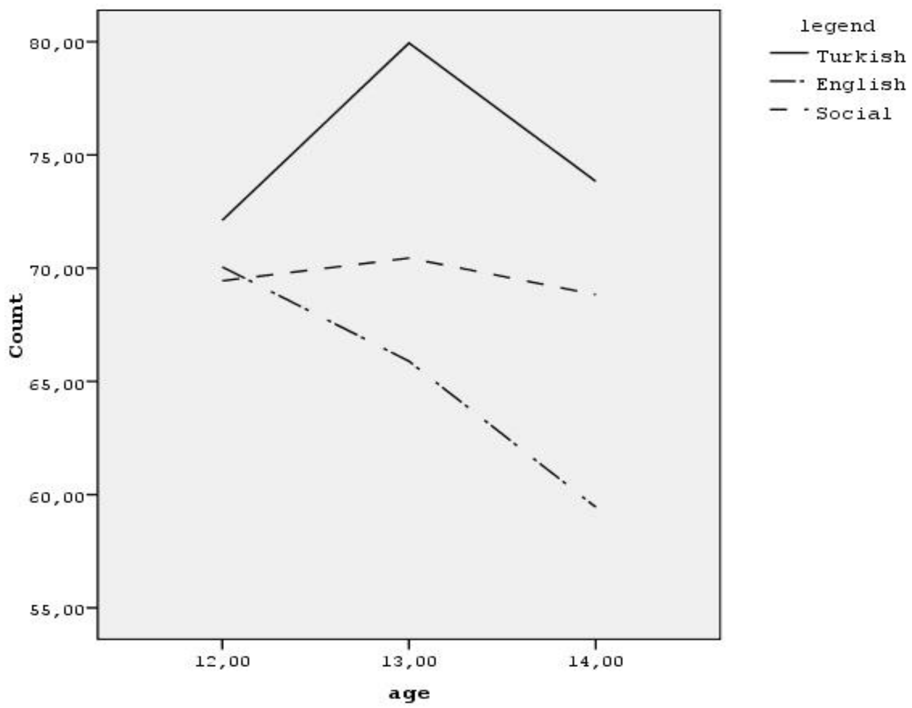

Figure 10. Turkish, English and Social Sciences achievement mean scores in age groups (12, 13, 14-year olds)

Surprisingly, performance in both logical-mathematical abilities declined within the examined ages (see Figure 11). This result might be due to the increase in the course attainment load through the end of the secondary school, particularly in 8th grade, in which the subjects in the curriculum get more detailed, comprehensive, thus, challenging.

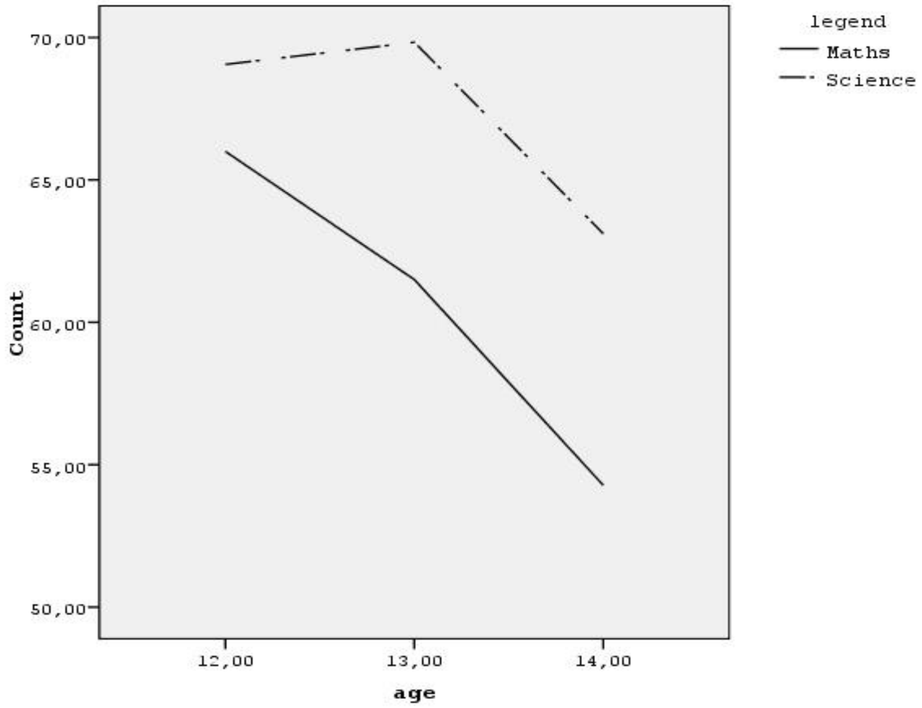

Figure 11. Mathematics and Science achievement mean scores in age groups (12, 13, 14- year olds)

Mean scores in gender groups. From the data in Figures 12 and 13, it is apparent that females performed better in core scholastic abilities than males did.

The significance of the observed difference was not analysed in that this issue emerged as a surprise and was outside of the major research questions of this study. Besides that, there seemed to be a low difference when the scale in the figures below was examined.

The striking point was that females achieved better in all key subjects in the curriculum without any outlier subject in spite of the fact that all the participants were randomly selected regardless of the previous success stories. Nevertheless, it is an issue that must be studied thoroughly with participants larger in number in order to eliminate the chance factor.

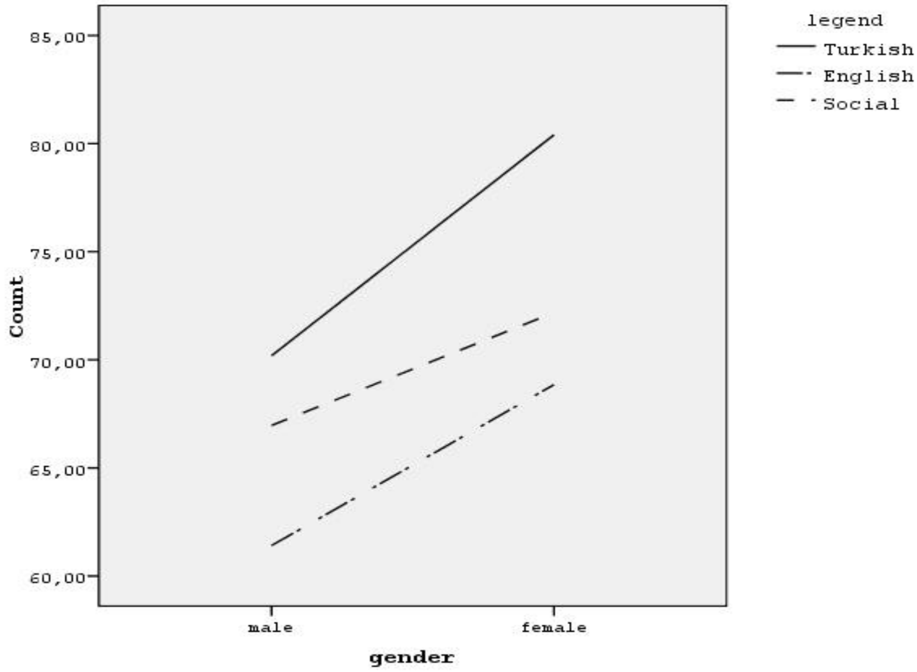

Figure 12. Turkish, English and Social Sciences achievement mean scores in males and females

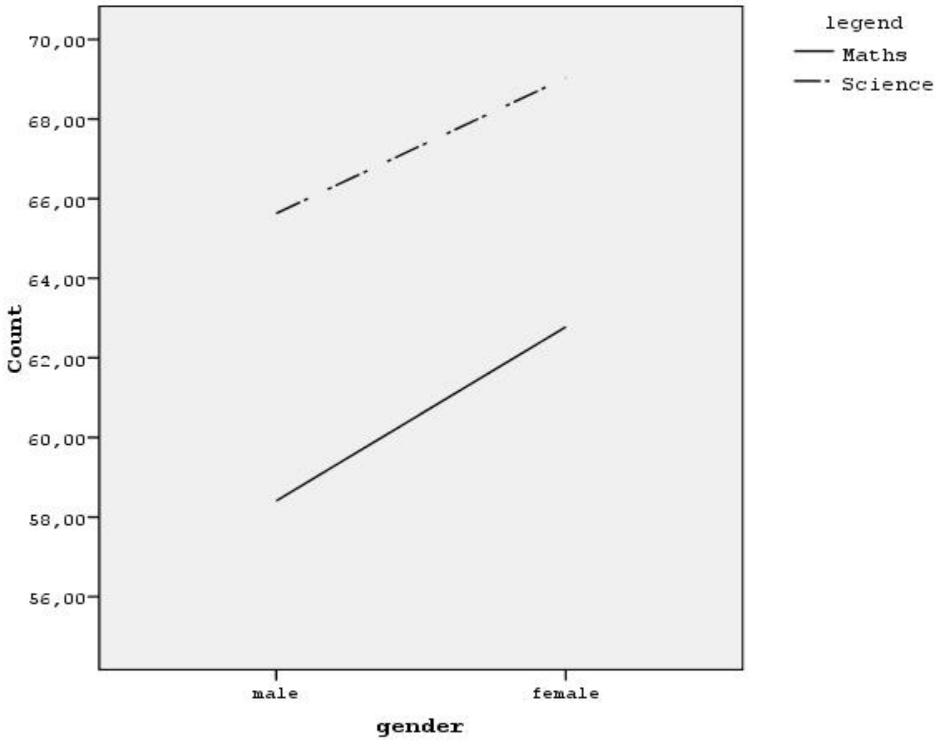

Figure 13. Mathematics and Science achievement mean scores in males and females

4.2. The Relationship between WMC and Overall Academic Achievement

The Pearson correlation (for RST, r = .42; for DST, r = .43) demonstrated that there is a strong relationship between the capacity of WM children have and their performance on academic abilities (see Table 9). Thus, this result proposes that children with high levels of WMC success better levels on academic abilities. Both verbal working memory measures are capable of predicting the performance of the children which was determined by the average achievement scores obtained from five main courses: Turkish, English, Social Sciences, Mathematics and Science.

This result confirms the presumed role of working memory in academic attainments and it is in line with outcomes of corresponding studies (Lamont et al., 2005; Brown et al., 2003; Gathercole & Pickering, 2000; Gathercole, Pickering, Knight, & Stegmann, 2004; Gathercole & Alloway, 2008)

Table 9. Correlation between WM test scores and Academic Achievement Scores (AAS)

		AAS
reading span score	Pearson Correlation	,429(**)
	Sig. (2-tailed)	,001
	N	54
digit span score	Pearson Correlation	,438(**)
	Sig. (2-tailed)	,001
	N	54

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

4.3. The Relationship between WMC and Turkish (L1) Success

The highest correlations (r=.37, p<.01, for RS; r=.40, p<.01, for DS) were observed in Turkish-WM pairs as illustrated in Table 10. This outcome is in consistency with several studies in literature (Just & Carpenter, 1989; St. Clair-Thompson & Gathercole, 2009; Lu et al., 2011; and Nevo & Breznitz, 2011) which investigated the role of WM in a number of language skills, particularly in reading abilities.

This strong correlation also supported Baddeley's (2003) assumption that working memory should have had implications for language processing assuming that it was a temporary storage system that underpinned our capacity for thinking.

Both verbal working memory scores correlated with Turkish achievement scores with a significance level of 0.01. It is possible to interpret the current result in two dimensions. First, verbal working memory measures are able to predict Turkish achievement of the students. Second, L1 abilities of the students are determined or constrained by their working memory capacities. A student with a high WMC is able to acquire L1 attainments or Turkish course requirements better than another student with a low WMC.

Table 10. Correlation between WM test scores and Turkish achievement scores

		Turkish Scores
reading span score	Pearson Correlation	,378(**)
	Sig. (2-tailed)	,005
	N	54
digit span score	Pearson Correlation	,408(**)
	Sig. (2-tailed)	,002
	N	54

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

4.4. The Relationship between WMC and English (L2) Success

RST scores provided significant correlation ($r = .28$) with the English achievement scores, whereas DST and English scores correlation was very low ($r = .16$), and not at a significance level (see Table 11). In this regard, WM seemed to contribute less to second language abilities in national curriculum. Among all curriculum subjects, English had the lowest association with WM.

This finding was in contrast with the proposal of many researchers (Just & Carpenter, 1989; Turner & Engle, 1989) who suggested a central role for working memory capacity in accounting for individual differences in language comprehension skill. This result was also contrary to the studies (Atkins & Baddeley, 1998; Adams et al., 1999) which indicated stronger correlations between WMC and L2 abilities.

Table 11. Correlation between WM test scores and English achievement scores

		English Scores
reading span score	Pearson Correlation	,282(*)
	Sig. (2-tailed)	,038
	N	54
digit span score	Pearson Correlation	,167
	Sig. (2-tailed)	,227
	N	54

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

Studies in literature linked WM to various aspects of L2 learning from vocabulary learning (Kormos & Sáfár, 2008), reading skills (Harrington & Sawyer, 1992) and to overall language proficiency (Service et al., 2002). However, the current study did not propose a link for WM to any particular language skill, instead it concentrated on the overall achievement of students in national curriculum attainments (i.e. L2 reading and listening comprehension, L2 writing, vocabulary acquisition, and communicative abilities).

A possible explanation for the insufficient relation is that sub-skills predominantly assessed in one testing type might be material to correlations. Among L2 domains, vocabulary learning has been assigned a central role and it has been the primary focus in L2 courses. Thus, SBS preparatory tests measured the students' ability in limited domains (i.e. reading comprehension, dialogue completion) and predominantly focused on vocabulary acquisition. End-of-year grades were, on the other hand, the average scores of students' performance on several domains (i.e. reading and listening comprehension, speaking, writing, comprehension of grammatical rules, sentence formation, responding a question, vocabulary, etc.).

In order to clarify which assessment had better correlations with WMC, the current research, further, examined the relation of working memory with each L2 achievement score separately (see Table 12).

Table 12. The correlation between WM measures and two types of L2 scores

		English end-of-year grades	English SBS prep test scores
RS score	Pearson Correlation	,356(**)	,181
	Sig. (2-tailed)	,008	,191
	N	54	54
BDS score	Pearson Correlation	,246	,100
	Sig. (2-tailed)	,073	,473
	N	54	54

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

As expected, end-of-year grades demonstrated a significantly high correlation ($r= .35$, $p< .01$) with reading span test scores (see Table 12). When the RST as a measure of WM and school grades as a measure of English competence are compared, result is in agreement with the previous L2 research, which suggests a strong relation. In other words, RST which assess the verbal working memory capacity is a good predictor of school achievement in English course.

This finding is consistent with studies in literature which compare the verbal working memory and phonological short-term memory as predictors of separate sub-skills in L2. They associated vocabulary learning more with phonological short-term memory (Service, 1992; Papagno & Vallar, 1995), and reading (Harrington & Sawyer, 1992) and overall competence (Service et al., 2002) with verbal working memory. Correspondingly, this study established a stronger link with verbal WM and overall English achievement (determined by end-of-school grades), rather than vocabulary attainment (target domain of L2 assessment in SBS preparatory exam).

No significant correlation was identified between backward digit span test and any of the English achievement scores (see Table 12). This result is in contrast to findings of Kormos and Safar (2008) who identified that backward digit span accounted for as much as 30.25% of the variance in the performance of a language test.

Another possible explanation for the previous low relation might be that students begin learning English as a foreign language in 4th grade at the age of 10, and they reach just the pre-intermediate level at the end of 8th grade, which might not be a satisfactory attainment level for drawing clear relations. In this regard, is it possible to put forward that relation gets stronger and more meaningful when students advance in language in the course of education?

The sample was split into age groups, and the correlation analysis was re-performed within each age group. In accordance with the recent assumption, the correlation increased gradually and reached a significance level of .04 ($r= .47$, $p< .05$) when the students reached the pre-intermediate level in English (see Table 13).

Table 13. Correlations between RST scores and English end-of-year grades in age groups of 12, 13, and 14.

age			English end-of-year grades
12,00	RS score	Pearson Correlation	,223
		Sig. (2-tailed)	,374
		N	18
13,00	RS score	Pearson Correlation	,451
		Sig. (2-tailed)	,060
		N	18
14,00	RS score	Pearson Correlation	,477(*)
		Sig. (2-tailed)	,045
		N	18

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

As a result of these findings, this study asserts that both L2 level and sub-skills assessed in L2 tests might determine the strength of the relationship between WMC and English (L2) achievement.

4.5. The Relationship between WMC and Social Sciences Success

The correlation analysis (see Table 14) revealed a strong correlation (r=.43, p=.01, for RS, and r=.41, p<.01) between verbal working memory and general ability in social sciences, assessed by average of all the grades obtained in an educational year.

This high correlation provided evidence that children with better abilities in Social Sciences (i.e. comprehension and interpretation of social affairs, reasoning and sequencing events in history) had higher levels of working memory capacities.

Table 14. Correlation between WM test scores and Social Sciences achievement scores

		Social Sciences Scores
reading span score	Pearson Correlation	,431(**)
	Sig. (2-tailed)	,001
	N	54
digit span score	Pearson Correlation	,411(**)
	Sig. (2-tailed)	,002
	N	54

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

4.6. The Relationship between WMC and Mathematics Success

Close associations were obtained between children's scores on working memory measures and their curriculum assessments in Mathematics. As Table 15 presents, whilst the correlation of achievement scores in mathematics with reading span test scores was notably strong (r=.34, p<.05), the relation with digit span had prior significance (r=.39, p<.01).

This result posits positive signals for the debate that WMC is probably task-dependent which assumed that better developed expertise at the background task freed additional WMC for the storage component of the task (Service et al., 2002). Thus, it is probable that learners with high mathematical abilities achieve better in a working memory task requiring digits to be recalled in the course of processing them. However, this claim needs further evidence since prior studies have not dealt with this association between digit span and mathematical abilities, albeit a handful of studies on reading span and reading achievement relation.

Table 15. Correlation between WM test scores and Mathematics achievement scores

		Mathematics Scores
reading span score	Pearson Correlation	,347(*)
	Sig. (2-tailed)	,010
	N	54
digit span score	Pearson Correlation	,398(**)
	Sig. (2-tailed)	,003
	N	54

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

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

This significant correlation suggests that WM has an influence on several Mathematical abilities. Unlike studies (Raghubar et al., 2010) focusing particularly on problem solving abilities, WMC, in this study, is associated with overall Mathematical competence involving several sub-skills (i.e. reasoning, analyzing, complex thinking, inferring, problem solving).

The current result of correlation analysis is in line with similar studies with young children in literature (De Smedth et al., 2009; Fitzpatrick & Pagani, 2011) which assign a predictive role for WM in mathematical skills, arithmetical abilities and problem solving accuracy.

It is also consistent with studies (Bull & Sherif, 2001; Raghubar et al., 2010; Lu et al., 2011) which revealed significant correlations between mathematical performance and WM.

4.7. The Relationship between WMC and Science Success

Correlations were reasonably high (see Table 16) between science attainment scores and the two working memory measures: Reading span (r=0.39, p<0.01), and digit span (r=0.38, p<0.01).

This result is consistent with the findings of Gathercole et al. (2004), Danii and Reid (2004), Yuan et al. (2006) and Krumm et al. (2008) who identified strong relationships between working memory measures and attainments in science education.

This high relationship affirmed that students with high WMC achieved better in mental operations, logical thinking, problem solving and other complex cognitive activities which are the attainments of science course.

The finding of this study provided evidence for the claim of Gathercole et al. (2004) who argued that intellectual operations required in Science were constrained by the limited capacity of working memory across the childhood years.

Table 16. Correlation between WM test scores and Science achievement scores

		Science Scores
reading span score	Pearson Correlation	,392(**)
	Sig. (2-tailed)	,003
	N	54
digit span score	Pearson Correlation	,384(**)
	Sig. (2-tailed)	,004
	N	54

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

4.8. Difference in WM - Achievement Correlations between Gender Groups

Table 17 demonstrates that complex verbal working memory measures correlated significantly with key scholastic abilities of female participants, whereas no significant correlation was obtained between WM and any of the scholastic domains in male group. From the output given below, the correlations between WM measures and scholastic attainments for males were quite low ($.06<r<.25$), while for females they were substantially higher ($p=.01$, $p<.01$), except for English attainments ($r=.32$, $p>.05$).

Table 17. Correlation statistics obtained when the data was split into two gender groups: Males and females

gender			Turkish	English	Social	Maths	Science	AAS
male	RS score	Pearson Correlation	,144	,067	,253	,193	,130	,191
		Sig. (2-tailed)	,475	,741	,203	,335	,518	,339
		N	27	27	27	27	27	27
	BDS score	Pearson Correlation	,251	-,006	,242	,156	,198	,255
		Sig. (2-tailed)	,206	,976	,224	,437	,322	,199
		N	27	27	27	27	27	27
female	RS score	Pearson Correlation	,650(**)	,503(**)	,565(**)	,484(*)	,618(**)	,659(**)
		Sig. (2-tailed)	,000	,007	,002	,010	,001	,000
		N	27	27	27	27	27	27
	BDS score	Pearson Correlation	,576(**)	,327	,545(**)	,638(**)	,553(**)	,615(**)
		Sig. (2-tailed)	,002	,095	,003	,000	,003	,001
		N	27	27	27	27	27	27

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

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

These results led the study to further investigate whether the observed difference in the strength of the relationship between the two gender groups was statistically significant. Table 18 demonstrates the calculated z_{obs} value for the difference between relationships among males and females.

Table 18. Significancy levels of differences in WM-Academic Achievement correlations between gender groups

	Turkish	English	Social	Maths	Science	AAS
RS	7.87*	6.07*	4.77*	4.17*	7.36*	7.48*
BDS	5.00*	4.32*	4.55*	7.46*	5.26*	5.63*

* Difference is significant at z_{obs}>1.96 level.

Results of the statistically significance test of the difference between correlation coefficients are presented in Table 18. The values higher than 1.96 define significant difference between coefficients.

All the values obtained are higher than z_{obs} 1.96 level, thus it is possible to conclude that there is a statistically significant difference between males and females in the strength of the correlation between WMC and all examined school subjects as well as overall academic achievement.

Regarding the results presented here, it is possible to draw the conclusion that WMC explains notably the variance in academic achievement for females, whereas it fails to explain the individual differences in several domains of learning for males.

This result was quite remarkable in that WMC perfectly predicted female students' achievement at school, while it failed to establish any significant link to male students' achievement.

4.9. Difference in WM - Achievement Correlations between Age Groups (12, 13, and 14 year olds)

As Table 19 represents, the distribution of the correlations at significant level do not allow the study to interpret that there is a difference across age groups.

Table 19. Correlation statistics obtained when the data was split into three age groups: 12, 13, and 14- year olds

age			Turkish	English	Social	Maths	Science	AAS
12	RS score	Pearson Correlation	,206	,164	,330	,310	,215	,262
		Sig. (2-tailed)	,412	,514	,182	,210	,393	,293
		N	18	18	18	18	18	18
	BDS score	Pearson Correlation	,598(**)	,186	,382	,500(*)	,245	,448
		Sig. (2-tailed)	,009	,460	,117	,035	,327	,062
		N	18	18	18	18	18	18
13	RS score	Pearson Correlation	,553(*)	,484(*)	,540(*)	,471(*)	,592(**)	,588(*)
		Sig. (2-tailed)	,017	,042	,021	,048	,010	,010
		N	18	18	18	18	18	18
	BDS score	Pearson Correlation	,296	,135	,350	,388	,483(*)	,393
		Sig. (2-tailed)	,232	,593	,155	,111	,042	,107
		N	18	18	18	18	18	18
14	RS score	Pearson Correlation	,455	,315	,450	,388	,490(*)	,499(*)
		Sig. (2-tailed)	,058	,203	,061	,111	,039	,035
		N	18	18	18	18	18	18
	BDS score	Pearson Correlation	,497(*)	,324	,546(*)	,526(*)	,573(*)	,582(*)
		Sig. (2-tailed)	,036	,189	,019	,025	,013	,011
		N	18	18	18	18	18	18

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

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

Unexpected results came from 12-year-old group, where only digit span score significantly correlated with a verbal domain, Turkish (r=.59, p<.01), and a mathematical domain, Mathematics (r=.50, p<.05), while very low correlations between WM measures and other domains of academic attainment were obtained.

A further striking result was that each scholastic attainment score of 13-year olds correlated significantly with reading span scores (.01<p<.05), whilst 14-year olds' scholastic attainment scores except English correlated significantly with backward digit span scores (p<.05).

Mathematical attainments seemed to correlate significantly (.01<p<.05) with both working memory measures in 13- and 14-year olds. On the contrary, the single correlation regarding foreign language attainments was observed with backward digit span scores in 13-year olds.

4.10. General Discussion

The results revealed that working memory assessed by reading and backward digit span tests highly correlated with academic achievement scores. There was a significant correlation between working memory capacity and overall scholastic performance, as well as key subjects of curriculum, in particular. The correlation analysis is summarized in Table 20.

The highest correlation was observed between overall academic achievement and working memory. Both measures of verbal working memory correlated (reading span test and backward digit span test) at a remarkable significance level of 0.001. This result has paramount importance in that it confirms the proposed link between WM and general academic performance reasonably well.

The contribution of working memory capacity to sub-domains in academic performance was also supported by the substantially high correlations (.001≤ p <.01) except with English achievement (see Table 20).

Table 20. Summary of the correlations between WM measures and academic achievement measures

		Turkish	English	Social	Maths	Science	AAS
RS scores	Pearson Correlation	,377(**)	,286(*)	,430(**)	,349(**)	,389(**)	,429(**)
	Sig. (2-tailed)	,005	,036	,001	,010	,004	,001
	N	54	54	54	54	54	54
BDS scores	Pearson Correlation	,408(**)	,167	,411(**)	,400(**)	,384(**)	,438(**)
	Sig. (2-tailed)	,002	,226	,002	,003	,004	,001
	N	54	54	54	54	54	54

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

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

The lowest relationship was obtained between working memory capacity and English performance scores (r= .36, p<.05 for RST). As for backward digit span test, the results indicated no significant correlation with English scores.

In contrast to earlier findings of research (Just & Carpenter, 1989; Turner & Engle, 1989; Harrington & Sawyer, 1992; and Service et al., 2002), a lower contribution of WM (assessed by RST) to English was detected (r= .36). This suspicious result led the study to further investigate the reasons underlying it.

The first assumption was that the limited sub-skills that SBS preparatory test assessed (i.e. vocabulary and dialogue completion with appropriate expressions) might mislead the results and fail to reveal the general competence of the students in English. In order to eliminate this factor, correlation was re-analyzed between WM measures and only end-of-year grades which consisted of a general assessment of several sub-skills (i.e. reading and listening comprehension, writing, speaking, comprehension of grammatical rules, sentence formation, vocabulary, etc.). Not surprisingly, these achievement scores correlated notably (r= .35, p< .01) with RST scores.

The second assumption was that the elementary level of younger age group might cause ineffective results. Thus, the data was re-evaluated in age groups separately. In line with expectations, the relation increased gradually (r=.37 for 12-year-olds with elementary L2 level, r=.06 for 13-year-olds) and became significant (r< .05) when the students reached the pre-intermediate level in English at 14 years old. Consequently, it is possible to assert that both L2 level and the sub-skills assessed in L2 tests might determine the strength of the relationship between WMC and English (L2) achievement.

The gender-related analysis revealed that working memory capacity was a far better predictor of academic achievement for females than for males. The study identified a significant difference between male and female groups regarding the proposed relation of WM with academic abilities. It is difficult to explain this result as there is no substantive research in this field, but it might be related to the functional organization in the brain responsible for working memory, which is assumed to differentiate problem-solving strategies in males and females (Speck et al., 2000).

The overall performance of females on both working memory tests was also detected to be slightly higher than that of males. The recent result needs further investigation for a better understanding of the cognitive factors in individual differences.

No age-related difference was recorded between 12, 13, and 14-year-old children regarding the correlations between WM measures and academic achievement scores. This study detected a slight increase in working memory capacity of 14-year olds, which was in line with Gathercole & Alloway (2008).

CHAPTER 5

CONCLUSION

5.0. Introduction

This final chapter commences with the summary of the study and concluding remarks. In the second part the significance of the findings and practical implications for education are discussed. Finally, the limitations of the study and the suggestions for further research are proposed.

5.1. Summary of the Study

WM is a brain system that provides temporary storage and manipulation of the information necessary for complex cognitive tasks such as language comprehension, learning and reasoning (Baddeley, 1986). The presumed role of working memory in many cognitive tasks gave rise to an interest in the extent to which individual differences in working memory capacity may explain individual differences in other cognitive domains (Waters & Caplan, 2003), involving children's ability to acquire knowledge and new skills (Cowan & Alloway, 2008).

Provided that working memory functions as a 'bottleneck' (Alloway et al., 2006) for learning, a relation might be proposed between working memory capacity and achievement in English (L2) as well as other subjects in curriculum.

Thus, the primary purpose of this study was to investigate the relationship between working memory and achievement in academic subjects comprising English (L2), Turkish (L1), Social Sciences, Mathematics and Science. The study also examined the possible effect of age and gender on this relation.

Participants were 54 secondary school students (27 males and 27 females) in the 12-14 age range from two state schools in Kırşehir, Turkey.

Working memory was assessed by two complex span measures:

1. Reading span test. In reading span test, participants were required to read a series of sentences and recall the final words.
2. Backward digit span test. In backward digit span test, participants heard a series of digits and repeated them in the reverse order.

Academic achievement scores were obtained by the average of end-of-year grades at school and SBS preparatory test scores.

5.2. Concluding Remarks

The results of this study shed light on several issues under discussion in literature. First, the assumed role of working memory in many complex cognitive activities and in learning new information has been proved by high correlations between students' academic achievement scores and their working memory test scores. As Gathercole and Alloway (2008) remark, working memory is employed in arithmetical abilities. It is apparent from the results that students operate their working memory while storing mathematical knowledge in mind and simultaneously processing the target mental arithmetic in problem solving activities. Working memory capacity has also significant influence on a number of learning abilities such as reading comprehension in the mother tongue, learning the rules of a foreign language, establishing a logical cause-effect relationship in history, comprehension of complex scientific knowledge, and so forth. In accordance with the findings of Alloway et al. (2009), students with poor working memory capacity performed poorly in such key learning outcomes. This is in line with Just and Carpenter's (1992) 'capacity constrained comprehension theory' in literature which presumed that one of the reasons of performance differences among individuals within a task was limitation of working memory capacity. It is obvious that WMC is one of the energy sources that people mentally rely on throughout learning processes. The strong relationship is also in line with Alloway's (2006) suggestion that WM provides a resource for the individual to integrate knowledge from long-term memory with information in temporary storage. Children with weak working memory capacities are therefore limited in their ability to perform successfully in complex activities in class. This verifies the view that WM acts like a 'bottleneck' (Alloway et al., 2006) for learning. Unless WM demands of learning episodes are met, process of acquiring skill and knowledge over the school years is disrupted.

Second, working memory was able to predict students' academic performance in many areas of curriculum. Although the core subjects, Turkish, Mathematics, Science and Social Sciences, highly correlated with both working memory span measures, a lower correlation was obtained with English achievement scores. This result can be based upon two reasons. First, English is at pre-intermediate level in secondary school years, thus higher correlations might be obtained when learners advance in language. They may not reveal their potential abilities for foreign language learning at the very beginning of the learning procedure. Second, SBS preparatory test scores do not reflect students' performance in all skills, but reveal just reading comprehension abilities. Therefore, in-class measurement scores of English language abilities correlate to a higher degree with WM test scores. The reason behind this is that in-class assessments reflect a more comprehensive capability in foreign language skills from vocabulary acquisition to listening and reading comprehension. In the light of the findings of this study regarding L2, it is possible to conclude that the effect of working memory capacity might be different in participants with an advanced level of the target language and with regard to all skills. This study laid the foundations of a new discussion for L2 and WM relationship, and highlighted that the level of language and the assessed language skills might influence the results. The argued impact of working memory can be examined on separate sub-skills of L2 acquisition with a number of complex span measures in order to justify its role on L2 learning.

Third, the current study provided new dimensions to WM and learning investigation and left new questions to be answered by further empirical research. This new dimension in the research area is regarding the effect of gender factor on WM and learning relationship. To the best of our knowledge, no study has identified a gender difference on the role of WM on academic abilities. The results of this study demonstrated that WM was able to predict achievement of females in all key subjects perfectly. Significant correlations were obtained with all variables in female group when the data was split into two gender groups. Surprisingly, in the male group no significant correlation was obtained in any of the variations compared. It is a challenging task to provide an explanation for this result by examining the current literature and the current findings. When the mean WM and achievement scores of the female and male groups were compared, a slight increase was observed in the female group. A possible explanation for this gender difference might be that females are able to reveal their potential for learning in secondary school years better than males. Females achieved better than males in both WM tests (RST and BDST) and academic achievement tests. They generally performed better in all subjects examined in this study. Males might fail to demonstrate their potential abilities in learning outcomes.

Finally, the strong link between this mental capacity and academic abilities might provide an evidence for Gathercole and Alloway’s (2008) discussion on the impact of WMC on following classroom instructions. It is possible that students who have insufficient WM capacities have difficulties in understanding, recalling and following the instructions for in-class activities and in examinations, which makes learning more challenging for them and results in failure. Unless this mental problem is resolved, such students cannot take a further step and obtain good levels of achievement. Therefore, the development of appropriate techniques for the improvement of WMC and its implementation before the formal education has vital importance for students’ future academic success. A working memory training programme can be included into the education system and individuals who have been detected to have low WM capacities and to have the potential to perform poorly in academic life can be trained so that their WM capacities can improve and no longer constrain learning. By appropriate WM improvement techniques, one of the cognitive factors affecting learning might be eliminated. This study provided strong evidence for the discussed WM- learning relationship. Future studies should investigate which WMC techniques can improve academic achievement effectively. The answer may totally change an individual’s future academic life.

5.3. Significance of the Findings

The findings from this study make several contributions to the current literature. First, the study has gone some way towards enhancing our understanding of working memory and its role on learning. The current findings add new perspectives to a growing body of literature on WM as one of the cognitive factors influencing learning and students’ attainments at school. The high correlations between WMC and academic achievement provided solid empirical evidence for the assigned role of WM in complex cognitive abilities and learning.

Second, the analysis regarding the second language performance suggests that WM is able to predict L2 achievement better when the learners advance in language and reach higher levels. Additionally, it seems possible that sub-components of working memory might be predictive of success in specific sub-skills in L2. A test assessing predominantly L2 vocabulary knowledge did not correlate with verbal WM. However, another test assessing attainments of several sub-skills of L2 showed significant correlation with verbal WM. In other words, verbal WM was predictive of general L2 achievement when the achievement was assessed in several domains and when the students advanced in the target language.

Finally, this study amply brought into light a remarkable factor which had great influence on the strength of the relationship between WM and academic achievement: Gender. The striking analysis uncovered that WMC was a perfect predictor of female students’ achievement at school, while it failed to establish any significant link to male students’ achievement, which might be related to different problem solving strategies in males and females.

5.4. Implications for Education

The findings that working memory accounted for individual differences in academic attainment have valuable implications for education.

Within the field of education, the child is central, and it is necessary to understand what is happening (or not happening) for the individual child if learning is proceeding smoothly (Gathercole & Alloway, 2008). As Danili & Reid (2004) suggested, educationalists must take into account cognitive factors in learners.

Furthermore, as Alloway & Alloway (2010) indicated, students frequently need to rely on working memory to perform a range of activities. Poor working memory may lead to failures in performing daily classroom activities such as remembering classroom instructions and in learning (Lamont et al., 2006). Without early intervention, working memory deficits cannot be made up over time and will continue to compromise a child's likelihood of academic success (Alloway, 2009). Therefore, it is suggested that students must be screened to identify the strengths and weaknesses of their working memory profile for effective management and support to bolster learning.

The current study uncovers that teachers and educators can employ one of the two complex WM measures in this study in order to determine their students' working memory capacity. This identification will enable them to guide the students properly for their future education. The predictive role of working memory capacity on academic abilities might have unique contribution to future academic life.

It is evident that WMC is one of the cognitive factors which constrains or facilitates learning as well as L2 acquisition. If WMC can be improved by appropriate techniques, learners can achieve better levels in academic courses, particularly in second language.

5.5. Suggestions for Further Research

Further research in the field regarding the role of WM in academic achievement involving L2 attainments would be of great help in drawing more precise conclusions on the issues discussed in previous chapter.

This research left the following questions hanging:

- What are the reasons for lower (though significant) relations of WM with English (L2) achievement?
- How can the gender difference in the strength of relationship between WMC and academic achievement be explained more precisely?
- What are the reasons underlying the superior scores of females both in WM measures and academic achievement measures?

As Yuan et al. (2006) highlight, improving WMC holds the promise of providing students with more cognitive resources for both knowledge acquisition and application. It may not only improve students' current achievement, but more importantly, also enhance their lifelong learning.

REFERENCES

Adams, A. M., Gathercole, S. E., Service, E., Hitch, G. J., & Martin, A. J. (1999). Phonological short-term memory and vocabulary development: Further evidence on the nature of the relationship. *Applied Cognitive Psychology, 13,* 65–77.

Alloway, T. P. (2009). Working memory, but not IQ, predicts subsequent learning in children with learning difficulties. *European Journal of Psychological Assessment, 25,* 92–98.

Alloway, T. P. (2007a). *Automated working memory assessment*. London: Pearson Assessment.

Alloway, T. P. (2007b). Working memory, reading, and mathematical skills in children with developmental coordination disorder. *Journal of Experimental Child Psychology,96,* 20-36.

Alloway, T. P. (2006). How does working memory work in the classroom. *Educational Research Review, 1*, 134–139.

Alloway, T. P., & Passolunghi, M. C. (2011). The relations between working memory and arithmetical abilities: A comparison between Italian and British children. *Learning and Individual Differences, 21*, 133-137.

Alloway, T. P., & Alloway, R. G. (2010). Investigating the predictive roles of working memory and IQ in academic attainment. *Journal of Experimental Child Psychology, 106*, 20-29.

Alloway, T. P., & Archibald, L. M. (2008). Working memory and learning in children with developmental coordination disorder and specific language impairment. *Journal of Learning Disabilities, 41*, 251-262.

Alloway, T. P., & Pickering, S. J. (2006). Verbal and visuospatial short-term and working memory in children: Are they separable? *Child Development, 77(6),* 1698-1716.

Alloway, T. P., Gathercole, S. E., Kirkwood, H. J., & Elliott, J. E. (2009). The cognitive and behavioural characteristics of children with low working memory. *Child Development, 80*, 606-621.

Alloway, T. P., Gathercole, S. E, Willis, C., & Adams, A. M. (2004). A structural analysis of working memory and related cognitive skills in early childhood. *Journal of Experimental Child Psychology, 87*, 85-106.

Alloway, T. P., Gathercole, S. E, Willis, C., & Adams, A. M. (2006). Working memory in children with reading disabilities. *Journal of Experimental Child Psychology, 93*, 265-281.

Alptekin, C., & Erçetin, G. (2009). Asssessing the relationship of working memory to L2 reading: Does the nature of comprehension process and reading span task make a difference?. *System, 37,* 627-639.

Anderson, J. R. (1983). *The architecture of cognition.* Cambridge, MA: Harvard University Press.

Aronen, E. T., Vuontela, V., Steenari, M. R., Salmi, J., & Carlson, S. (2005). Working memory, psychiatric symptoms, and academic performance at school. *Neurobiology of Learning and Memory, 83*, 33-42.

Atkins, P. W. B., & Baddeley, A. D. (1998). Working memory and distributed vocabulary learning. *Applied Psycholinguistics, 19,* 537–552.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 2, pp. 89-195). New York: Academic Press.

Baddeley, A. D. (2010). Working memory. *Current Biology, 20(4),* 136-140.

Baddeley, A. D. (2003). Working memory and language: an overview. *Journal of Communication Disorders, 36,* 189-208.

Baddeley, A. D. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience, 4*, 829-839.

Baddeley, A. D. (2000a). The episodic buffer: A new component of working memory? *Trends in Cognitive Sciences, 4*, 417-423.

Baddeley, A. D., (2000b). Short-term and working memory. In E. Tulving and F. Craik (Eds.), *The Oxford Handbook of Memory* (pp. 77-92). New York: Oxford University Press.

Baddeley, A. D. (1996). Exploring the central executive. *Quarterly Journal of Experimental Psychology, 49A (1)*, 5 – 28.

Baddeley, A. D. (1986). *Working memory*. Oxford: Oxford University Press.

Baddeley, A. D., & Logie, R. H. (1999). Working memory: The multiple-component model. In A. Miyake & P. Shah (Eds.), *Models of working memory* (pp. 28-61). New York: Cambridge University Press.

Baddeley, A. D, & Hitch, G. (1974). Working memory. In G. Bower (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47-90). New York: Academic Press.

Baddeley, A. D., Gathercole, S. E., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105*, 158-173.

Baddeley, A. D., Lewis, V. J., Eldridge, M., & Thompson, N. (1984). Attention and retrieval from long-term memory. *Journal of Experimental Psychology: General, 113,* 518-540.

Bayliss, D. M., Jarrold, C., Gunn, M. D., & Baddeley, A. D. (2003). The complexities of complex span: Explaining individual differences in working memory in children and adults. *Journal of Experimental Psychology: General, 132,* 71-92.

Brown, L., Gathercole, S. E., & Pickering, S. J. (2003). Working memory assessments at school entry as longitudinal predictors of national curriculum attainment levels. *Educational and Child Psychology, 20*, 109-122.

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Shifting, inhibition, and working memory. *Developmental Neuropsychology*, *19*, 273-293.

Carlson, N. R. (2009). *Psychology: the science of behavior*. Canada: Pearson.

Carretti, B., Cornoldi, C., De Beni, R., & Romano, M. (2004). Updating in working memory: A comparison of good and poor comprehenders. *Journal of Experimental Child Psychology, 91*, 45-66.

Case, R., Kurland, M., & Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of Experimental Child Psychology, 33*, 386–404.

Chi, M. T. H. (1976). Short-term memory limitations in children: Capacity or processing deficits? *Memory and Cognition, 4*, 559-580.

Conlin, J. A., Gathercole, S. E., & Adams, J. W. (2005). Children's working memory: Investigating performance limitations in complex span tasks. *Journal of Experimental Child Psychology, 90*, 303-317.

Cowan, N. (2005). *Working Memory Capacity*. Hove, UK: Psychology Press.

Cowan, N. (1999). An embedded-process model of working memory. In A. Miyake & P. Shah (Eds.), *Models of working memory* (pp. 62-101). New York: Cambridge University Press.

Cowan, N., & Winkler, I. (2005). From sensory to long-term memory: evidence from auditory memory reactivation studies. *Experimental Psychology, 52 (1),* 3-20.

Cowan, N., & Alloway, T. P. (2008). The development of working memory. In N. Cowan (Ed.), *Development of memory in childhood* (2nd ed., pp. 303-342). Hove, UK: Psychology Press.

Daneman, M. & Carpenter, P. A. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, *19(4)*, 450-466.

Daneman, M., & Merikle, P. M. (1996). Working memory and language comprehension: A meta-analysis. *Psychonomic Bulletin & Review, 3*, 422-433.

Danili, E., & Reid, N. (2004). Some strategies to improve performance in school chemistry, based on two cognitive factors. *Research in Science and Technological Education*, *22,* 203–226.

De Jong, P. F. (1998). Working memory deficits of reading disabled children. *Journal of Experimental Child Psychology, 70*, 75-96.

De Smedt, B., Janssen, R., Bouwens, K., Verschaffel, L., Boets, B., & Ghesquière, P. (2009). Working memory and individual differences in mathematics achievement: A longitudinal study from first grade to second grade. *Journal of Experimental Child Psychology, 103,* 186-201.

Ellis, N. C. (1996). Sequencing in SLA: Phonological memory, chunking, and points of order. *Studies in Second Language Acquisition, 18,* 91-126.

Engel, P. M. J., Heloisa Dos Santos, F., & Gathercole, S. E. (2008). Are working memory measures free of socio-economic influence? *Journal of Speech, Language and Hearing Research, 51,* 1580-1587.

Engle, R. W. (1996). Working memory and retrieval: An inhibition-resurce approach. In M. Marschark (Series Ed.) & J. T. E. Richardson (Vol. Ed.), *Counterpoints: Cognition, memory and language: Vol. 3. Working memory and human cognition* (pp. 89-199). New York: Oxford.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent variable approach. *Journal of Experimental Psychology: General, 125,* 309 – 331.

Fitzpatrick, C., & Pagani, L. S. (2011). Toddler working memory skills predict kindergarten school readiness. *Intelligence, 40*, 205-212.

Gardner, R. C. (1985). *Social psychology and second langauge learning: The role of attitudes and motivation*. London: Edward Arnold.

Gathercole, S. E. (1999). Cognitive approaches to the development of short-term memory. *Trends in Cognitive Sciences, 3(11)*, 410-419.

Gathercole, S. E., & Baddeley, A. D. (1989). Development of vocabulary in children and short-term phonological memory. *Journal of Memory and Language, 28,* 200–213.

Gathercole, S. E., & Baddeley, A. D. (1993). *Working memory and language*. Hove: Erlbaum.

Gathercole, S. E., & Baddeley, A. D. (1996). *The children's test of nonword repetition*. London: Psychological Corporation.

Gathercole, S. E., & Pickering, S. J. (2000). Working memory deficits in children with low achievements in the national curriculum at 7 years of age. *The British Journal of Educational Psychology, 70*, 177−194.

Gathercole, S. E., & Alloway, T. P. (2008). *Working Memory and Learning*. London: Sage Publications.

Gathercole, S. E., Willis, C. S., Emslie, H., & Baddeley, A. D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. *Developmental Psychology, 28,* 887–898.

Gathercole, S. E., Pickering, S. J., Knight, C., & Stegmann, Z. (2004). Working memory skills and educational attainment: Evidence from national curriculum assessments at 7 and 14 years of age. *Applied Cognitive Psychology, 18,* 1–16.

Gathercole, S. E., Alloway, T. P., & Pickering, S. J. (2006). Verbal and visuo-spatial short-term and working memory in children: Are they seperable? *Child Development, 77*, 1698-1716.

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology, 40(2)*, 177-190.

Gathercole, S. E., Alloway, T. P., Kirkwood, H. J., Elliott, J. G., Holmes, J., & Hilton, K. A. (2008). Attentional and executive function behaviors in children with poor working memory. *Learning and Individual Differences, 18*, 214-223.

Harrington, M., & Sawyer, M. (1992). L2 working memory capacity and L2 reading skill. *Studies in Second Language Acquisition, 14*, 25-38.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. In G. H. Bower (Ed.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 22, pp. 193-225). San Diego, CA: Academic Press.

Hitch, G. J. (1984). Working memory. *Psychological Medicine, 14*, 265-271.

Isaacs, E. B., & Vargha Khadem, F. (1989). Differential course of development of spatial and verbal memory span: A normative study. *British Journal of Developmental Psychology, 7,* 377-380.

Iuculano, T., Moro, R., Butterworth, B. (2011). Updating working memory and arithmetical attainment in school. *Learning and Individual Differences, 21*, 655-661.

James, W. (1905). *Principles of psychology* (Vol. 4). London: Methuen.

Jonides, J., Lacey, S. C., & Nee, D. E. (2005). Processes of working memory in mind and brain. *Current Directions in Psychological Science, 14*, 2-5.

Juffs, A. (2004). Representation, processing and working memory in a second language. *Transactions of the Philological Society, 102(2),* 199-225.

Just, M. A., & Carpenter, P. A. (1989). The role of working memory in language comprehension. In D. Klahr & K. Kotovsky (Eds.), *Complex information processing: The impact of Herbert A. Simon* (pp. 31-68). Hillsdale, NJ: Erlbaum.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *The Psychological Review, 99*, 122-149.

Kane, M. J., & Engle, R. W. (2002). The role of prefrontal cortex in working memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin and Review, 9*, 637-671.

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: A latent variable approach to verbal and visuo-spatial memory span and reasoning. *Journal of Experimental Psychology: General, 133*, 189-217.

Kelly, K., & Phillips, S. (2011). *Teaching literacy to learners with dyslexia: A multisensory approach*. London: Sage Publications.

Kintsch, W., Healy, A. F., Hegarty. M., Pennington, B. F., & Salthouse, T. A. (1999). Models of working memory: Eight questions and some general issues. In A. Miyake & P. Shah (Eds.), *Models of working memory* (pp. 412-441). New York: Cambridge University Press.

Kormos, J., & Sáfár, A. (2008). Phonological short-term memory, working memory and foreign language performance in intensive language learning. *Bilingualism: Language and Cognition, 11*, 261-271.

Krumm, S., Ziegler, M., & Buehner, M. (2008). Reasoning and working memory as predictors of school grades. *Learning and Individual Differences, 18*, 248-257.

Lamont, E., Gathercole, S. E., & Alloway, T. P. (2006). Working memory in the classroom. In S. Pickering (Ed.), *Working memory and education* (pp. 219-240). Oxford, UK: Elsevier.

Lamont, E., Gathercole, S. E., Alloway, T. P, Adams, A. M., Willis, C., & Eaglen, R. (2005). Working memory and other cognitive skills as predictors of progress towards early learning goals at school entry. *British Journal of Developmental Psychology, 23*, 417−426.

Logie, R. H. (1995). *Visuo-spatial working memory*. Hove, UK: Erlbaum.

Logie, R. H. (2003). Spatial and visual working memory: A mental workspace. *Psychology of Learning and Motivation, 42*, 37-78.

Logie, R. H. (1996). The seven ages of working memory. In M. Marschark (Series Ed.) & J. T. E. Richardson (Vol. Ed.), *Counterpoints: Cognition, memory and language: Vol. 3. Working memory and human cognition* (pp. 31-65). New York: Oxford.

Lu, L., Weber, H. S., Spinath, F. M., & Shi, J. (2011). Predicting school achievement from cognitive and non-cognitive variables in a Chinese sample of elementary school children. *Intelligence, 39*, 130-140.

Miyake, A., & Shah, P. (Eds.). (1999). *Models of working memory: Mechanisms for active maintenance and executive control.* New York: Cambridge University Press.

Miyake, A., & Friedman, D. (1998). Individual differences in second language proficiency: Working memory as language aptitude. In A. F. Healy & L. E. Bourne (Eds.), *Foreign language learning: Psycholinguistic studies on training and retention* (pp. 339-364). Mahwah, NJ: Lawrence Erlbaum.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81-97.

Miller, G. A., Galanter, E., & Pribram, K. H. (1960). Plans and The Structure of Behavior. New York: Holt.

Monette, S., Bigras, M., & Guay, M. C. (2011). The role of the executive functions in school achievement at the end of grade 1. *Journal of Experimental Child Psychology 109,* 158-173.

Nation, K., Adams, J. W., Bowyer-Crane, C. A., & Snowling, M. J. (1999). Working memory deficits in poor comprehenders reflect underlying language impairments. *Journal of Experimental Child Psychology, 73*, 139-158.

Neisser, U. (1967). *Cognitive psychology*. New York: Appleton- Century- Crofts.

Nevo, E., & Breznitz, Z. (2011). Assessment of working memory components at 6 years of age as predictors of reading achievements a year later. *Journal of Experimental Child Psychology, 109*, 73-90.

Newell, A. (1973). Production systems: Models of control structures. In W. G. Ghase (Ed.), *Visual information processing*. New York: Academic Press.

Niaz, M., & Logie, R. H. (1993). Working memory, mental capacity and science education: Towards an understanding of the "working memory overload hypothesis". *Oxford Review of Education*, *19*, 511–525.

Osaka, M., & Osaka, N. (1992). Language- independent working memory as measured by Japanese and English reading span tests. *Bulletin of the Psychonomic Society, 30*, 287-289.

Pallant, J. (2011). *SPSS Survival Manual: A Step by Step Guide to Data Analysis using SPSS 4th Edition*. Australia: Allen & Unwin.

Papagno, C. & Vallar, G. (1995). Verbal short-term memory and vocabulary learning in polyglots. *Quarterly Journal of Experimental Psychology, 48A (1),* 98–107.

Pickering, S. J., & Gathercole, S. E. (2004). Distinctive working memory profiles in children with special educational needs. *Educational Psychology*, *24*, 393 – 408.

Pickering, S. J., & Gathercole, S. E. (2001). *Working Memory Test Battery for Children*. London: Pearson Assessment.

Raghubar, K. P., Barnes, M. A., & Hecht, S. A. (2010). Working memory and mathematics: A review of developmental, individual difference, and cognitive approaches. *Learning and Individual Differences, 20*, 110-122.

Richardson, J. T. E. (1996). Evolving issues in working memory. In M. Marschark (Series Ed.) & J. T. E. Richardson (Vol. Ed.), *Counterpoints: Cognition, memory and language: Vol. 3. Working memory and human cognition* (pp. 120-154). New York: Oxford.

Roivainen, E. (2011). Gender differences in processing speed: A review of recent research. *Learning and Individual Differences, 21,* 145-149.

Seigneuric, A., Ehrlich, M. F., Oakhill, J. V., & Yuill, N. M. (2000). Working memory resources and children's reading comprehension. *Reading and Writing, 13*, 81-103.

Seitz, K., & Schumann-Hengsteler, R. (2000). Mental multiplation and working memory. *European Journal of Cognitive Psychology, 12,* 552-570.

Service, E. (1992). Phonology, working memory, and foreign-language learning. *Quarterly Journal of Experimental Psychology, 45A,* 21–50.

Service, E., Simola, M., Metsaenheimo, O., & Maury, S. (2002). Bilingual working memory span is affected by language skill. *European Journal of Cognitive Psychology, 14*, 383-407.

Shah, P., & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General, 125*, 4-27.

Shallice, T., & Warrington, E. K. (1970). Independent functioning of verbal memory stores: A neuropsychological study. *Quarterly Journal of Experimental Psychology, 22,* 261-273.

Speck, O., Ernst, T., Braun, J., Koch, C., Miller, E., & Chang, L. (2000). Gender differeces in the functional organization of the brain for working memory. *Neuroreport, 11 (11),* 2581-2585.

St. Clair-Thompson, H. L., & Gathercole, S. E. (2009). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *Quarterly Journal of Experimental Psychology, 59*, 745–759.

Swanson, H. L. (1994). Short-term memory and working memory: Do both contribute to our understanding of academic achievement in children and adults with learning disabilities? *Journal of Learning Disabilities, 27*, 34-50.

Swanson, H. L., & Beebe-Frankenberger, M. (2004). The relationship between working memory and mathematical problem solving in children at risk and not at risk for math disabilities. *Journal of Education Psychology, 96,* 471-491.

Swanson, H. L., & Howell, M. (2003). Working memory, short-term memory, and speech rate as predictors of children's reading performance at different ages. *Journal of Educational Psychology, 93,* 720–734.

Swanson, H. L., & Sachse-Lee, C. (2001). Mathematical problem solving and working memory in children with learning disabilities: Both executive and phonological processes are important. *Journal of Experimental Child Psychology, 79*, 294-321.

Tillman, C. M., Nyberg, L., & Bohlin, G. (2007). Working memory components and intelligence in children. *Intelligence, 36*, 394-402.

Towse, J. & Cowan, N. (2005). Working memory and its relevance for cognitive development. In W. Schneider, R. Schumann-Hengsteler, & B. Sodian (Eds.), *Young children's cognitive development* (pp. 9-37). Mahwah, NJ: Lawrence Erlbaum.

Towse, J. N., & Hitch, G. J. (1995). Is there a relationship between task demand and storage space in tests of working memory capacity?. *Quarterly Journal of Experimental Psychology, 48*, 108–124.

Towse, J. N., Hitch, G. J., & Hutton, U. (1998). A reevaluation of working memory capacity in children. *Journal of Memory and Language, 39*, 195-217.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language, 28,* 127-145.

Vallar, G., & Papagno, C. (2003). Neuropsychological impairments of short-term memory. In A. D. Baddeley, M. D. Kopelman, & B. A. Wilson (Eds.), *Handbook of memory disorders* (pp. 249 – 270). Chichester, UK: John Wiley & Sons.

Van den Noort, M. W., Bosch, P., & Hugdahl, K. (2006). Foreign language proficiency and working memory capacity. *European Psychologist, 11(4)*, 289-296.

Waters, G. S., Caplan, D., DeDe, G. & Kemtes, K. (2004). The relationship between age, verbal working memory and language comprehension. *Psychology and Aging, 19(4)*, 601-616.

Waters, G. S., & Caplan, D. (2003). The reliability and stability of verbal working memory measures. *Behavior Research Methods, Instruments and Computers, 35*, 550-564.

Waters, G. S., & Caplan, D. (1999). Verbal working memory capacity and language comprehension. *Behavioral and Brain Science, 22*, 114-126.

Waters, G. S., & Caplan, D. (1996). The measurement of verbal working memory capacity and its relation to reading comprehension. *Quarterly Journal of Experimental Psychology, 49A*, 51-74.

Waugh, N. C., & Norman, D. A. (1965). Primary memory. *Psychological Review, 72*, 89-104.

Wechsler, D. (1993). *Wechsler objective reading dimensions*. London: Pearson Assessment.

Wechsler, D. (1996). *Wechsler objective numerical dimensions*. London: Pearson Assessment.

Yuan, K., Steedle, J., Shavelson, R., Alonzo, A., & Oppezzo, M. (2006). Working memory, fluid intelligence and science learning. *Educational Research Review, 1*, 83-98.

Zheng, X., Swanson, H. L., & Marcoulides, G. A. (2011). Working memory components as predictors of children's mathematical word problem solving. *Journal of Experimental Child Psychology, 110*, 481-498.

Zoelch, C., Seitz, K., & Schumann-Hengsteler, R. (2005). From rag(bag)s to riches: Measuring the developing central executive. In W. Schneider, R. Schumann-Hengsteler, & B. Sodian (Eds.), *Young children's cognitive development* (pp. 9-37). Mahwah, NJ: Lawrence Erlbaum.

APPENDICES

Appendix A: Sentences in the Reading Span Test

Sentences in the Reading Span Test

2 Sentences

Set-1

1. Yavru kedinin tüyleri pamuk gibi yumuşacık ve kar gibi **beyaz**.

2. Şairin, duygularını dizelere aktardığı en değerli hazinesidir **kalem.**

Set-2

3. Ali'yi odasına çağırdı ve sınıfın camını nasıl kırdığını sordu **müdür.**

4. Sarı saçları, boncuk gibi gözleriyle ne kadar tatlı bir **bebek.**

3 Sentences

Set-1

5. Ne kadar da lezzetlidir fırından yeni çıkmış taptaze bir **ekmek.**

6. Sırtında yük, kucağında bebekle çok yorgun görünüyordu zavallı **kadın.**

7. Suya batırılan bir kuş gibi can çekişir denizden çıkarılan **balık.**

Set-2

8. Annemin bu seneki doğum günü hediyesi yeni, pembe bir **çanta.**

9. Yoğun kar yağışından dolayı trafik çok yavaş ilerliyor bu **akşam.**

10. Uçan balonunu elinden kaçırınca ağlamaya başladı küçük **çocuk.**

4 Sentences

Set-1

11. Çocukları hayal dünyasında gezdirir ve yepyeni ufuklar açar **kitap.**

12. Burası, meyve ağaçları ve güzel kokulu çiçeklerle dolu bir **bahçe.**

13. Masmavi göklerde özgürce dalgalanıyor şanlı, ay yıldızlı al **bayrak.**

14. Uçak kalkmadan önce hava ve uçuş hakkında bilgiler verdi **pilot.**

Set-2

15. Dallarda ötüşen neşeli kuşlar baharın gelişini kutluyor bu **sabah.**

16. Kalabalık ailemi ve çocukluğumu hatırlatıyor bana karşı duvardaki **resim.**

17. Öyle akıllı ki, sahibi ne söylerse hemen yapıyor sevimli küçük **köpek.**

18. Kimine kör karanlık, kimine ise tozpembe görünür bu yalan **dünya.**

5 Sentences

Set-1

19. Bu sıcak yaz gününde sahildeki kumları yakıp kavuruyor **güneş.**

20. Sokakta neşeyle oynayan çocukları izlerken mutlu oluyor **insan.**

21. Yüksek binaları ve kalabalık sokaklarıyla beni bunaltıyor bu **şehir.**

22. Eski dostları uzun zaman sonra tekrar buluşturdu dün akşamki **yemek.**

23. Tiyatroda herkesi bir heyecan ve merak duygusu sarar açılınca **perde.**

Set-2

24. Bilgi yarışmasının büyük ödülü son model kırmızı bir **araba.**

25. Karanfil, capcanlı renkleri ve güzel kokusuyla ne hoş bir **çiçek.**

26. Boğazdaki vapurları ve kanat çırpan martıları hatırlatır bana **deniz.**

27. Karganın ağzından peyniri almak için onu kandırmaya çalışır **tilki.**

28. Hayvanların yuvası, toprağın örtüsü ve yurdun can damarıdır **orman.**

Appendix B: Backward Digit Span Test

Backward Digit Span Test

2 Digits

Set-1: 5-8

Set-2: 9-3

3 Digits

Set-1: 2-7-1

Set-2: 5-2-8

4 Digits

Set-1: 4-9-2-8

Set-2: 7-3-1-6

5 Digits

Set-1: 5-1-8-2-6

Set-2: 3-7-8-2-4

6 Digits

Set-1: 2-5-6-8-1-3

Set-2: 6-9-3-4-8-1

Appendix C: Tez Fotokopisi İzin Formu

TEZ FOTOKOPİSİ İZİN FORMU

ENSTİTÜ

Fen Bilimleri Enstitüsü	
Sosyal Bilimler Enstitüsü	X
Uygulamalı Matematik Enstitüsü	
Enformatik Enstitüsü	
Deniz Bilimleri Enstitüsü	

YAZARIN

Soyadı : Çalışkanel
Adı : Gamze
Bölümü : İngiliz Dili Öğretimi

TEZİN ADI (İngilizce) : The Relationship between Working Memory, English (L2) and Academic Achievement in 12-14 year-old Turkish Students: The Effect of Age and Gender

TEZİN TÜRÜ : Yüksek Lisans [X] Doktora [ ]

1. Tezimin tamamından kaynak gösterilmek şartıyla fotokopi alınabilir. [ ]
2. Tezimin içindekiler sayfası, özet, indeks sayfalarından ve/veya bir bölümünden kaynak gösterilmek şartıyla fotokopi alınabilir. [ ]
3. Tezimden bir (1) yıl süreyle fotokopi alınamaz. [X]

TEZİN KÜTÜPHANEYE TESLİM TARİHİ: