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Final Dissertation

Echoes of the Early Years: Investigating Auditory Working Memory Development in the First Years of Life

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ABSTRACT

The present study investigates the relationship between auditory working memory and language in 21 Turkish infants aged from 6 to 25 months. The participants (N=21) were assessed through two instruments, namely the ADAM experiment -used to evaluate the phonological working memory capacity of the infants- and the MacArthur-Bates Communicative Development Inventory -employed to evaluate the language development-. All assessment process was conducted online. The ADAM experiment was conducted twice. The second test was fifteen days apart from the first. The results showed that the mean value for phonological memory span was calculated to be 2, indicating a two-item memory capacity. Moreover, no statistically significant evidence was found to support that language comprehension has a relationship with working memory scores after controlling for age. On the other hand, analyses regarding the link between language production and phonological working memory capacity indicated that there is a modest significant relation between the two constructs. Because of the preliminary nature of the study and the limited sample size, future studies are needed to expand the results of this research.

Keywords: auditory working memory, language development, infants, ADAM experiment, MB-CDI.

INTRODUCTION

In developmental and cognitive research, the role of auditory working memory emerges as an essential factor in both language acquisition and overall cognitive advancement. This dissertation explores the interaction between auditory working memory and language development during infancy. Despite its significance, the developmental trajectory of auditory working memory and its connection with language acquisition in infancy remains relatively unexplored. Previous studies have provided insights into this relationship, yet the full scope of this interaction remains vague, particularly within the context of Turkish infant development. Therefore, this preliminary research attempts to investigate the developmental course of auditory working memory among a cohort of 21 Turkish infants, aged between 6 and 25 months.

This dissertation is organized into five distinct chapters, each contributing to the general understanding of the relationship between auditory working memory and language acquisition in infancy.

Chapter One, Literature Review, delves into the theoretical foundations of working memory, central models, and the developmental facets of auditory working memory. It also addresses cognitive factors influencing auditory working memory and presents a synthesis of prior research in this domain.

Chapter Two, Introduction, clarifies the background and significance of the study, outlines research objectives, and poses research questions that serve as guidelines for the study.

The Methodology chapter outlines the research design, participant selection, data collection methods, measures and instruments, data analysis techniques, and ethical considerations to ensure credible findings.

Chapter Four, Results, unfolds the outcomes of the study through descriptive analyses of participants, an in-depth examination of auditory working memory performance, and an exploration of correlations between auditory working memory and language acquisition.

The fifth chapter, Discussion, offers an interpretation of the research outcomes, highlighting key findings, discussing their implications both theoretically and practically, and suggesting recommendations for future studies in this domain. This chapter also addresses potential limitations and concludes the dissertation by summarizing its contributions to the understanding of auditory working memory and language development in infancy.

CHAPTER 1

LITERATURE REVIEW

1.1. Working Memory: Concept and Theoretical Framework

Even though the term "working memory" can have different meanings depending on the setting, it is generally used as the system responsible for temporarily holding and manipulating information related to the current cognitive task (Baddeley, 1992). The working memory system is crucial in various aspects of everyday life, such as decision-making, problem-solving, reasoning, and learning (Goldstein, & Naglieri, 2011). This flexible yet limited system enables individuals to temporarily retain behaviorally relevant information in their minds. Also, it is crucial to execute mental tasks depending on current goals (Bledowski et al.,2012).

1.1.1. Central Models for Understanding Auditory Working Memory

Various models explain the theoretical framework of auditory working memory, and Baddeley and Hitch (1974) and Baddeley (1986) are the best-known models of working memory and its components. The first model to provide an explanation of information processing and was developed by Baddeley and Hitch in 1974.

Baddeley's model

According to the model, the mind functions like a machine by taking in stimuli as inputs and producing outputs. The authors suggested that working memory is a multi-component system with various subsystems. It was also recognized that the stimulus is an important factor when it comes to performance. For instance, some would perform better when the stimuli were visual, and others would perform better when they were auditory (Baddeley and Hitch, 1974).

Moreover, Baddeley and Hitch (1974) showed that the brain's ability to store and manipulate information relies on general cognitive functions and is linked to individual limits of attention.

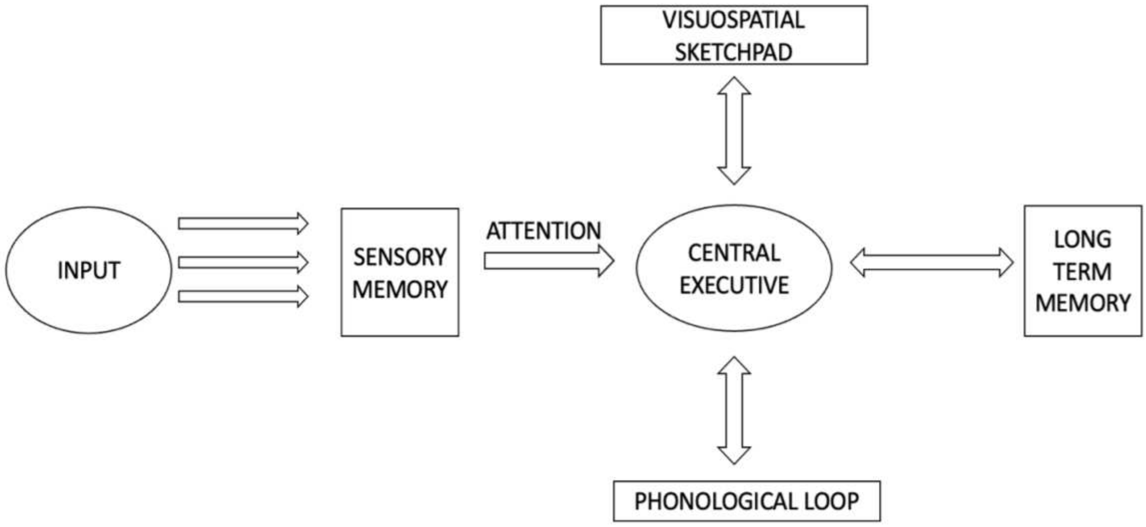

Figure 1- Working Memory Model of Baddeley and Hitch, 1974

The components of the model are the central executive, phonological loop, and visuospatial sketchpad. The central executive focuses attention on important information and in order to match task demands, it regulates working memory capacity. Secondly, the phonological loop is responsible for holding verbal and auditory information such as sounds, or words. Lastly, the visuospatial sketchpad serves a comparable purpose to the phonological loop, but with visual stimuli. (Baddeley 2000).

In 2000, Baddeley added a new component named episodic buffer to the original model. The episodic buffer plays an important role in combining information from different sources into one.

In 2011, Baddeley, Allen, and Hitch created a new version of the model that added the sensory modalities that were missing before. In the new model, they highlighted the importance of the episodic buffer in integrating these modalities. The central executive only manages the episodic buffer, which is not connected to other subsystems like previously believed.

Allen, Baddeley, and Hitch (2014) made an interesting observation about the central executive in their research. To explain individual differences in visuospatial tasks, a dual-attentional component in the central executive is proposed.

Participants were given a working memory task where the first three items were presented with matching information. For instance, they see a red square, a yellow rectangle, and a green circle. Participants were able to recall the information for the first three stimuli (e.g., red square, yellow rectangle, and green circle). However, after the fourth stimulus, their performance changed. The findings suggested that there is a different attentional system involved for the later items.

Working memory has a component that focuses specifically on retaining and manipulating auditory information (Cowan, 2014). This is known as auditory working memory. It specifically centers on the ability to temporarily store and operate auditory input (Roy, 2018). Auditory working memory is critical for language comprehension, speech production, reading, and other auditory-related tasks. It enables people to briefly retain and manipulate auditory information, such as words, sounds, or syllables.

Cowan's model

The second important model for the theoretical framework of auditory working memory is the embedded processes model by Nelson Cowan (1999). This theoretical model encompasses the main components and functions of auditory working memory. It aims to explain how auditory information is processed while performing cognitive tasks.

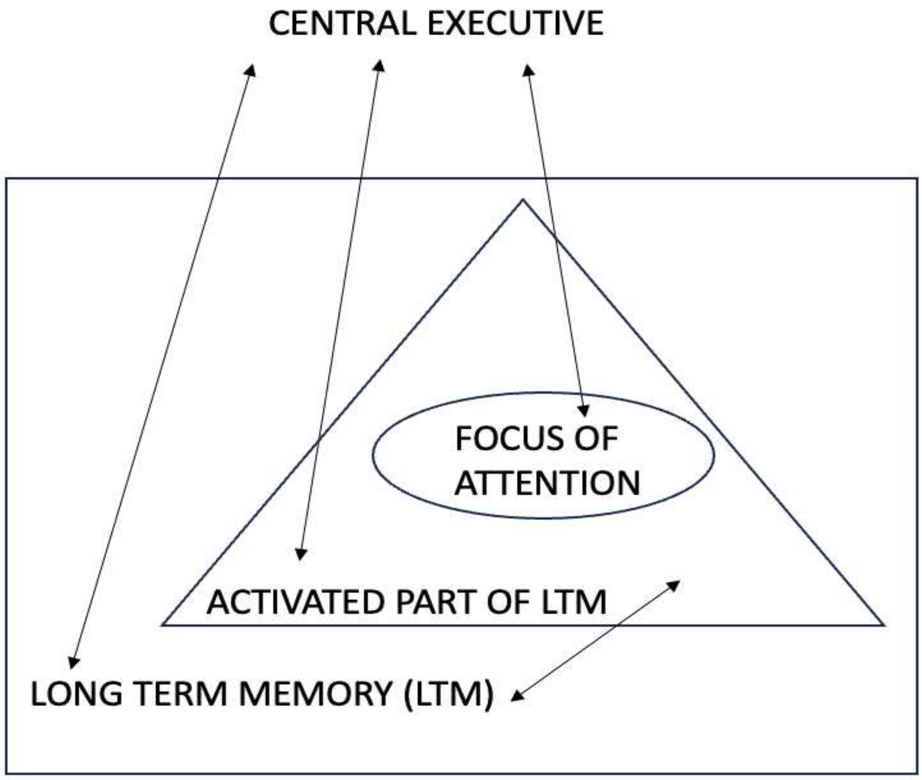

Figure 2- Cowan (1999) embedded processes model

Cowan (1999) proposed a hypothesis stating that working memory holds embedded courses including long-term memory and attention. While Cowan's model does not deny the definitions provided by other models for the working memory process, it does offer a more comprehensive explanation.

In his model, Cowan (2010) emphasizes a framework for understanding the features of attention and long-term memory as interconnected processes. Based on this model, the working memory functions in a singular manner, regardless of the stimulus or input it receives (Cowan 1999, 2010).

Cowan argues that Baddeley's model is limited to phonological and visuospatial short-term memory and overlooks other forms of representation. Cowan (2010) proposed that various modalities of representation exhibit differences compared to auditory and visuospatial stimuli.

The properties of these representations may change depending on their encoding features. If someone knows the names of the items, verbal encoding is better than serial recall for remembering. The initial process of how information is stored can affect how well it can be remembered and retrieved in the future. When information is presented visually and the person knows the names of the items, they can use a verbal strategy to remember it more effectively.

When organizing items based on their direction or position, a visuospatial encoding strategy is more effective. This involves picturing the spatial arrangement of objects. It works particularly well when the relationships between items depend on their relative positions, such as recalling the order of items in a clockwise or counterclockwise arrangement.

1.1.2. Neural Correlates of Auditory Working Memory

In addition to the theoretical framework, understanding the neural correlates of auditory working memory is crucial. Exploring the neural correlates of auditory working includes identifying the important brain regions and neural networks involved in this cognitive function. The neural correlates of auditory working memory can vary depending on the task. For instance, auditory and visual working memory tasks may not involve the same brain regions and networks.

Moreover, phonological short-term memory is vital when it comes to language learning. Baddeley (2003) proposed a neurobiological basis for the phonological loop. According to this theory, the temporary storage system is in Brodmann area 44 while the rehearsal system is centered in Brodmann area 40 (Broca's area). In this context, auditory information is evaluated and sent to a short-term storage facility. Then, the information can move to an output system and this can result in spoken output or rehearsal. Furthermore, visually presented material can be converted from an orthographic code to a phonological code and stored within the phonological output system. This process helps maintain and process linguistic information during language-related tasks (Vallar & Papagno, 2002).

The superior temporal sulcus and the superior temporal gyrus are in the auditory cortex and are important regions for understanding the neural correlates of auditory working memory. The superior temporal gyrus and superior temporal sulcus are involved in the initial encoding and representation of auditory stimuli (Zevin, 2009). Secondly, the prefrontal cortex, specifically the dorsolateral prefrontal cortex (DLPFC), plays major role in working memory. It is responsible for maintaining and manipulating auditory information. The DLPFC holds auditory items in mind and updates the content as new information is presented (Curtis & D'Esposito, 2003).

Another central neural correlate that plays an important part in auditory working memory is the parietal cortex. It is associated with temporarily storing and recalling verbally coded information. The storage and manipulation of auditory information during working memory tasks are also executed by the parietal cortex (Jonides et al., 1998).

Additionally, the thalamus is another significant part of the brain that helps us understand auditory working memory. It acts as a transit station between the various brain regions involved and mutually communicates signals between them. It helps coordinate and integrate information in auditory processing (Fama & Sullivan, 2015).

Besides considering the role of specific brain regions, it is crucial to take into account how the various areas interact. Indeed, neural oscillations are another important mechanism for auditory working memory. In several studies (Pina et al., 2018; Von Stein and Sarnthein, 2000; Kahana et al., 2001; Klimesch et al., 2010), specific patterns of neural oscillations were observed during auditory working memory tasks. These rhythmic electrical activities help synchronize activity between different brain regions and may contribute to the maintenance and manipulation of auditory information (Arski et al., 2021).

1.1.3. Developmental Aspects of Auditory Working Memory

Auditory working memory is an essential function that enables people to temporarily hold and manipulate auditory information, such as speech, and sounds. It plays a fundamental role in various aspects of everyday life, such as language comprehension, problem-solving, and communication (Baddeley & Hitch, 1974). The developmental aspects of auditory working memory are also important when it comes to understanding how this cognitive ability evolves throughout human life.

In infancy, auditory working memory capabilities are elementary. Infants show basic abilities to detect and recognize sounds and voices. They can briefly hold simple auditory stimuli in memory. A study by Colombo et al. indicated that the activation period for the mental representation of young infants is shorter (Colombo et al.,1990). When a fixation on a visual target was paired with an auditory reward, a 3-month-old could remember either only the pattern or only the location of the pattern. They failed to remember the association after a 5-minute break (Colombo et al., 1990).

The study by Ross-Sheehy & Newman (2015) examines the capacity of auditory short-term memory for non-linguistic sounds in 10-month-old infants. The experiment involved exposing infants to auditory sequences of repeating patterns. The musical patterns consisted of either two or four distinct instruments, such as flute, piano, or cello, played for durations of either 350 or 700 milliseconds, followed by a 500-millisecond pause. There were two types of sequences: constant and varying by one instrument in each repetition. The researchers measured how long the infants listened to each type of auditory sequence by observing infants' head-turn preferences. Preferring the varying sequences indicated the infants were using auditory short-term memory because recognizing the new instrument required remembering all the instruments in each sequence. The results indicated that infants paid more attention to the varying sequences for 2-instrument sequences with 350-millisecond notes.

Similar to current research, another preliminary study by Grasso (2022) was conducted with 24 Italian infants aged from 7 to 27 months old. The researcher used the ADAM experiment to assess auditory working memory in 24 infants. The results of the preliminary research showed that as the child's age increased processing speed in recognizing, the target sequence was decreased. However, this negative correlation was not statistically significant. In this preliminary study, the link between working memory and language comprehension was also investigated. The results showed that while controlling for the age of the children, a modest positive correlation between language comprehension and phonological memory was observed. The study found no significant correlation between language production and phonological working memory for 24 Italian infants aged from 7 to 27 months.

In early childhood, there is a remarkable development in auditory working memory. Children become more proficient at remembering and repeating short sounds or words. For instance, they can accurately repeat a series of numbers or recall a set of words they were just exposed to. Case and colleagues investigated the concept of counting span, where children were asked to count the object numbers and then recall the precise order of the items in previous displays (Case et al., 1982). The evaluation of operational efficiency meant measuring the duration it took for the child to repeat a word immediately after hearing it. The study concluded that a linear relationship exists between operational efficiency and memory span among children within the age range of 2 and 6 years old. Therefore, with an increase in the speed of repetition, the memory span also showed a corresponding increase. Research findings indicate that with age, 3-4 years old infants require less mental effort to perform tasks, leading to increased storage capacity in the brain (Gathercole, 1998).

Middle childhood is a critical phase for auditory working memory development. Children in the 7-11 age range demonstrate improvements in their working memory capacity. The capacity of working memory increases during middle and late childhood. They can hold and operate more complex auditory information. Studies have indicated that the improved effectiveness of working memory in this age group is a result of both heightened processing speed and a better ability to prevent irrelevant information from entering memory (de Ribaupierre & Ludwig, 2002). Probably, the improvement in processing speed and the capacity to filter out insignificant stimuli are due to alterations in myelination and synaptic pruning in the cortex (Kail et al., 2013). Neural networks supporting auditory working memory experience significant development, and factors like attention, executive functions, and phonological processing contribute to these advances.

Adolescence is a period of further improvement in auditory working memory skills. As the prefrontal cortex develops, higher-level thinking like problem-solving and planning integrates with working memory. This developmental stage is characterized by greater cognitive flexibility, which enables adolescents to switch between tasks and handle multiple streams of auditory information effectively (Schweinsburg et al., 2005).

It is essential to recognize that individual differences exist in the development of auditory working memory. Genetic factors, environmental influences, and early experiences can impact the trajectory of auditory working memory growth in children. Some may demonstrate remarkable working memory abilities, while others might struggle in this domain.

The capability to hold, manipulate, and process auditory information, known as auditory working memory, is a vital cognitive function that progresses significantly from infancy through adolescence. As children grow and develop, their competency in this area becomes more advanced. Understanding the developmental aspects of auditory working memory can be a useful resource for educators, researchers, and parents.

1.1.4. Cognitive Factors Influencing Auditory Working Memory

Auditory working memory is a complex cognitive process and fundamental to cognitive functioning. Therefore, it is crucial to understand the cognitive factors that play a role in shaping and influencing auditory working memory.

Attention is a cognitive factor that significantly influences auditory working memory. Cowan (1995) proposed that working memory contains activated memories from long-term memory. From this perspective, it can be assumed that attention and working memory are closely linked. Both concepts aim to process information effectively by prioritizing relevant information over irrelevant information (Awh et al., 2006).

On the other hand, according to Fougnie (2008), attention plays a minor role in the maintenance of working memory, but it holds significance in the processes of encoding and manipulating information within working memory. Therefore, independently of the theoretical framework, the ability to selectively focus on relevant information while filtering out distractions seems crucial for working memory.

Executive functions are a set of higher-order cognitive processes (Miller & Wallis, 2009) and play an essential role in auditory working memory. As explained above, Baddeley proposed that working memory contains a central executive system (CES), and this system regulates the distribution of attentional resources and coordinates information within a limited capacity. The CES of working memory is closely related to other aspects of executive function like inhibition, cognitive flexibility and goal directed behavior (D'Esposito et a., 1995). Executive function skills provide the ability to concentrate, recall information, adhere to rules, and adapt to changes (Meuwissen & Zelazo, 2014).

Phonological processing is the capacity to process and operate sounds in language (Wagner & Torgesen, 1987). It is a critical factor affecting auditory working memory, especially when dealing with verbal information. Phonological processing allows individuals to encode, maintain, and manipulate phonological representations in working memory (Wagner & Torgesen, 1987).

Auditory working memory is influenced by a range of cognitive factors that interact and shape one's ability to process auditory information. Educators and researchers can improve auditory working memory performance and learning by understanding these cognitive influences.

1.2. Language Acquisition in Infancy: The Role of Auditory Working Memory

Language acquisition during early childhood is the initial process for linguistic development. It involves phonological, semantic, and grammatical structures in a specific language. Auditory working memory during language acquisition enables infants to temporarily store and manipulate auditory information and facilitates the recognition and understanding of speech sounds, words, and sentences. As Hasenstab wrote in her article, "Knowledge of linguistic acquisition stages or levels and the sequence of development that occurs in normal children is extremely valuable and will serve as a guideline in early language evaluation and intervention programs" (Hasenstab, 1982, page 14).

Auditory working memory plays a vital role in phonological processing during infancy. Early ability in auditory stimuli is critical for the development of vocalizations and other auditory information fundamental to following language development (Hasenstab, 1982). By holding and manipulating phonemic representations in their working memory, infants can discriminate between speech sounds and recognize phonological patterns (Baddeley, 2003). In his article, Baddeley (2003) investigates the crucial relationship between language processing and working memory. By taking his model into account (Baddeley and Hitch, 1974), he proposed that language tasks often rely on both the phonological loop and the central executive for successful completion (Baddeley, 2003).

Baddeley and his colleagues (Baddeley et al.,1998) studied the role of the phonological loop in language learning. They proposed that the phonological loop is a key component of working memory by facilitating the processing and retention of sounds and phonetic elements. The short-term storage and manipulation of auditory and verbal knowledge are other capacities of the phonological loop (Baddeley et al.,1998).

In addition, the researchers discuss how the phonological loop enables learners to encode and maintain phonetic information in a new language. They proposed that the rehearsal and repetition of language elements within the phonological loop contribute to the consolidation of linguistic knowledge (Baddeley et al.,1998).

Auditory working memory is also linked to vocabulary development during infancy. The link between auditory working memory and vocabulary development becomes more apparent as infants progress from single sounds to multi-word phrases. They acquire new words through exposure to their linguistic environment and interactions with caregivers and the surrounding world (Hasenstab, 1982). According to Baddeley (2003), working memory plays a significant role in acquiring new vocabulary. It assists in remembering new words long enough for them to be transferred to long-term memory.

Hasenstab (1982) also highlights the importance of language comprehension in addition to expressive language. Understanding the meaning of words and sentences precedes the ability to produce them. The role of auditory working memory (AWM) in grammatical development is evident as infants learn and produce more complex grammatical structures. Baddeley (2003) highlights the role of working memory in sentence comprehension. As infants process sentences, the phonological loop helps retain the beginning while the central executive works to link subsequent words. AWM enables them to process and apply grammatical rules, such as subject-verb agreement and word order, in their speech (Baddeley, 2003).

1.3. Relevance of Auditory Working Memory for Educational and Clinical Settings

There have been a considerable number of studies on the topic of working memory. As one of the crucial components of working memory, auditory working memory has also received some attention from researchers over the years.

One of the most important conclusions the studies have reached is the limited capacity of auditory working memory. Studies consistently demonstrate that auditory working memory has a limited capacity, typically holding around 5 to 9 items in adults (Miller, 1956; Cowan, 1998; Cowan, 2010). According to Cowan (1998) even though the limited capacity of the working memory can easily be observed, the determinants of it are challenging to specify. He proposed that the limited capacity is influenced by the details of the stimuli. For instance, participants performed better in retaining lists of words that can be pronounced quickly compared to given instructions to pronounce the same words slowly (Cowan, 1998).

This capacity is influenced by factors such as individual differences and the complexity of the information being processed. In his study, Logie (2011) mentions that the notion of identifying individual differences in working memory capacity is crucial for understanding the variance in performances. Logie (2011) proposed that one reason for such variation in individual performances on working memory tasks could be different cognitive abilities such as differences in attentional control, cognitive flexibility, and inhibitory control (e.g., Chen & Cowan, 2009; Johnson et al., 2010; Logie et al., 1996).

Another commonly reached conclusion of the previous studies on auditory working memory is dual-task interference. Auditory working memory tasks can be disrupted when individuals perform concurrent auditory or non-auditory tasks. This may indicate that auditory working memory shares cognitive resources with other processes. In their research, Fougnie and Marois (2011) investigated the factors that constrain working memory capacity, focusing on the simultaneous storage of visual and auditory information. The researchers conducted experiments to investigate whether working memory limitations are caused by domain-specific sources. The findings suggest that there are limits to visual and auditory information storage in working memory. Working memory capacity is constrained by modality-specific factors, indicating that the ability to store visual and auditory information simultaneously is limited. Participants showed better memory recall when dealing with the same modality (e.g., visual-visual, or auditory-auditory) compared to mixed-modality (e.g., visual-auditory).

In addition to dual-task interference, some studies have tried to improve auditory working memory through training programs. Even though working memory has been evaluated as having a limited capacity, there are still studies reporting that it can be improved by adaptive and extended training (Klingberg, 2010).

In their article, Schneiders and colleagues studied if auditory working memory processes can be trained and, if so, which changes lead to these effects (Schneiders et al., 2012). The researchers examined whether practicing working memory with different auditory stimuli only improves performance in an auditory working memory task or extends to a visual working memory task as well. Significant improvements in the auditory working memory task were observed after completing the memory training. The changes in activity were detected in the right inferior frontal gyrus, indicating increased efficiency in processing auditory stimuli (Schneiders et al., 2012).

In another article, Klingberg and colleagues developed a new training program for children with ADHD (Klingberg et al., 2005). This training involves the repeated practice of working memory tasks. After each trial, feedback and rewards were given according to accuracy. The training sessions last for 30-40 minutes per day, five days a week, over five weeks, totaling approximately 15 hours. The task difficulty is adjusted during the training on a trial-by-trial basis to match the individual's working memory capacity.

The outcomes obtained from this training method have been promising. Participants, especially children with ADHD, have shown significant improvements in their working memory capacity after the training program. These gains were not limited to the trained WM tasks but extended to other cognitive abilities and academic skills as well (Klingberg et al., 2002- 2005).

By using the technique developed by Klingberg and colleagues, numerous studies have demonstrated improvements in working memory tasks. Training in working memory has been shown to bring about improvements in cognitive functions such as inhibition and reasoning (Conway et al., 2003; Davidson et al., 2006).

The clinical implications of previous research on auditory memory are also essential. Many psychological disorders such as attention deficit hyperactivity disorder (ADHD), schizophrenia, and language impairments have been associated with auditory working memory deficits. Understanding these deficits may offer insights into these disorders and potential treatment strategies.

Archibald (2016) investigated the relationship between working memory and language learning. Her review aimed to provide an understanding of how working memory capacity influences the process of acquiring a new language and predicting language learning outcomes.

She specifies that children with speech, language, and communication needs (SLCN) include diverse profiles. It is obvious that multiple factors can contribute to these developmental challenges. Some children may experience a deficit in the domain-general executive attentional system and working memory, which can delay language learning and functioning. On the other hand, children experience difficulties in learning because of a domain-specific deficit in processing linguistic stimuli. She concludes that when addressing intervention strategies, clinicians must consider the strengths and weaknesses of each child in relevant processes (Archibald, 2016).

In another study, Menon and others (2001) aimed to understand the neural basis of auditory working memory in individuals with schizophrenia. The study sought to shed light on potential neural mechanisms that contribute to cognitive impairments in the disorder. The researchers conducted a functional MRI study with male participants diagnosed with schizophrenia (N = 11) and control subjects (N = 13). They employed a two-back auditory WM task and used region of interest analysis (Menon et al., 2001).

The results showed that individuals with schizophrenia were slower compared to the participants in the control group and their performance were significantly worse. Moreover, they exhibited reduced lateralization of activation and significant deficits in brain activation related to working memory. These findings suggest that disrupted working memory processing in schizophrenia may be associated with specific symptoms, particularly unusual thought content and thinking disturbances (Menon et al., 2001).

1.4. Cultural Factors and Language Development: The Case of Turkey

Since this study is conducted with Turkish infants, it is important to review some Turkish research that focus on auditory working memory and language studies in Turkish literature. It is important to note, however, that the studies carried out so far in Turkey mostly focused on school children. No study of auditory working memory and language in infancy (the age group relevant for the current thesis) was retrieved from the literature review.

The first article that will be reviewed here is aimed at assessing the differences in phonological storage processes among children with reading difficulties and examining the constraints on phonological storage capacity and its impact on reading performance. The study by Tercan and her colleagues involved a group of 4 girls and 15 boys aged 6 to 14 (a total of 19 participants) who had been diagnosed with reading disabilities. Two control groups, one for verbal abilities (n = 19) and the other for performance abilities (n = 19), were carefully matched in terms of age, gender, number of words read per minute, and WISC-R subtest scores (Tercan et al., 2012).

The findings indicated that children with reading disabilities showed poorer performance in repetition tasks compared to control groups. Specifically, they made errors in word and sentence tasks. These results suggest that Turkish children with reading difficulties encounter difficulties in the phonological memory process and have a restricted phonological storage capacity, which consequently impacts their reading performance (Tercan et al., 2012).

Based on the conclusions of Tercan and her colleagues, it is vital to assess the capacity of phonological storage as an additional approach to identifying at-risk groups for reading disabilities among school-age children, even before they enter school (Tercan et al., 2012).

Another study by Demirtas and Ergul aimed to compare first-grade children with low reading achievement to their peers who have average reading achievement, focusing on the connections between word reading, phonological awareness, rapid naming, and working memory skills. The study included 35 children with low reading achievement and 35 children with average reading achievement, all enrolled in first grade. The children's word reading performance was assessed using the Word Reading Test, their phonological awareness levels were measured using the Early Literacy Test, rapid naming skills were evaluated using the Rapid Naming Test, and their working memory performance was calculated using the Working Memory Scale (Demirtas & Ergul, 2019).

The results showed that first-grade children who are identified as having low reading achievement exhibited lower performance in all assessed areas compared to their peers with average reading achievement. Moreover, it was found that children with low reading achievement performed less successfully in the subskills that represent phonological awareness compared to their peers with average reading achievement. Lastly, according to the results, children with low reading achievement demonstrated significantly lower performance in working memory compared to their peers with average reading achievement (Demirtas & Ergul, 2019).

1.5. Summary

To summarize, working memory is an essential part of everyday life. It can be defined as holding and manipulating information related to a concurrent cognitive task (Baddeley, 1992). Auditory working memory entails temporarily retaining and manipulating specifically auditory information (Roy, 2018).

In this chapter, the concept and theoretical framework to study auditory working memory have been mentioned since the current study investigates auditory working memory in 21 Turkish infants aged from 6 to 25 months. Under the concept and theoretical framework of auditory working memory, the central models of working memory, the neural correlates of auditory working memory, and the developmental and cognitive aspects of auditory working memory have been examined by mentioning previous studies in the literature. Secondly, the role of language acquisition on auditory working memory is also a crucial topic of this study since the current research assesses language development in infants 25 months of age. In this section, the significance of working and auditory working memory related to language development has been discussed. Additionally, to give a comprehensive overview of the previous research on these topics, several studies relevant to the subject of the current study have been discussed and analyzed in the third section. Lastly, in the final section, several Turkish studies relevant to auditory working memory and language development have been reported in light of the value of understanding the cultural background of the current research.

CHAPTER 2

CURRENT RESEARCH

2.1. Background and Significance

Since auditory working memory plays a significant role in cognitive development, it is considered a significant area of developmental and cognitive research. To date, however, only a few studies have addressed the development of working memory and its relationship with language development in infancy. This is the case in studies carried out both in W.E.I.R.D. (Western, Educated, Industrialized, Rich and Democratic), populations, as well as in non-WEIRD cultures. Thus, this study aims to investigate the developmental trajectory of auditory working memory in 21 Turkish infants aged 6 to 25 months.

While examining the important characteristics of this study, such as its aim, objective, and results, some aspects should be considered. The first feature can be the age range of the research. The study focuses on twenty-one Turkish infants between the ages of 6 to 25 months. This age range is specifically chosen to examine the development of auditory working memory in the early years of life.

The second one may be the geographic aspect of the research. The study will be conducted with twenty-one Turkish infants. Therefore, Turkey's cultural and linguistic context is most likely to play a meaningful role in understanding the auditory working memory development of the participants in the results.

The assessment tools are also an important scope of the study. The research utilizes two assessment tools to measure auditory working memory and language development. The ADAM (an acronym for ADAptive Memory) experiment is used to assess auditory working memory specifically, while the MacArthur-Bates Communicative Development Inventory (MB-CDI; Arcalar et al., 2009) is used to evaluate overall language development.

The data collected from the MB-CDI will be correlated with the infants' performance in the ADAM experiment to explore the relationship between auditory working memory and language development in infants aged 6 to 25 months. Studying the development of auditory working memory and its link to early language skills can support creating successful interventions for at-risk infants with language and cognitive impairments.

2.2. Research Objectives and Questions

The aim of this preliminary research is to investigate the development of auditory working memory and explore its trajectories in twenty-one Turkish infants aged 6 to 25 months. Moreover, the key objectives of this research are determined as follows: firstly, assessing the auditory working memory capacity of Turkish infants aged 6 to 25 months using the ADAM experiment. This evaluation will enable the researchers to comprehend how the auditory working memory changes and is shaped in the early stages of life.

Additionally, since phonological working memory capacities are associated and predict language proficiency in older children (Baddeley et al.,1998; Hasenstab, 1982) it is vital to understand whether this association emerges in the course of development with the appearance of language production skills or can be rather observed from early infancy. The current study aims to explore language development in infants by also using the MacArthur-Bates Communicative Development Inventory. Lastly, examining the relationship between auditory working memory and language development in Turkish infants aged from 6 to 25 months is also central to the research. Examining the link between these two areas will contribute to developing a deeper understanding of early working memory development.

The research questions of the study are determined based on the aim and essential objectives of the study. Accordingly, the first research question that aims to be answered in the study is to measure working memory in a group of children within a certain age range. This preliminary study aims to uncover auditory working memory through an experimental game called ADAM in infants aged 6- 25 months old.

Another important research question that aims to clarify is whether there will be a relationship between auditory working memory capacity and language development in Turkish infants aged 6 to 25 months.

CHAPTER 3

METHODOLOGY

3.1. Research Design

The research design includes two essential assessment instruments: an online experimental task named ADAM (an acronym for ADAptive Memory) and the MacArthur Bates Communicative Development Inventory (MB-CDI). While ADAM measures auditory working memory capacity, MB-CDI assesses language development across receptive and expressive areas.

3.2. Participants

A total of 21 participants aged 6 months to 25 months completed the required procedures in this study. Twelve of them were girls and 9 were boys (mean age = 14.23 years).

All participants in the study were Turkish. However, of the 21 participants, 9 resided outside of Turkey (USA and Germany). Therefore, the infants were exposed to another language aside from Turkish, 6 of them to German, and 4 of them to English. The remaining 11 participants lived in Turkey and were only exposed to Turkish in their daily lives. The parents of the infants were primarily middle class and had higher education.

Participants were recruited through the snowball sampling technique using online platforms such as WhatsApp groups. The brochures of the study were distributed and interested people contacted the researcher at first. Families that accepted to participate directed the researcher to other parents. After the initial recruitment, 30 parents were contacted. However, 9 of them stopped responding after the first interaction. All 21 participants completed the entire procedure, providing valuable data for analysis.

3.3. Data Collection

Data collection took place for two months. Each participant completed 2 sessions. Sessions were scheduled 15 days apart. The sessions were held in a quiet and comfortable home environment, minimizing distractions and helping infants to pay full attention to the screen. All required data for the analysis was obtained online.

Before the baby started his/her first session online, the researcher conducted a Zoom meeting with the parent and went through the basic steps of the procedure as well as the methodological aspects to consider during the session. Parents were asked to use a personal computer throughout the procedure with a minimum screen size of 13 inches, excluding tablets or cell phones. They were also instructed to choose a bright and quiet room in their house, with the baby facing the main light source. It was also important that the baby paid undivided attention throughout the session so there were no distractions on or near the screen. Lastly, since the infants' gaze was recorded throughout the whole session, the distance of the baby was adjusted. The infants were seated on their parent's laps at 50 cm from the monitor. After the 10-minute introduction meeting, the baby started his/her first session on the computer.

The stimuli were presented using the Labvanced platform, available at https://www.labvanced.com/. Before running the ADAM study (see Measures and Instruments), a calibration process on Labvanced was performed to ensure the correct display of visual stimuli and the quality and volume of the audio stimuli.

After the first ADAM session, the parent completed the language inventory called The MacArthur Bates Communicative Development Inventory (MB-CDI; Arcalar et al., 2009). The inventory was sent through WhatsApp chat as a PDF document. After the parent completes the inventory, the first session was over.

Two weeks later, another individualized meeting was scheduled for each participant and the second session was conducted. The parents were again reminded of the procedure's important steps before starting ADAM on Labvanced. After the basic adjustments and calibrations, the last session started on the screen.

The first time the infants completed ADAM, they all started at Level 3 regardless of their age (based on numerous studies showing that young infants successfully learn information out of three-syllable sequences, e.g. Marcus et al., 1999; Saffran et al., 1996; Kovács & Mehler, 2009; Kabdebon & Dehaene-Lambertz, 2019). The second time the infants adaptively completed either Level 2 or Level 4 according to their score in the first ADAM, Level 3. Of twenty-one participants, 10 of them completed Level 4, and 11 of them continued with Level 2 in their second session.

PROCEDURE	DATE	ACTIVITY
PARTICIPANT RECRUITMENT	THROUGHOUT NOVEMBER	REACHING OUT TO PARENTS
FIRST SESSION	FIRST TWO WEEKS OF FEBRUARY	10-MIN INTRODUCTION ADAM GAME LEVEL 3 MB-CDI
	2 WEEKS LATER	
SECOND SESSION	FEBRUARY- MARCH	REMINDERS BEFORE THE SESSION ADAM GAME LEVEL 2/LEVEL 4

Figure 3- Data collection procedure

3.4. Measures and Instruments

3.4.1. MB-CDI

The MacArthur Bates Communicative Development Inventories (MB-CDIs) are widely used evaluation tools designed to assess language development in infants aged 8 to 30 months. It consists of a series of parent-report questionnaires that comprehensively understand an infant's early communication skills (Fenson, 2007).

The questionnaire includes both receptive and expressive language domains, including vocabulary, early gestures, and comprehension abilities. By relying on parents' responses, the MB-CDI captures a detailed picture of an infant's language abilities in an everyday context (Fenson, 2007).

In this study, the Level I inventory (i.e. short version of the CDI: Words and Gestures Form) was used. The extend of the questionnaire was decided according to the participant's age. Since the Turkish version has not been open to the public, the researcher translated the English version herself before distributing it to the parents. After the translation, another researcher who speaks both languages (English and Turkish) reviewed it.

3.4.2. e- ADAM

The second tool that is used in this study is an e-game named ADAM. It is an auditory working memory task used in psychology to measure an individual's ability to recall and manipulate auditory information in their auditory working memory (Benavides-Varela & Reoyo-Serrano, 2021).

In ADAM, participants are presented with a series of auditory stimuli, such as tones or verbal sequences. The stimuli are designed to test different aspects of auditory working memory. During the task, participants are required to listen carefully to the presented auditory stimuli and make judgments based on the information they hear (Benavides-Varela & Reoyo-Serrano, 2021).

Block structure

In this study, ADAM consisted of three blocks, with each section containing six familiarization trials and two test trials.

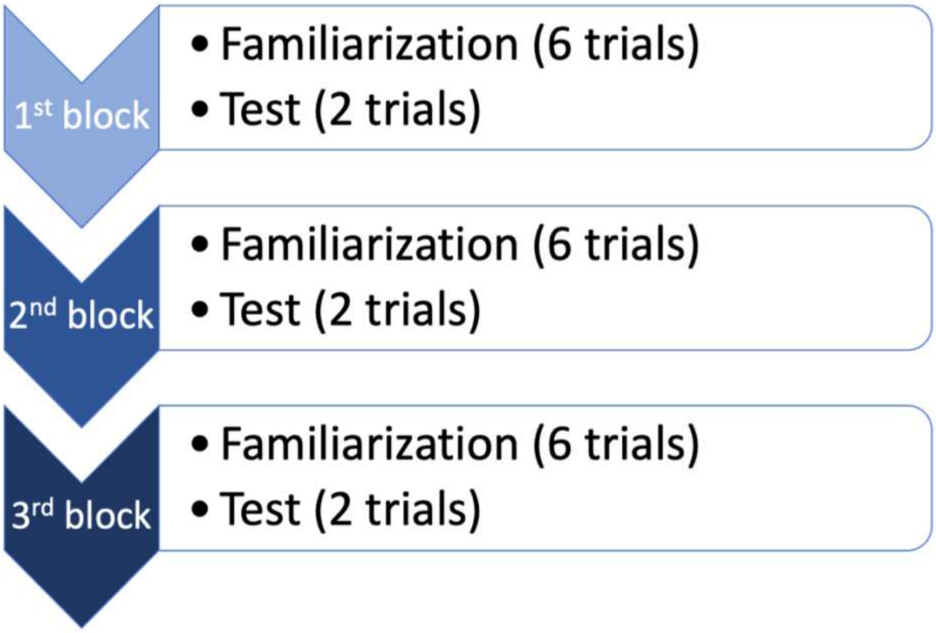

Figure 4- The structure of ADAM blocks

Trial structure

At the beginning of each trial, a central stimulus, and two white squares, one on the left and one on the right side of the screen were displayed. The purpose of the central stimulus was to grab the child's attention and direct their gaze toward the center. Once the child was focused on the center, the auditory sequence was played. After it was concluded, the attractor disappeared, leaving only the two white squares visible for a duration of 1 second.

Then, a puppet appears on one of the white squares for 2 seconds. When the child heard the target sequences, the puppet appeared on one side of the screen (counterbalanced across participants). On the other hand, when they hear the distractor, the puppet would appear on the other side. In each block, participants were presented with three target sequences and three different distracting sequences. The two types of sequences alternated in a semi-random way, with each type presented no more than twice in a row. The key difference between familiarization trials and test trials is that in the latter, there are no puppets involved, and the infant only listens to the sounds.

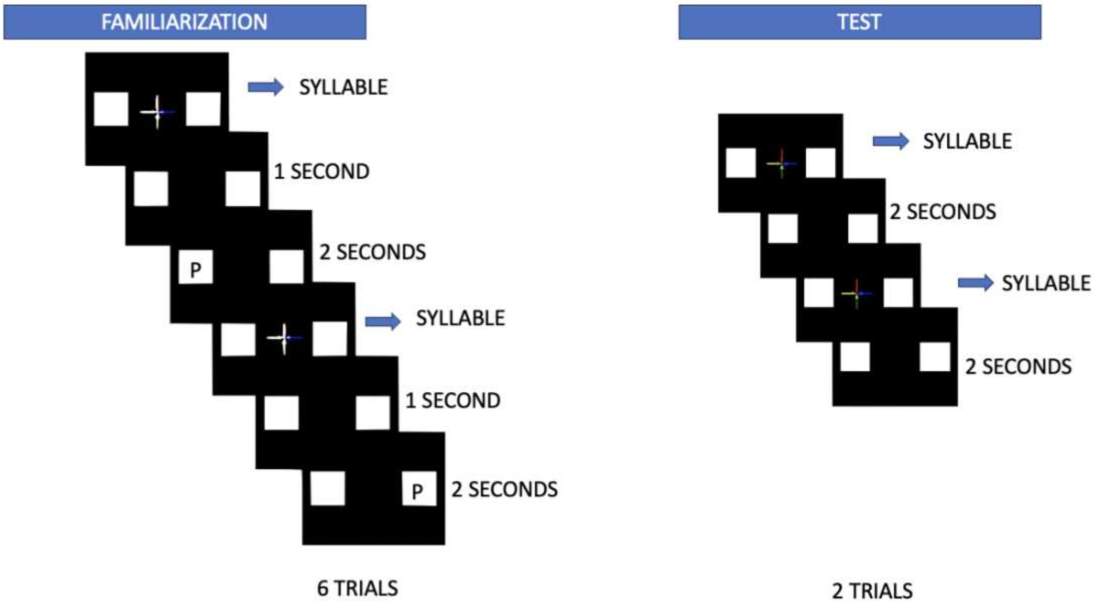

Figure 5- The structure of familiarization and test trials

Progression from Session 1 to Session 2

All infants in the study started with ADAM Level 3 and thus were exposed to 3-syllable sequences in the first session. The sequences have been specifically selected to have no meanings in Turkish. While creating the experiment, all sounds from all levels were checked, and made sure that they do not contain any meaning in Turkish.

After the infants completed Level 3, their test trial videos were coded (see Coding Procedure). The, the infants' capacity to retain 3-syllables sequences in auditory working memory was assessed through the calculation of the difference score (see below). The difference score also determined the starting level in the next session.

If the infant failed to retain the 3 syllable sequences, s/he continues with Level 2, i.e., hears 2-syllable words. On the other hand, if s/he succeeded with the 3 syllable sequences, s/he continues with Level 4, and thus was presented 4-syllable sequences in the last session.

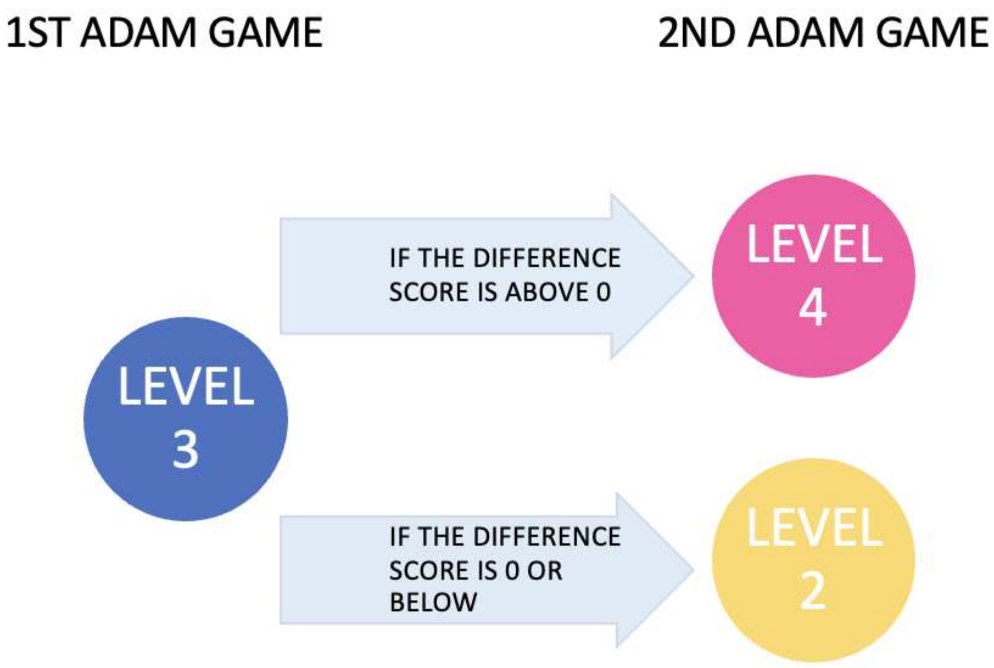

Figure 6- The levels of ADAM

3.5. Coding Procedure

The data analyses consisted of several steps. The first step was to complete the coding of the infant's gaze in the ADAM experiment. The infants' gaze was recorded through the families' webcams throughout the sessions. After the first session, the researcher downloaded the recorded videos from Labvanced. The videos were categorized under three names: test, anticipation, and toy, and included respectively 2, 1, and 1 second of the infants' gaze.

Firstly, with the help of the application named Smart Converter, all the videos were down-sampled to 25 frames per second. Then, the converted videos were analyzed frame by frame every 40 milliseconds by using an app named ELAN. By slowing down the videos the eye moments of the infants and the time were tracked when the infants' gaze was directed towards the stimuli.

3.5.1 Dependent variables

During the coding procedure, the main variables taken into account were first look, total look, and latency time. First look referred to the initial gaze of the child, whether it was directed right or left. Secondly, total look aimed to understand for how long the child looked to either left or right throughout the entire trial. Finally, latency time indicated how long it took for the child to shift their gaze away from the center.

After the first ADAM game (Level 3) the scores for each child, regarding both "first look" and "total look," were determined by taking into account the number of accurate and inaccurate responses to the target and distractor stimuli.

Difference score

The difference score was calculated based on the number of correct and incorrect responses in target and distractor trials. It is the calculation of the correct responses minus incorrect responses divided by the total number of responses.

$$\text{Difference Score} = \frac{\text{Correct Answers} - \text{Incorrect Answers}}{\text{Correct Answers} + \text{Incorrect Answers}}$$

The second step for the data analysis of this study was to organize and examine the data for MB-CDI. For the analysis of the MB-CDI, firstly, the data was properly organized in a spreadsheet including all participants in the study. Since all participants fully completed the inventory, no data were removed from the analysis.

The analyses were conducted using three variables for the language inventory. The first one was related to the vocabulary of the infant by assessing the words s/he can understand and/or produce. The second one was the actions and gestures the infants shows in their everyday life. Finally, language-related behaviors the infants do daily were also taken into consideration.

3.6. Description of Statistical Analyses

In order to gain insights into the participant characteristics, descriptive analyses were performed including the mean, mode, and median of the population. To evaluate the phonological working memory span of the sample, the Spearman correlation was computed. The relationship between latency and age was explored through the Spearman correlation analysis while ensuring reliability through a power analysis. Lastly, the relationship between language comprehension and working memory capacity was assessed through a partial regression while holding age as a constant. The same analysis was conducted for the investigation of the link between language production and working memory capacity.

3.7. Ethical Considerations

Throughout conducting this research, ethical implications were taken into consideration. Firstly, the parents were informed before and throughout the research by providing information about the purpose, and procedures of the study. After they showed interest in the study and before each session on Labvanced, the parents were once again informed about the procedure and asked for their verbal as well as written consent. Secondly, during data analysis, random numbers were used to ensure confidentiality. All data collected were coded and stored securely and accessed only by the research team. The anonymity of the data was maintained throughout the study. The study was approved by the Ethics Committee of the School of Psychology at the University of Padova.

CHAPTER 4

RESULTS

4.1. Descriptive Analysis of Participants

A descriptive analysis of the participant's demographic characteristics, the educational backgrounds of the parents, and the language development of the infants in the study were conducted. This aims to gain insights into the typical characteristics of infants at various ages. The sample for the current study consisted of 21 Turkish infants between the ages of 6 to 25 months.

	Option	Count	Percentage
Gender	Girl	12	57,14
	Boy	9	42,86
Age (mean) in months	Total	14.23	
	Girl	16.16	
	Boy	13.66	
Parental Education	Less than high school	0	0
	High School	2	4,77
	Bachelor's degree	33	78,57
	Master's degree or higher	7	16,66
Medical Information	Sight or hearing problems	0	0
	Linguistic problems	0	0
	Developmental problems	0	0
	Any sight or hearing related problems in the family	3	14,2

Figure 7- Descriptive information of the sample

As seen in Figure 7, the descriptive analysis of 21 participants revealed an average age of 14.23 months. The participant group was composed of 9 boys and 12 girls. The average age of boys was 13.66 months, while the girls had a slightly higher average age of 16.16 months.

The descriptive analysis of participants' parents revealed that the majority of mothers, totaling 20, have a robust educational background, having achieved university graduation (bachelor's) or higher qualifications. Only one mother had high school diplomas as her highest level of education. Similarly, 20 fathers received a bachelor’s diploma or higher education. Only one father had a high school diploma as the highest level of education.

All 21 infants were Turkish. Nine resided outside of Turkey (USA and Germany). Six of them were exposed to German, and 4 of them were exposed to English apart from Turkish. The remaining 11 infants lived in Turkey and were only exposed to Turkish in their daily lives.

None of the parents reported concerns about their infants' communication, language, sight, or hearing abilities. A subset of 3 parents disclosed the presence of linguistic or hearing problems within their own families. These parental characteristics and perspectives play an integral role in understanding the broader context, thus contributing to a comprehensive interpretation of the research outcomes.

4.2. Analysis of Auditory Working Memory Performance

The auditory working memory of the sample was examined. For the analysis of this preliminary study, the difference score for total looking time in the ADAM test has been taken into account.

Firstly, at the beginning of the research, all participants regardless of their age had completed level three for the ADAM experiment. In order for an infant to be involved in the analysis, s/he must complete at least 4 trials out of 8 total trials for the test phase. During the analyses, it was realized that 3 participants in the study had completed less than 4 trials in ADAM experiment level 3. For that reason, these participants were removed from the analysis.

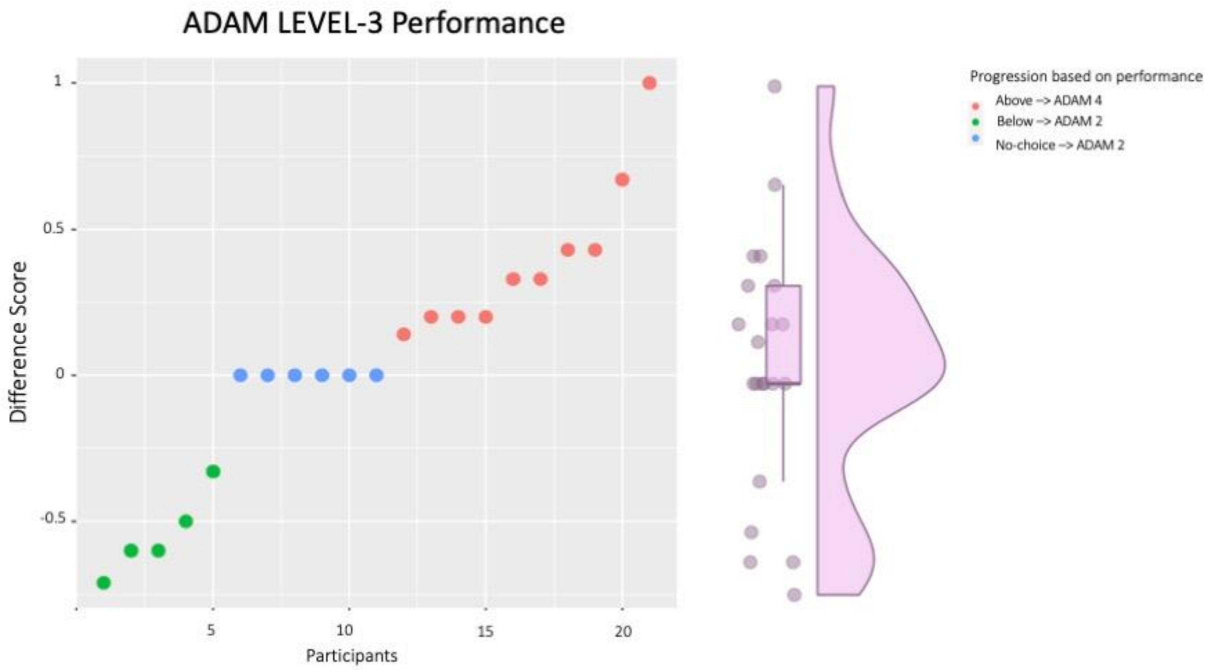

Figure 8- All participants' performance on ADAM Level 3

Figure 8 shows the difference score for total looking time on ADAM 3. Results highlight the variability in the participants' responses. Ten out of 19 infants passed the test with a positive score and continued with level 4 for the second experiment. While 5 children were unable to pass the test and got negative scores, 6 infants showed different responses and got 0 for their performance on ADAM 3.

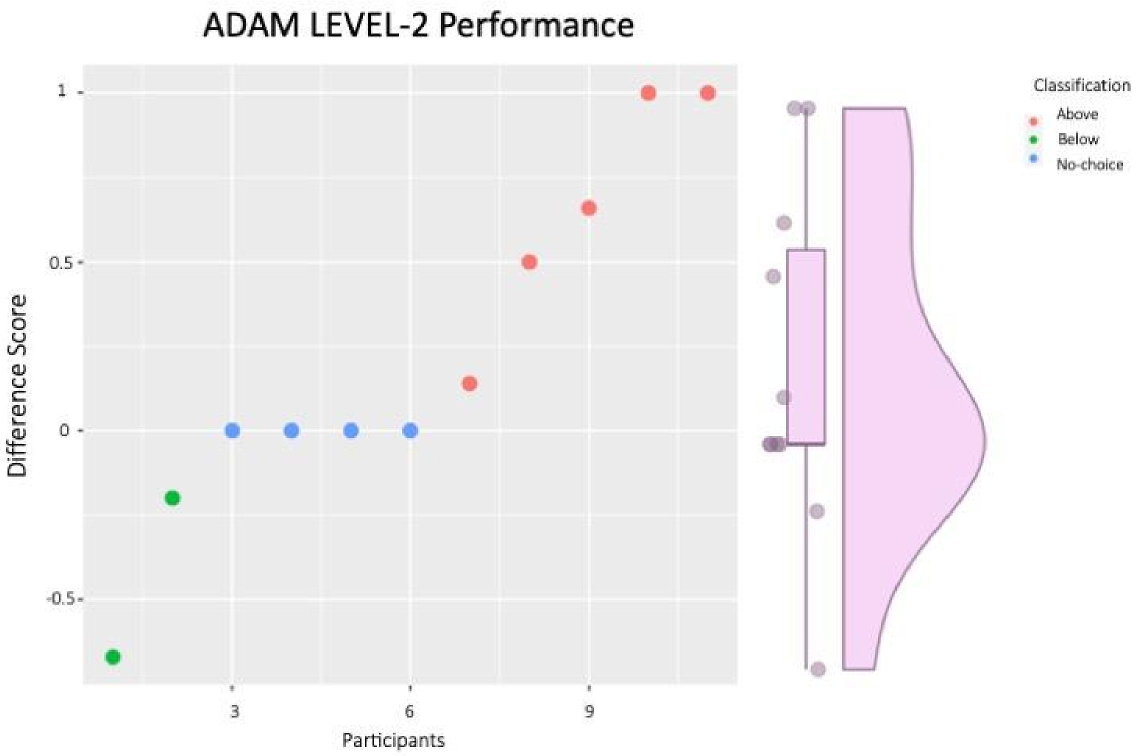

Figure 9- The participants' performance on Level 2

As mentioned before, infants who got 0 or above continued with Level 2 in the second experiment. Eleven participants completed at least 4 or more trials and were considered for the analyses of the difference score for total looking time. As displayed in Figure 9, there is a wide variability in the infants' responses. Specifically, five out of 11 infants were able to pass the second level with a positive score. This time, two infants received negative scores while the other four received zero.

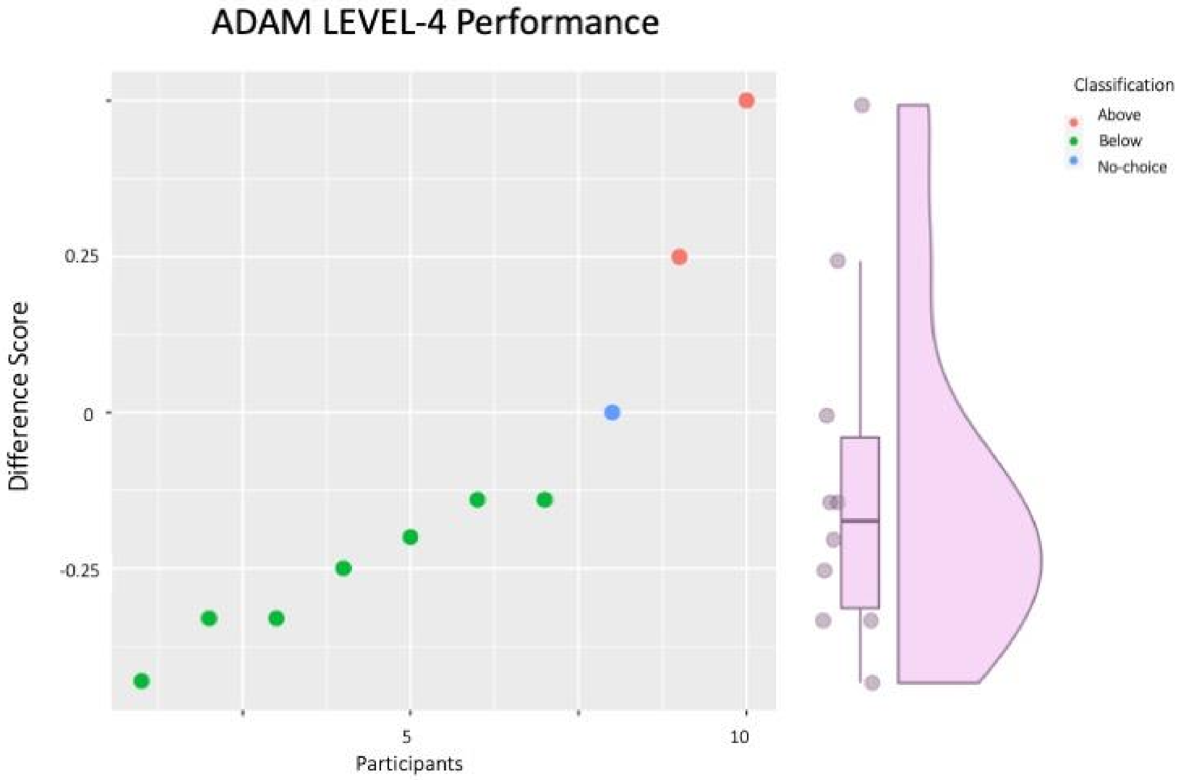

Figure 10- The infants' performance in the ADAM experiment Level 4

Figure 10 shows that, in ADAM 4, only two out of 10 participants achieved positive scores. In addition, 7 infants scored negatively and did not pass, while 1 other child showed random responses and scored 0.

4.2.1 Phonological Working Memory Span of the Sample

Based on the performances in the two ADAM tests, each child was assigned a score ranging from 1 to 4. The analysis was scored based on the following criteria: If a child received a positive score in both ADAM 3 and 4, they were given a score of 4. If they scored positively in ADAM 3 but negatively in Level 4, they got 3. Furthermore, if the score was negative or neutral in ADAM 3 but positive in ADAM 2, they were scored 2. If none of these happened, score 1 was given.

Based on the data presented in Figure 11, it can be seen that the mode is 1. Moreover, the mean value of phonological memory span is 2 for this sample.

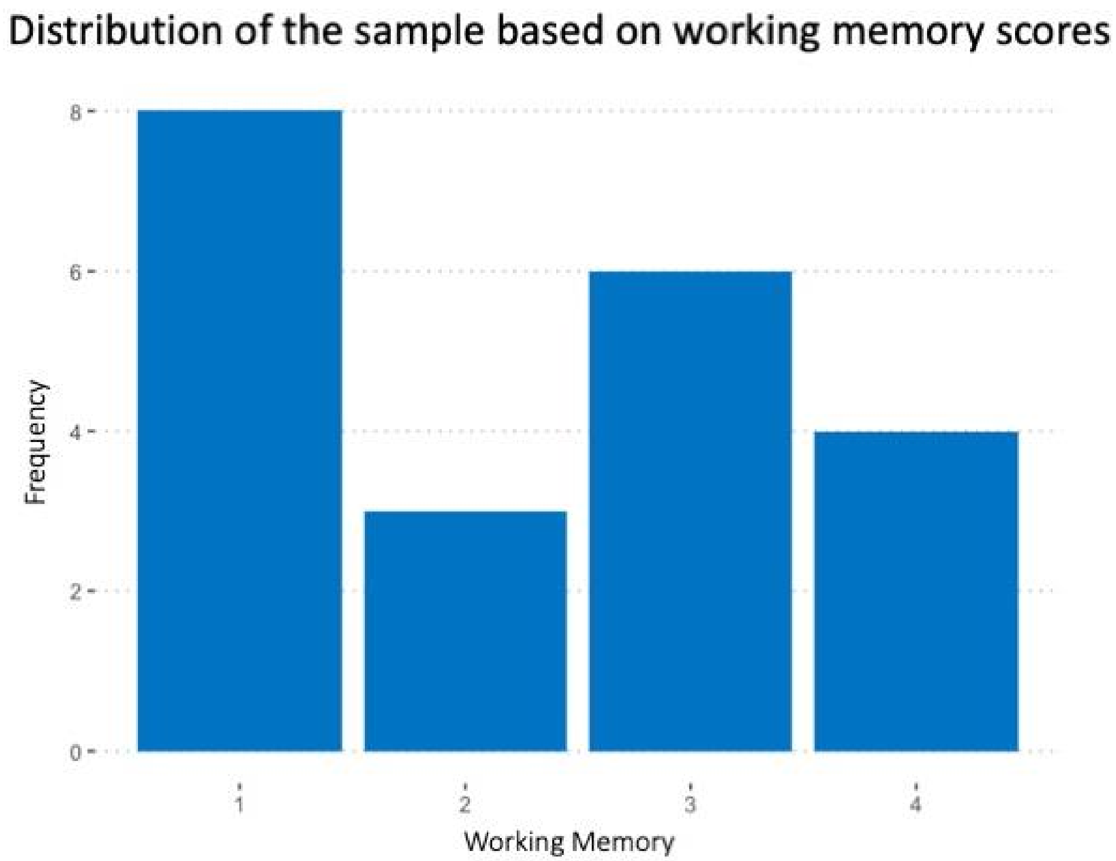

Figure 11- The phonological memory score for the sample

The relationship between participant's responses and age

When the Spearman correlation was analyzed, it was found that there is no statistically significant correlation between working memory and participants' age ($r_s = 0.04$, $p = 0.85$).

Another measure that is often used to evaluate participant's responses is the time it takes for a child to identify a target sequence, namely the latency. On average, the measured latency was 434 milliseconds, with a standard deviation of 110 milliseconds.

In Figure 12, a negative association with the child's age was observed. As the child's age increases, a decrease in latency time is observed although, this negative correlation was not statistically significant ($r_s = -0.32$, $p = 0.15$).

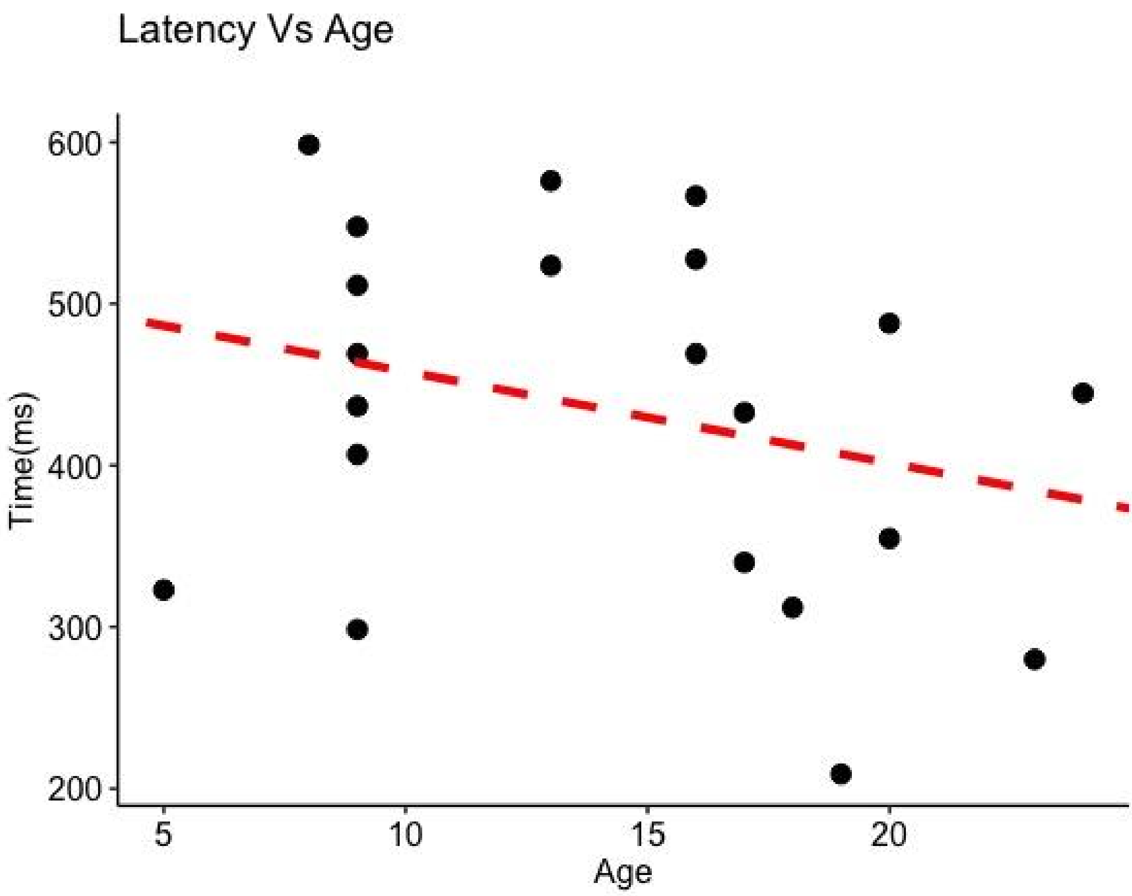

Figure 12- The relationship between latency and the age of participants

To assess the power achieved in this analysis, a post-hoc power analysis was performed in G*Power. The estimated statistical power of the analysis was found to be approximately 80% given this sample size (N=21), and the calculated effect size of .56.

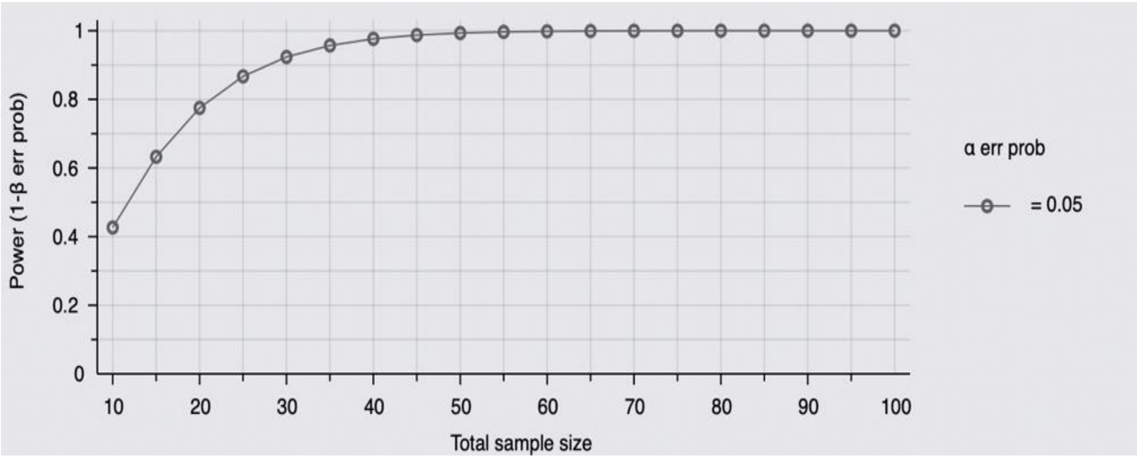

Figure 13- Correlation bi-variate normal model to estimate the achieved power

4.3. The Relationship Between Auditory Working Memory and Language Acquisition

4.3.1. Language Comprehension and Phonological Working Memory

The analysis investigating the link between language comprehension and working memory, while controlling for age, indicates that neither the predictor variable of interest in the model (language comprehension; t= -.19, p= .85) nor age (t= .31, p=.75) significantly explains the variance in working memory R^2 = -.10, $F(1,18)$ = 0.06, p =.93 (See Figure 14). The coefficient for age, instead is a highly significant predictor of language comprehension capacities in this group (t= 8.17, $p < 0.00001$), as it predicts up to 77% of the variance R^2 = .77, F (1,19) = 70.5, $p < 0.00001$ (See Figure 15).

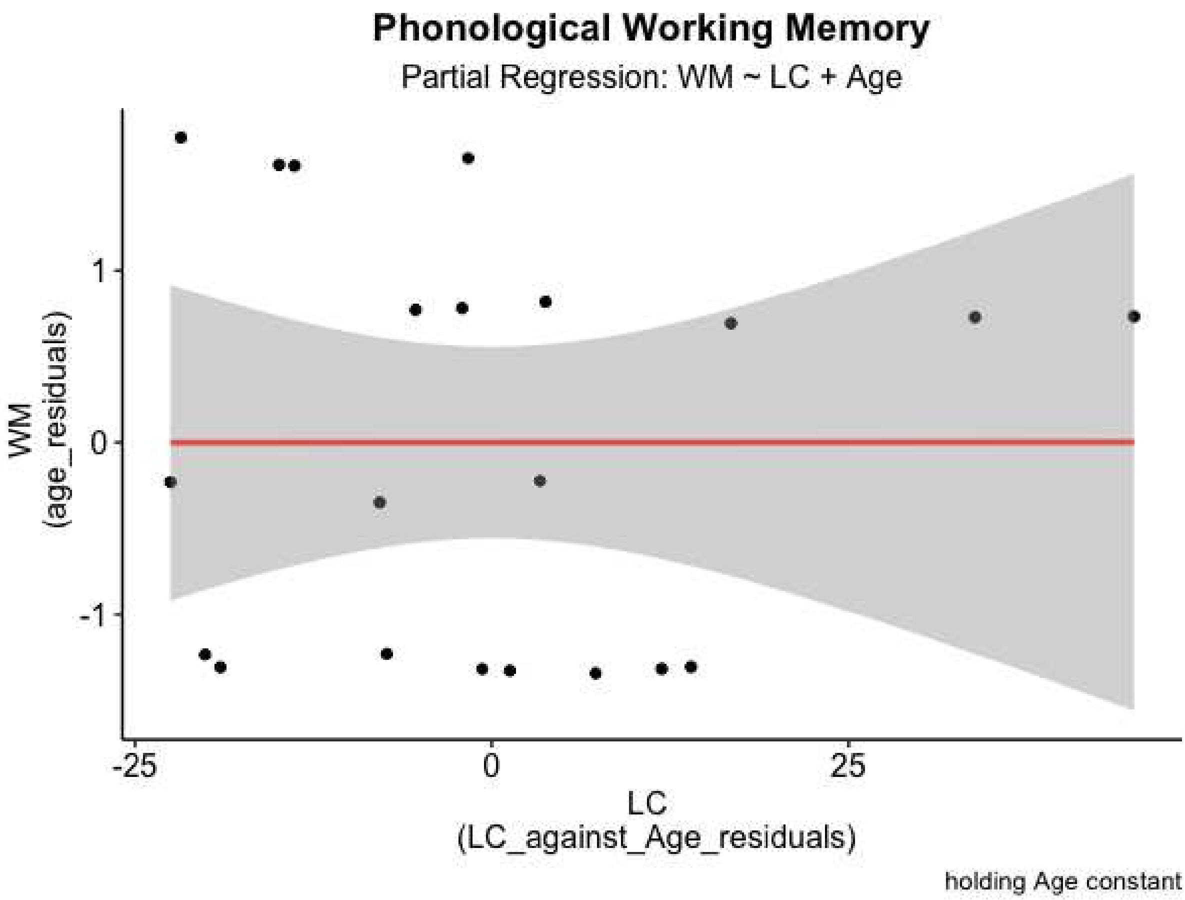

Figure 14- The plot for the partial correlation between working memory and language comprehension. The linear regression generates the red line fit while controlling for age, with the 95% confidence interval boundary represented by the grey area.

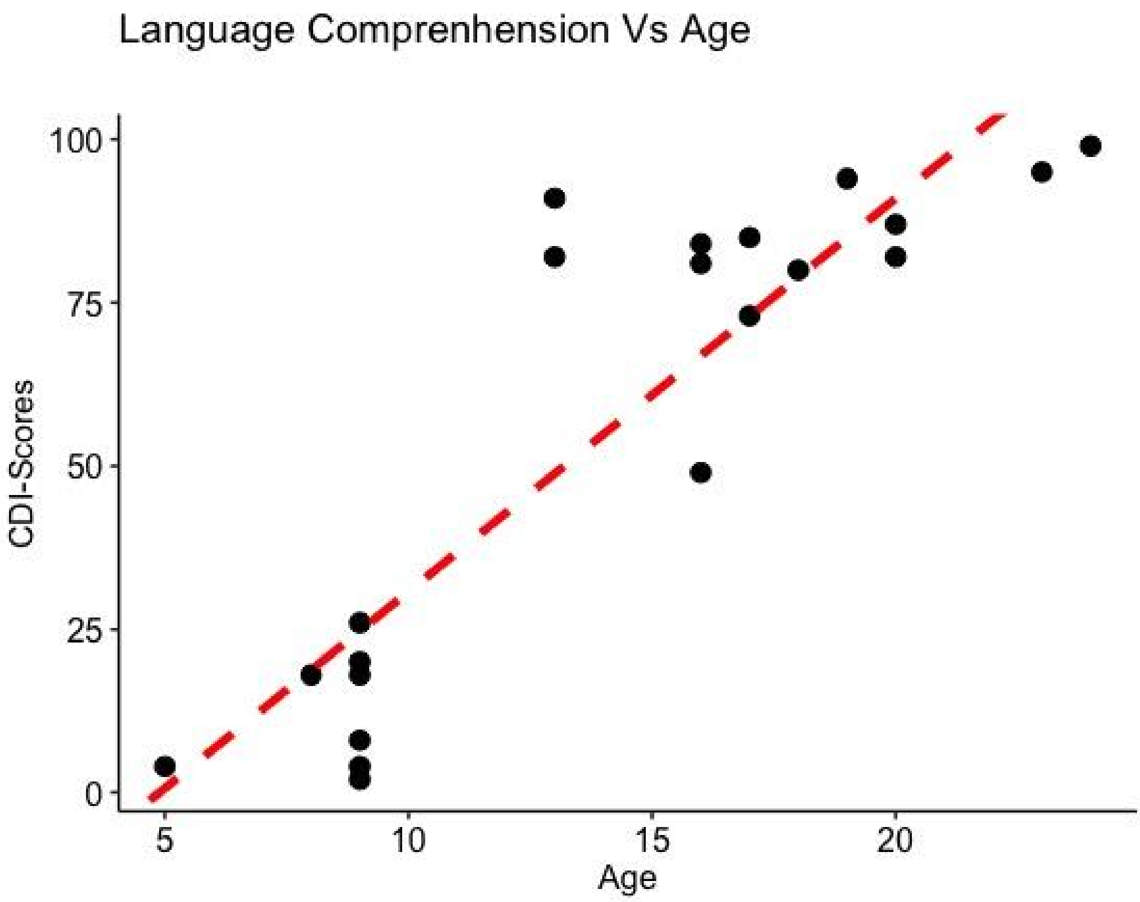

Figure 15- The relationship between Language Comprehension Scores and the age of participants

4.3.2. Language Production and Auditory Working Memory

Regarding the analysis investigating the link between working memory and language production, while controlling for the age of the children indicated that the predictor variable of interest in the model (language production; t= 2.32, p= .03) but not age (t= -1.57, p=.13) significantly explain a portion of the variance in working memory (23%). The model including age as a significant predictor, however, does not reach significance, R^2 = .15, F (2,18) = 2.76, p =.09 (See Figure 16).

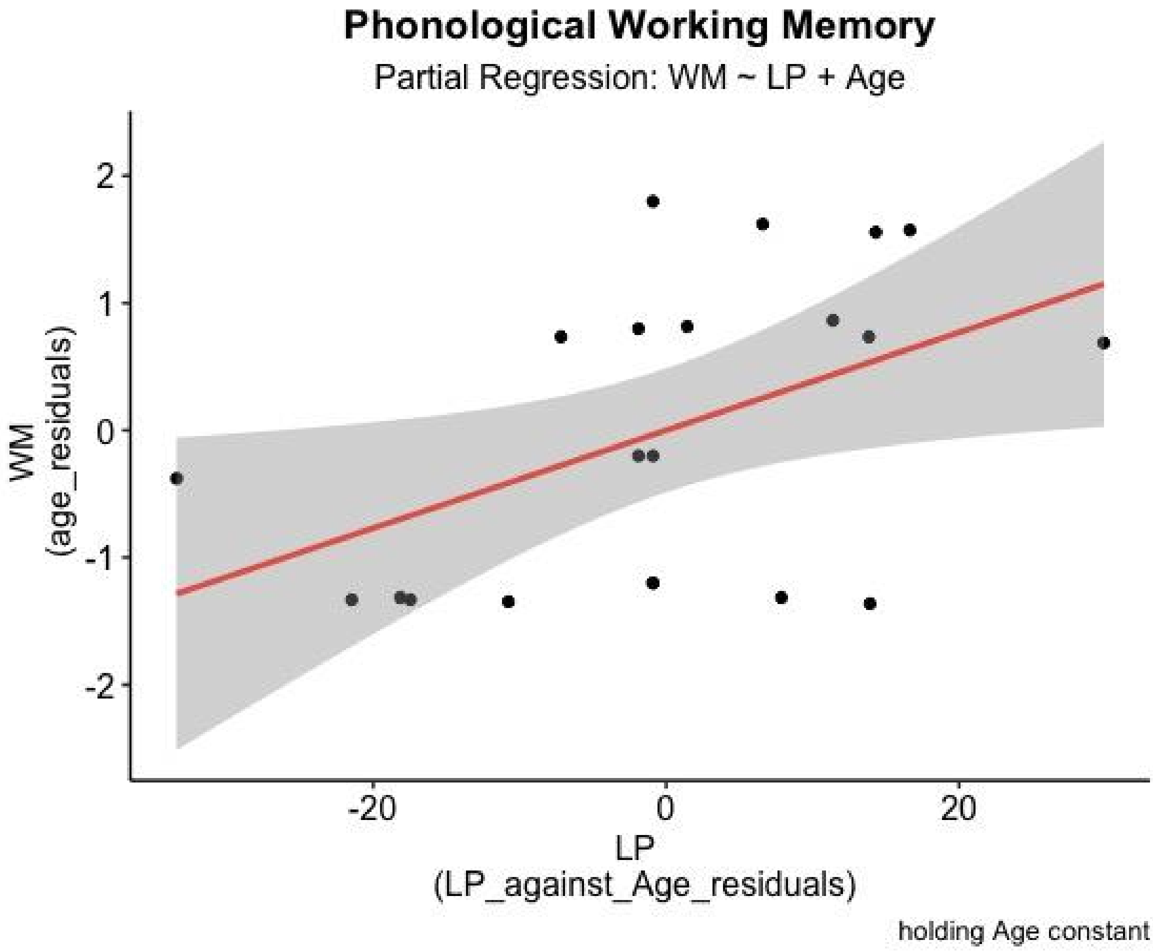

Figure 16- Partial regression plot illustrating the relationship between working memory and language production. The linear regression generates the red line fit while controlling for age, with the 95% confidence interval boundary represented by the grey area.

It also appears that age is significantly associated with language production in this group $R^2 = .58$, $p < 0.0001$ (See Figure 17).

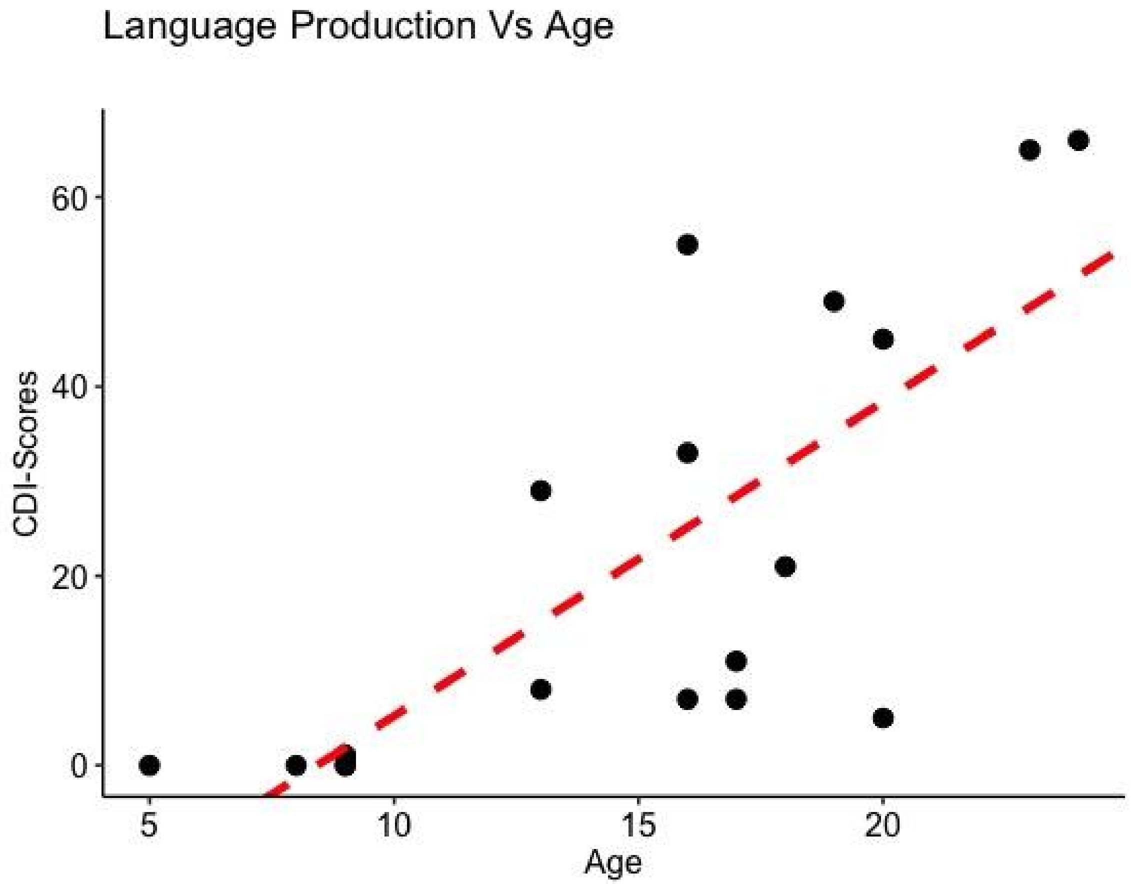

Figure 17- The relationship between Language Production Scores and the age of participants

CHAPTER 5

DISCUSSION

5.1. Discussion of Key Findings

The present preliminary study aimed to investigate auditory working memory and its relationship with language development in Turkish infants aged 6 to 25 months. The study utilized the ADAM experiment and MB-CDI assessment instruments to measure auditory working memory capacity and language development. The results offer valuable insights into working memory in early infancy and its connections with language comprehension and production.

The following answers were found based on the research questions in this study. Firstly, assessing the auditory working memory capacity of Turkish infants aged 6 to 25 months using the ADAM experiment was important for this preliminary analysis. The analysis revealed significant findings regarding phonological working memory capacity in Turkish infants aged between 6 to 25 months old. By assigning scores ranging from 1 to 4 based on their performance in the ADAM tests, the mean value for phonological memory span was calculated to be 2, indicating a two-item memory capacity. These findings align with existing research suggesting that infants of this age group tend to exhibit limitations in working memory capacity, potentially due to their developmental stage (e.g., Zosh & Feigenson, 2015).

However, a similar study was done by Grasso (2022) using the ADAM experiment with 24 Italian infants aged from 7 to 27 months. The results of this preliminary study revealed that most participants have a memory capacity of 1 item. The average value of the phonological memory span was 1.79 items (Grasso, 2022). Since the mean age for the study with Italian infants was 14.37 months and for the current study it is 14.23, the difference in item capacity is most likely not derived from age.

The difference might come from the fact that different cultures and languages may emphasize different cognitive skills and processing strategies. The linguistic structure of a language, such as the complexity of sentence structures and the phonological characteristics, can impact working memory demands. For example, a language with longer or more complex words and sentences may require more working memory capacity to process effectively.

A study done by Gervain and Erra (2012) analyzed Hungarian and Italian infant-directed speech and the results showed that cross-linguistic differences in statistical segmentation may arise between languages with different morphological richness. The study suggests that statistical segmentation is influenced by language-specific factors and may play a significant role in language acquisition. Since both Turkish and Hungarian are agglutinating languages with vowel harmony (Törkenczy, 2011), the results of this study might give an idea about the comparison of Italian and Turkish phonological characteristics as well.

Secondly, the link between phonological working memory and age was analyzed by the Spearman correlation analysis. The results indicated that there is no statistically significant correlation between working memory capacity and participants' age. This result implies that within the selected age range of 6 to 25 months, working memory capacity does not appear to significantly change as infants grow older. This finding contrasts with studies involving older children and adults, where age-related improvements in working memory have been well-documented (e.g., studies with adults: Cowan, 2001; Luck & Vogel, 1998; with children: Cowan, 1999; Cowan et al., 2005; Riggs et al., 2006; Simmering, 2012). Since these studies do not involve infants' working memory capacities, the findings suggest that the rate of improvement of phonological working memory changes across development, with greater improvements observed in older children. Moreover, because the above-mentioned studies did not include Turkish participants, it possible to hypothesize that the relationship between phonological working memory and age may be influenced by specific cultural and environmental factors of the study's population.

Additionally, a negative association between the child's age and latency was observed after the analyses. The negative correlation is not statistically significant. These results can be interpreted as age does not have an important role in determining the processing speed at which the child demonstrated the ability to recall and recognize target syllables. However, it should be noted that the sample size included in this study was limited. As a result, the conclusions should be interpreted considering this point.

Moreover, examining the relationship between auditory working memory and language development in 21 Turkish infants was fundamental. The analysis indicated that there is no statistically significant relationship between language comprehension and working memory scores when controlling for age. This implies that other factors beyond language comprehension may contribute to individual differences in working memory capacity during early infancy. For example, it is seen in the literature that phonemic awareness may be influenced by both the level of maternal education (Dollaghan et al., 1999) and socioeconomic status (Bornstein & Haynes, 1998).

However, in contrast with the language comprehension findings, the current study discovered a modest relationship between language production and phonological working memory. The analysis revealed a statistically significant p-value of 0.03 and suggested that phonological working memory may be indicative of variations in language production skills among the studied infants. Importantly, the modest relationship was not observed anymore when controlling for age, suggesting that the effect might be strongly modulated by maturational factors. This finding aligns with the study by Adams and Gathercole (1995). In their study, the authors found out that children with stronger working memory skills not only had a richer vocabulary but also produced longer and more syntactically complex sentences.

These results imply that working memory may influence various aspects of language, including vocabulary size and the ability to construct more complex sentences (Adams and Gathercole, 1995). Even though the age groups of these two studies differ, it is important to explore various working memory abilities aspects in relation to language development to be able to have a broader understanding of the implications of these results in infancy.

5.2. Limitations

There are several important limitations that need to be considered for this preliminary study.

The first limitation can be the limited sample size of the study. The current preliminary study was conducted with 21 Turkish infants therefore the limited sample size might affect the generalizability of the results to the larger infant population.

The cultural and linguistic background of the participants might be another important limitation of this preliminary study. The study focuses on Turkish infants, therefore, limits the generalizability of the findings to other infants from different cultural and linguistic backgrounds. Other infants from different regions and backgrounds might show different outcomes. For this reason, generalization of the current results would be challenging.

The other limitation is the assessment of language development. Since the participants' language development was assessed through MB-CDI reports by relying on parent statements, biased, or inaccurate reporting of answers might occur. This can affect the reliability of the language development data.

Ecological validity might also be a limitation of this study. Since the ADAM experiment was conducted online, it may not completely replicate real-life situations for auditory stimuli. This may impact the ecological validity of the findings.

5.3. Theoretical and Practical Implications

The results of this preliminary study have some important theoretical implications.

It was found that the working memory capacity for 21 Turkish infants in the study was two. This finding highlights the limitations of working memory at the early stage of life and aligns with the hypothesis that short-term memory is a finite resource even in infancy. In their study, Vuontela et al (2003) investigated the effects of age on visuospatial and audiospatial working memory. The results support the idea that age is an important determinant for performance and maturation of underlying cognitive processes. Even though the study was conducted with older children, the results can help understand the implications of the current study. The limited working memory capacity observed in these Turkish infants implies that, even at this young age, there are constraints on the amount of information an infant can temporarily hold and manipulate.

Another finding from this preliminary research underlies that there is no age-related effect on working memory capacity for 21 Turkish infants in the study. This challenges the idea that working memory development follows a linear course during the studied age range. As a result, a more comprehensive developmental model that considers the interaction of cognitive and neural factors to shape working memory in infancy may need to be developed.

Based on the results, a complex interaction between language development and working memory was found. The association between language comprehension and working memory was found statistically non-significant for 21 Turkish participants in the study. The difference in these results could be because language production tasks may require heavier work on working memory due to the need to retrieve and organize words and grammar while also maintaining the overall structure of the sentence being constructed (Deldar et al., 2021). Comprehension tasks, on the other hand, may involve a different profile of cognitive demands on working memory, such as tracking the meaning of a sentence (Deldar et al., 2021; Schwering & MacDonald, 2020).

In her study, Adams (1996) examined the relationship between speech production skills and working memory abilities in 4-year-old children. The results showed that there is a significant association between various aspects of language development such as vocabulary range, sentence length, and complexity in syntax and verbal short-term memory span. This suggests that the relationship between language acquisition and working memory abilities is not only due to similar demands shared by language and memory tasks. In order to understand working memory mechanisms for language development, comprehensive studies with more participants are required.

This preliminary study also has some practical implications.

The current study highlights the importance of a more holistic approach considering multiple cognitive factors in interventions. The results of this study suggest that language comprehension might not be the only predictor of working memory capacity for infants. Therefore, in order to improve early development, more comprehensive strategies are needed.

The current study also emphasizes the need for age-appropriate interventions that take the unique cognitive profiles of infants and young toddlers into consideration since a non-linear relationship between age and working memory in this age group is found after the analysis.

5.4. Recommendations for Future Research

While this study provides valuable insights into the relationships between auditory working memory, and language development in Turkish infants, several points for future research need to be assessed.

The first recommendation can be conducting longitudinal assessments to a broader age range. Even though this study holds important results, because of its limited sample size and time frame, it is difficult to generalize the results to a broader population. Therefore, it might be useful to conduct a longitudinal assessment of a broader population to get more accurate conclusions in what developmental trajectories concern.

Secondly, using neuroimaging techniques such as functional magnetic resonance imaging (fMRI) or electroencephalography (EEG) could be an important improvement for future studies. These techniques could provide insights into the brain regions involved in auditory working memory development.

The third recommendation for future studies could be to explore the influence of bilingualism or multilingualism on early working memory development. Investigating the experience of multiple languages and comparing it to monolingual environments might expand our understanding of the relationship between language and working memory capacity.

Last but not least, cross-cultural studies might be crucial for the future. Evaluating whether the relationship between working memory and language development is consistent across diverse linguistic and cultural contexts could be an interesting topic. This could provide more information about the universal versus culturally specific aspects of these associations.

CONCLUSION

This thesis focused on the development of phonological working memory in 21 Turkish infants between the ages of 6-25 months. It has certain significance since no studies had previously been conducted with infants of such a young age in the field of auditory working memory. Another strength is the tool used for measuring auditory working memory: the ADAM, an adaptive memory test administered online.

Based on the results of this study: First, the average item recall score for phonological working memory demonstrated by 21 Turkish children was 2. This is consistent with what has been found in Zosh & Feigenson's (2015) study on working memory. They investigated the phenomenon of "catastrophic forgetting" in infants and examined whether the characteristics of the stimuli influence how infants' memory functions.

Secondly, age was expected to show a correlation with the ADAM performance of the participants; however, no relationship between age and ADAM performance was found. Similarly, there was no statistically significant relationship between latency and age.

Last but not least, the link between phonological working memory capacity and language development consists of important results. Language development was assessed with two components, namely language comprehension, and language production. In both analyses, age remained a constant. After the results, it was seen that there was no statistically significant evidence that language comprehension has a relationship with working memory scores. On the other hand, analyses regarding the link between language production and phonological working memory capacity indicated that there is a statistically significant relation between the two constructs. In other words, it seems that for the current sample, auditory working memory capacity predicts language production. This relationship, however, is does not hold, when controlling for participants' age.

Because of the preliminary nature of the study and the limited sample size, it is not possible to generalize these results. Therefore, future studies will be needed to expand the results of this research. For future studies, it is also important to consider additional cognitive and contextual factors apart from the ones analyzed in this preliminary study.

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APPENDIX

MacArthur Kelime Dağarcığı Envanteri Kısa Form: Seviye II (A Formu)

Bebeğin ismi:____ Cinsiyeti:___________ Doğum tarihi:_________________________________ Bugünün tarihi:_______________

Kelime Dağarcığı Envanteri
Çocuklar söyleyebildiklerinden daha fazla kelimeyi anlarlar. Bu envanterde çocuğunuzun hangi kelimeleri SÖYLEDİĞİYLE daha cok ilgileniyoruz. Eger aşağıdaki kelimeler arasında çocuğunuzun farkli telaffuz ettikleri varsa onları da işaretleyiniz.

hav hav (köpek)	eldiven	çiçek	yazmak
mee mee (koyun)	gözlük	ay	oturmak
cik cik cik	ayakkabı	deniz	gelmek
köpek	ağız	taş	yüksek
at	el	kaydırak	yakışıklı
timsah	göbek deliği	çocuk	iyi
horoz	kulak	kendi ismi	ısı
kedi	ayak	anneanne/babaanne	siyah
kurt	dolap	hanım/bey	ağır
balık	duş	amca/dayı	kırık
penguen	buzdolabı	uf olmak	kirli
kuş	yatak	teşekkür ederim/rica ederim	üzgün
otomobil	kapı	hayır	hala
bisiklet	televizyon	bitt/kalmadi	sonra
oyuncak bebek	anahtar	iyi çocuk	gece
top	emzik	açmak	pek
su	inek	öpmek	ben
bisküvi	ışık	dans etmek	benim

karamel	kalem	içmek	ne?/hangisi?
et	saat	kapatmak	…nun

süt	tarak	koşmak	aşağısında
mama	diş fırçası	vermek	altında
patates	telefon	sallanmak	bir/tek
düğme	anaokulu	bitirmek	diğer/öbür
mont	ev	yemek	bu

EYLEMLER VE JESTLER

Çocuklar iletişim kurmaya başladıklarında, istediklerini iletmek için genellikle hareket ve jestleri kullanırlar. Aşağıda saydıklarımızdan çocuğunuzun yaptığı hareket/jestlere en çok benzeyenleri belirtiniz.

Elinde ne olduğunu karşısındaki yetişkine gösterir	öpücük yollar	bebek arabasında oyuncak bebek iter

Bir şey istediğini göstermek için kollarını ileri doğru uzatır	Çatal-kaşık kullanır	Oyuncağına sarılır
Bir nesneyi ya da olayı işaret eder	Yuzunu veya ellerini peçeteyle/bezle//havluyla silebilir	Fırça ile süpürür
Sıcak bir yiyeceğe/içeceğe üfler	Topu atar	Anahtarı kilide takıp çevirebilir
Bir yemeği beğendiğinde el hareketleriyle anlatir	Bir kase veya kapta kaşıkla yemek karıştırabilir	Kalem ile yazabilir/çizebilir
"Bravo" anlamında alkışlar	Yatağına oyuncak ile yatar	Kolye, bilezik ya da saat takabilir

Çocuğunuzda Aşağıdaki Davranışlardan Hangisini Gözlemliyorsunuz?

1. Tanıdık sesler duyduğunda etrafına bakınır mı? (Kapı zili, telefon ya da tanıdığı birinin sesi)
2. Ona hitap ettiğinizi bilir mi? (Örneğin, "hayır hayır" dediğinde anlık olarak da olsa yaptığı işi bırakır mı?)
3. Bir objenin ismini elinizle işaret etmeden söylediğinizde o objeyi eliyle gösterir mi ya da eline alır mı?

4. Basit bir emir verdiğinizde bunu yerine getirir mi? (örneğin; kapıyı kapat ya da bardağı bırak gibi)
5. Karmaşık cümleleri anlar mı?(topu yerden al ve onu arkadaşa at)
6. Bir hikaye anlattığınızda ilgi gösterir mi?
7. Aynı sesleri tekrarlar mi?(örneğin, ba-ba-ba.., da-da-da…, ma-ma-ma…)
8. Birbirinden farklı ses dizileri üretir mi? (de-da-pa…, ma-ta-da…)
9. Çevresinde duyduğu sesleri tekrarlar mı?
10. Söylediği kelimeleri: A)Yetişkinler gibi telaffuz etmese de herkes ne dediğini anlar. B)Yalnızca aile fertleri anlar.
11. Olmayan bir nesneyi, kişiyi veya olayı istemek veya adlandırmak için kelimeler kullanır mı?(bahçede düşüp dizini acıttığı günü anlatmak için "uf uf" demek gibi)
12. Bir nesnenin başka bir nesne olduğunu varsayarak, onu ikame nesne olarak adlandırır mi? (Örneğin, bir küpü sanki bir oyuncak arabaymış gibi iterek "vinn vin" demek)
13. İstedigi bir objeyi işaret eder mi? (örneğin, kendi kendine uzanıp alamayacağı ya da yerinden çıkarmayacağı bir oyuncak gibi)
14. Kendi ilgisini çeken bir olay ya da objeye sizi de yönlendirmeye çalışır mı? (örneğin, "uçak uçuyor", "araba geçti")
15. Gördüğü bir nesneyi istemek veya bir şey yapmak için iletişimsel jestler kullanır

mı? (örneğin, telefonu istediğini söylemek için elini kulağına götürür)
16. Olmayan bir nesneyi veya olayı belirtmek için iletişimsel jestler kullanır mı? (Örneğin, elini yanağına götürüp gözlerini kapatarak uyumak istedigini anlatmak)
17. Oyun oynarken bir nesne yerine başka bir nesne kullanır mı? (örneğin bir çubuğu kaşık olarak kullanmak)
18. Bir kelimeyi ve bir hareketi iki farklı anlamla birleştiriyor mu? (örneğin, "mama" der ve lezzetli olduğunu anlatmak için parmak uçlarını birleştirerek elini yukarı aşağı sallar

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