The influence of language on the formation of number concepts; Evidence from pre-school children who are bilingual in English and Arabic

Rima S. Alhaider

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Declaration

I, Rima Alhaider confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

This study examined the role of language on early number concepts from the perspective of bilingualism. Arabic/English bilinguals were studied since the Arabic language provides a distinctive linguistic context for the learner through its system of nominal number marking. Arabic is unusual in distinguishing between singular, dual and plural nouns. When a noun appears in dual form it is interpreted as referring to precisely two entities. Research suggests that exposure to dual case provides accelerated access to the concept of two. We asked whether early number knowledge in general is influenced by such exposure, and further examined the extent to which such influence is either (a) limited to number knowledge as expressed in the Arabic language, or (b) extended to include number knowledge as expressed in the English language. Furthermore, we examined the relationship between transcoding and number knowledge.

A sample of 77 Arabic/English bilingual children was recruited. Arabic and English language skills, knowledge of the spoken number sequence in Arabic and English and comprehension of dual case nominal number marking in Arabic were assessed. Early number concepts were assessed in Arabic and English languages through cardinality and number identification testing, employing a widely used procedure and including comparison of the range of scoring systems represented in the literature. Convergent results from logistic and linear regression analyses demonstrated that number concepts assessed in Arabic, but not English, showed significant independent influence of dual case

comprehension, indicating linguistic specificity of early number concepts. However, extended statistical models showed significant further influence of English concepts of Arabic concepts and vice versa. Furthermore, cardinality concepts played an important role in transcoding skills in both languages. However, the pattern of mutual transfer of cardinality concepts between languages was not found for transcoding skills.

Our findings indicate that very early number concepts, developed within a specific set of linguistic contexts, may be represented at an abstract level, capable of transfer across languages.

Impact statement

The study presented in this thesis has provided new insight into the influence of language on early natural number concepts, the fundamental basis of mathematical knowledge. This work addressed the central theoretical question of the relationship between language and cognition in early development while at the same time offering insights into the learning process for bilingual learners, with important implications for education in the early years.

Our findings indicate that very early number concepts, developed within a specific set of linguistic contexts, may be represented at an abstract level, capable of transfer across languages. This finding extends previous work in the field, and may have general importance for understanding the development of early number concepts in bilingual and multilingual populations more widely.

We interpret our findings as demonstrating the powerful foregrounding role of dual-case marking in the child's experience of the world around them, with consequent effects on concept formation. At the same, we suggest that number concepts acquired in this way may be represented abstractly and, in the case of the bilingual child, transferred across languages. In addressing these questions we applied both conceptual and quantitative scoring systems to the classic give-a-number task, evaluating children's understanding of cardinality. The quantitative approach appeared to show greater sensitivity, allowing use of multiple linear regression and identifying a greater number of significant variables.

Our findings concerning both linguistic specificity and abstract transfer, as well as methods of assessment of concepts, may have impact within academia. There are also implications for education professionals concerning assessment of children's skills, moderation of expectations, and encouragement of bilingualism at the earliest stages of number learning.

There is less certainty concerning our study of transcoding. Marginal findings in relation to the influence of English transcoding on both Western Arabic transcoding and Eastern Arabic transcoding, in the absence of transfer between Arabic forms, provide suggestive evidence that a language-specific process may be in operation. There is a need for replication of findings, particularly in a longitudinal study. If confirmed longitudinally, these findings might suggest that the representation of written numerals is not underpinned by abstract transfer. Under these circumstances early educators might wish to provide consistent language-specific inputs to pre-school bilingual learners, in order to establish a stable basis for later cross-linguistic learning.

A partial report of this study was presented as a poster at the Experimental Psychology Meeting (6 Jan 2021), and as a verbal presentation at the Experimental Psychology Meeting (6 Jan 2022).

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My PhD journey was not an ordinary one. During this journey, I had obstacles as most of the students with the COVID-19 pandemic. Also, I went through two months' hospitalization due to brain abscess, suffering from neuropathy, depression, and the loss of my father.

I am very grateful to my family and friends for their continuous love, encouragement and support…

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Chapter 1: Introduction

1.1 Background

This chapter will present an overview of studies of the development of number knowledge and the influence of grammatical number marking on the formation of early number concepts and symbolic understanding. To date, research that looked into cross-linguistic evidence on how grammatical morphology supports number word learning in bilingual context is limited. The findings of the influence of dual case marking as an example of grammatical number marking on number concepts in a bilingual context will be interpreted and discussed.

Children have some understanding of number very early in life, even before their first words. For instance, six-month-old children can differentiate between two and three jumps of a puppet (Wynn, 1996). This suggests that children’s number word learning is mapped onto an already existing concept as infants at six months of age do not have count words; however, they have the ability to represent numbers. The accumulator theory is a mental model presented by Wynn (1996) suggesting that the infant's brain captures images of repeated events or objects through the visual system These are stored in a primitive memory, which accumulates successive inputs, and represents approximate number. Evidence has shown that young human infants and other animal species share this foundation of numerical understanding (Dehaene, 1997). Earlier work by Gelman and Gallistel (1978) suggested that innate foundations of number support children at the age of 3-5 learning number words and understanding the counting principles. Based on these foundations, children learn to count effectively. They learn the number word sequence and use it in correspondence with objects; based on one-to-one correspondence between the number words and the objects, the concept of cardinality is established.

There are conflicting theories of numerical development. One theory which has attempted to account for the development process is based on the idea of an Approximate Number System (ANS). The ANS is a cognitive system that supports a basic sense of number in humans and non-human species. This system is present from birth and stays active through the entire lifespan and has a defining role in children's later mathematical abilities (Halberda, et al., 2008). Furthermore, the ANS is broadly independent of language and other cognitive processes (Dehaene, 1997).

An alternative account of foundational number concepts developed is the Parallel Individuation system (PIS), a pre-verbal system that underlies the linguistic structure from which children learn the meaning of number words (Carey, 2004).

The PIS lends itself to identifying objects and one-to-one mapping; the number words being used in correspondence with those objects requires that those objects are identified as individual objects and then counted in sequence.

The PIS can be seen as Carey's attempt to provide an early basis for bootstrapping through the number sequence to develop number concepts. Carey (2004) proposed an account in which language plays a critical role in the development of number concepts. She used the bootstrapping theory to explain how language helps children learn number word meanings. At the outset, foundational number concepts are associated with number words and applied to small sets of objects. The theory suggests that the spoken number sequence itself operates as a 'bootstrap' to allow understanding of larger numbers and access to enhanced number concepts.

The following was included in p.19 "Historically, Gelman and Gallistel (1978) identified the innate foundations of the numerical system as a set of principles which are triggered by experience. These principles of one-to-one correspondence, stable order, cardinality, abstraction and order irrelevance will be discussed in more detail in Chapter 3. In a later paper (Gelman & Gallistel 1992) it is proposed that the mechanism whereby numerical principles emerge is that of 'pre-verbal counting' (Gelman & Gallistel (1992) p.22), as evidenced in animal and human research and subsequently formalized as 'an evolutionarily ancient approximate number system (ANS) that is shared by adults, infants and non-human animals' (Halberda, Mazzocco & Feigenson (2008) p. 665). A critical difference remains between higher level conceptual principles, especially the cardinality principle, which emerges over an extended period of development (Wynn 1990) and the lower level function of the ANS.

It is important to note that the ANS is an approximate rather than exact representation of numerical magnitude. Furthermore, the numerosity discrimination of this system is abstract and presents a noisy representation of approximate numbers that captures the relationship between different quantities. This system does not provide precise discrimination but is related to ratio rather than numerical difference.

In contrast, the PIS has limited capacity as it focuses on small numbers of objects, and it deals with the precise presentations of distinct individuals.

To understand the exact meaning of number words it is essential to understand the counting process (Wynn, 1990). The last step in children's understanding of number words is to join their innate numerical system as suggested by Gelman and Gallistel (1978) and the counting system that potentially can support children's understanding of the infinity of number words (Bloom, 1994).

Numerous studies have used Wynn's Give-N task (Wynn, 1990; 1992) and have provided extensive support for her proposal of stages of acquisition of number words, or 'knower-levels'. The first stage is the 'non-knower' stage when children can point at objects and recite the count list (one, two, three, four…etc.) without understanding its quantitative meaning (Le Corre, Van de Walle, Brannon & Carey, 2006; Marušič et al., 2016). The second stage is the 'one-knower stage', which comes after the age of two, when children understand the exact meaning of number one (Barner & Bachrach, 2010; Le Corre et al., 2006). Subsequent number meanings are acquired gradually and in consecutive stages (subset knower levels) up to four, but even 'four-knowers' are unable to apply their knowledge of the count words to set sizes beyond their knower-level (Le Corre et al., 2006; Spaepen, Gunderson, Gibson, Goldin-Meadow, & Levine, 2018). The final stage in the process is called the 'cardinal principle' stage or 'CP knower' stage, in which children are able to apply their understanding of the principles of counting to quantify larger set sizes (Le Corre

& Carey, 2007; Lee & Sarnecka, 2010; Spaepen et al., 2018; Wynn, 1990; 1992).

Bloom (1994) proposed that the development of understanding number concepts is shaped by language, particularly that counting is embedded in natural language. Bloom and Wynn (1997) investigated the role of language by examining the linguistic input of three one- and two-year-old English-speaking children received from their parents and the children's speech. Their analysis revealed that in children's speech and the input they receive from their caregivers that number words are only used with count nouns and not mass nouns. Also, children did not differentiate between number words and adjectives such as 'big' and 'little'. It was also revealed that children and their parents did not use number words with modifiers and that number words always precede adjectives. These results do not show a causal relationship between number words and linguistic structures, but they show the relationships between the linguistic cues children receive from their caregivers and children's number knowledge as it helps them in understanding number words meanings. They concluded that linguistic cues significantly facilitate the development of number-word meanings as children generate their understanding of number through semantic and syntactic structures of the linguistic counting system.

Furthermore, research has shown that grammatical morphology adds a further contribution to the development of early number concepts. The presence of dual case marking in some languages (Arabic, Slovenian) can provide an additional perspective on the question of linguistic influence on number knowledge (Almoammer, et al., 2013).

The dual case is a unique morpheme that is attached to nouns and indicates two entities. For example, in Arabic, the dual case is formed by adding the suffix; /-tain/ for feminine nouns and /en/ for masculine nouns, e.g. /warda/ which is a feminine singular for one flower /warda-tain/ meaning two flowers. Almoammer et al. (2013) examined the influence of dual case marking on number word acquisition by comparing knower levels in Saudi Arabic and Slovenian pre-school children to those of English pre-school children. They tested three- and four-year-old Saudi Arabic and two- four-year-old Slovenian children as these languages are exceptional in having dual case marking. The influence of dual case marking on number word acquisition was examined by comparing knower levels in Saudi Arabic and Slovenian preschool children to those of English preschool children. Their findings indicate that grammatical number marking supports the formation of number concepts.

Similarly, there is evidence that children learning languages that have obligatory singular/plural number marking (such as English and Russian) become one-knowers faster than those learning languages which do not have obligatory singular/plural marking, such as Japanese and Mandarin (Barner et al., 2009; Sarnecka, Kamenskaya, Yamana, Ogura, & Yudovina, 2007).

Wagner, Kimura, Cheung and Barner (2015) offered a further research perspective by exploring linguistic effects on number concept formation within a bilingual sample. They examined the linguistic specificity of knower levels in different bilingual groups. Their results indicated that children learn numbers in each language independently for each subset knower level (1-knower, 2-knower, 3-knower, or 4-knower). Knower levels in the non-dominant language were not predicted either by their dominant language counting ability or by knower level, indicating linguistically independent acquisition. However, this was not true for the CP knower level. Children who were CP knowers in the dominant language, were most likely to be CP knowers in the non-dominant language. They suggested the presence of transfer of concepts across linguistic boundaries for children whose foundational understanding of cardinality was already established.

The knower levels are strong predictors of early arithmetic skills (Geary et al., 2018). Other studies have shown that transcoding, which is the ability to map spoken numbers to symbolic numerals, also predicts later arithmetical skills (Göbel, Moeller, Pixner, Kaufmann, & Nuerk, 2014; Habermann, Donlan, Göbel, & Hulme, 2020). Furthermore, according to one account, understanding symbols for Arabic numerals is based on knowledge of the spoken number sequence (counting) combined with an understanding of the cardinality principle (Reynvoet & Sasanguie, 2016). If this is the case, the knower-level concepts could support children's understanding of written number symbols. Mix, Prather, Smith and Stockton (2014) tested children as young as three years old on a simple transcoding task. This study suggested that preschool children were able to map multi-digit written numerals to spoken numerals, even before having formal education or instruction. Furthermore, the study implied that children who had not yet established the cardinality principle could still understand number symbols.

The current study is aims to address the questions posed by Almoammer et al. (2013) about the influence of dual case understanding on number concept development. Second, following Wagner et al. (2015) in showing the presence of transfer of numerical concepts in bilingual learners, we added the dual case contrast to the methodology. Finally, looking at the relationship between number concepts and transcoding in bilingual learners.

This study is the first to look at the influence of dual case marking on number knowledge in bilingual children. There is limited published research about the influence of language and, specifically, dual case comprehension on number concepts in a bilingual context. Similarly, there is limited understanding of transcoding issues in bilingual children. The studies reported below are designed to address this gap in the literature.

1.2 Description of the current research

The research is divided into two parts: the first is the main part of the study, exploring the influence of language on understanding cardinality. The second part will investigate the relationship between transcoding and the number knowledge.

The first and central part of this study explores the relationship between grammatical morphology and number concepts in pre-school children, examining the contrast between Arabic and English languages. The question is whether grammatical number marking has a specific influence on the formation of early number concepts. In particular, does dual case marking comprehension support young children's understanding of cardinality. Studies of early number word learning by Wynn (1990; 1992) drew attention to the lengthy process by which children learn the meanings of the first words in the count sequence. Wynn used her 'Give a Number' task to define stages in the development of understanding of number word meaning. Numerous studies have used Wynn's Give-N task (Wynn, 1990; 1992). Findings have provided extensive support for her proposal of stages of acquisition, or 'knower-levels.' In the current study, we focus on one possible factor contributing to the formation of cardinality concepts: this is the grammatical structures which represent number in natural language, independent of the count words. Therefore, according to the combined findings of Almoammer et al. (2013) that grammatical number marking, specifically dual case number marking, supports the formation of number concepts, and Wagner et al. (2015) regarding the presence of transfer of conceptual understanding across linguistic boundaries, it might be predicted that there should be a direct effect of dual case comprehension on Arabic but not English cardinality. It is important to note that investigating the influence of dual case within a contrastive bilingual context allows a novel perspective on the notion of transfer of number concepts between languages.

Our approach here can be characterized under three different theoretical models (Figure 1.1) The first model (Fig 1.1) represents dual case marking as providing early access to a general concept of twoness which is not language-specific; we would expect to find effects of dual case comprehension on cardinality concepts in both languages. The second model (Fig 1.2) proposes that if the effects of dual case inputs are contained within their primary linguistic context, we would expect to see the effects of dual case comprehension on Arabic cardinality concepts but not on English cardinality concepts. The third model (Fig 1.3) draws on the particular findings of Wagner et al. (2015) concerning transfer; we are proposing the presence of transfer even if children did not reach the cardinal principle (CP) knower level. Testing a bilingual sample (English/Arabic) allows examining how differential experience of grammatical number marking may be influential as the structures of number marking vary across languages.

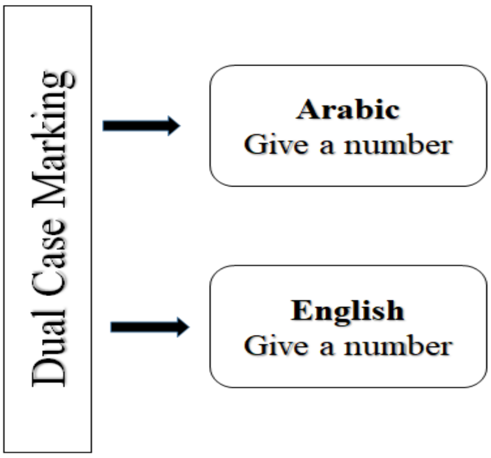


Figure 1.1 Dual Case has direct effect on knower levels in both languages

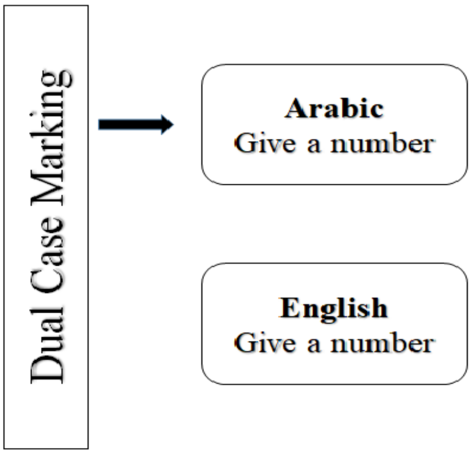


Figure 1.2 Dual Case has direct effect on Arabic knower levels, but not on English knower levels

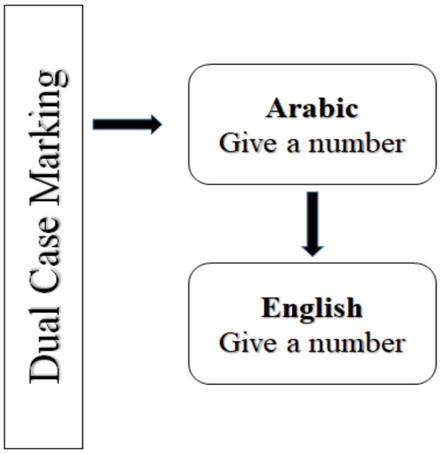


Figure 1.3 Dual Case has direct effect on Arabic knower levels, with subsequent transfer of abstract concept from Arabic to English knower levels

The second part of this study has investigated transcoding. Transcoding refers to the ability to associate spoken and written Arabic numerals, e.g., ‘thirteen’ and 13. It is tested through a number identification task in which spoken numerals were presented to be matched to the corresponding Arabic numeral, with a range of targets including single-, double- and three-digit numbers. By definition, transcoding is related to number words. The main question of this part of our study is the mechanism by which number words and written numerical symbols (digits) become associated? Transcoding provides an essential basis for early arithmetic skills and supports the understanding of place value (Cheung & Ansari, 2021; Malone, Burgoyne, & Hulme, 2020). We need more evidence to understand whether bilingual children exploit language-specific number knowledge. Further investigation is required to examine the base of transcoding skills and whether it is based on abstract conceptual understanding. Furthermore, we are investigating the relationship between children's concepts of cardinality at age three and their transcoding skills, and whether this relationship is independent of general language skills and knowledge of the spoken count sequence.

1.3 Purpose and hypothesis

The study's primary purpose is to examine the role of learning two languages in the development of number knowledge. The general hypothesis is that number knowledge is influenced by linguistic structures (Bloom & Wynn, 1997). The specific hypothesis is that dual case marking in natural language gives advantaged access to the concept of cardinality.

The transcoding part of the study is exploratory as it attempts to advance understanding of the early foundations of transcoding in bilingual learners.

The research questions in this study are the following:

1. Is the influence of dual case understanding on number concepts language-specific?

2. To what extent are concepts of cardinality mutually transferable between languages?
3. Does children’s understanding of cardinality influence their transcoding skills?

1.4 The objectives

1- To examine the role of language structure on number knowledge by exploring the influence of dual case number marking on cardinality
2- To explore the concept of transfer of number knowledge across linguistic boundaries for bilingual children.
3- To explore the relationship between transcoding skills and cardinality.

This study is using a correlational research design. Bilingual preschool children aged 3.00 – 3.11 were tested on multiple tasks in both English and Arabic language. First, the language test to test the overall language level to provide an estimate of their linguistic abilities. Second, the dual case comprehension task is to identify children’s understanding of the dual case marking in Arabic. Third, counting is to test children’s knowledge of the sequence. Finally, the Give-Number task, which is the main task of the study, is used to establish the child’s concept of cardinality. All tasks were set in a friendly, fun, games like setting. All data collected were analyzed through R statistical program.

1.5 Outline of thesis chapters

Chapter 2 will provide an overview of the studies related to language acquisition and a detailed description of the Arabic language. And an overview of the studies related to bilingualism.

Chapter 3 will overview studies on number concept development, cardinality concepts, language number relation, and transcoding. All of which are explained within a bilingual context.

Chapter 4 will explain the methods of the study, including the design, participants, the procedure, and the materials of different tasks.

Chapter 5 presents the results of the study.

Chapter 6 presents the interpretations and discussion of the results

Chapter 7 presents the conclusion of the study, including limitations and implications.

Chapter 2: Language and bilingualism

This chapter presents an overview of bilingualism, including definitions, fundamental background information about bilingualism, language acquisition theories, bilingualism theories, and the language development milestones of bilingual and monolingual children. Also, this chapter describes the morphological structures of Arabic and English languages.

The current research is located in Riyadh, Saudi Arabia, and the Arabic part of the study is based on Saudi Arabic dialect (Najdi), Riyadh in particular.

2.1 Bilingualism overview

Bilingualism is the ability to speak two different languages and bilinguals generally have an L1 or native language and L2 or second language. The dominant language is the strongest language, not necessarily the native language (Byram & Hu, 2013).

There is vast and growing literature on the field of bilingualism. An important question in bilingualism research is the role of languages and cross-linguistic influences in the development of cognitive representations of concepts. The current research focused on the role of linguistic structures in the development of number concepts

Every language has its own linguistic properties, which are likely to influence cognitive representations. Number knowledge is likely to be uniquely influenced by the native language and could also be further influenced by the second language (Dehaene, 1996); therefore, the bilingualism domain is excellent for indirectly investigating the role of language on cognitive representations. The current study takes a unique perspective on the role of linguistic competence in numerical development offered through the lens of bilingualism.

The term ‘bilingualism’ has different interpretations and definitions according to the age at which the second language is introduced and the level of exposure to that language. Simultaneous bilingualism is where children are exposed to two languages simultaneously from birth or early childhood before the age of three. De Houwer (1990, 2009) proposes that simultaneous bilingualism only applies to children exposed to two languages from birth to one week old, whereas Paradis, Genesee and Crago (2011) present a more flexible definition where exposure to L2 starts anytime from birth to three years of age. On the other hand, the term successive bilingualism refers to children exposed to a second language after age three (Paradis et al., 2011). The current study focuses on simultaneous bilingualism as the subjects are three-year-old children whose exposure to Arabic and English began from birth. In Chapter 4, the methodology section provides a detailed description of the measurement of language proficiency of the bilingual children in the study.

There are various ways exposure to two languages can be defined, depending on the parents’ native language or first language and the community language or second language. Romaine (1995) described different types of bilingual input strategies. For example, one person-one language where each parent speaks one language to the child. For example, in a Saudi family, one parent speaks Arabic (native language), and the other speaks English (Second language).

This method is ancient and claimed to be the most effective in raising bilingual children (Romaine, 1995; Ronjat, 1913). However, recent studies have shown that this method could be stressful for the children as the exposure to the two languages is hardly ever equal and that children who are raised with parents who speak both languages become better bilinguals (De Houwer, 2007). A second strategy is the one-language-one-environment, where parents speak one language at home, and the child is exposed to the other language only outside the home, e.g. at school. A further strategy is a mixed language method where the parents and the community are bilingual and employ code-switching. Code-switching is when a bilingual person speaks two languages within the same sentence or discourse, and it is considered a signal of linguistic competence (Fromkin, Rodman, & Hyams, 2019).

In conclusion, Barron-Hauwaert (2004) recommended the best way the children can get for the long term is to switch between languages effectively and to use the languages effectively in context.

The bilingual children in this study were exposed to Arabic and English from birth. However, the degree of exposure varies in the sample depending on multiple factors, including whether both parents or only one of them are bilingual, the presence of elderly relatives speaking Arabic in the home, and the presence of a caregiver who does not speak Arabic.

2.1.1 Theories of first language acquisition

Nativist theory proposed by Chomsky's (1965), states that language acquisition could not depend solely on linguistic input and that language acquisition is an innate ability. He put forward the Language Acquisition Device (LAD), a hypothetical cognitive 'tool' that allows infants to learn language, based on universal principles. He suggested that all languages share the same fundamental grammatical principles, proposing a Universal Grammar. For language development in children, linguistic input supports them in applying these principles to the parameters of their own specific language.

Constructivism is a general theory of learning whereby the learner does not receive knowledge passively, but constructs new understanding through experience and social discourse. Piaget and Inhelder (1969), a key exponent, viewed language learning as a constructive process within the general framework of cognitive development. Vygotsky's theory (1962), Bruner's social interaction theory (1985) and Tomasello's usage-based theory (2003) are also considered under the general framework of constructivism.

Constructivist theories explain how children construct their language from their developing social cognitive abilities and the input they receive from their environment. These theories provide supportive evidence proven in the field of language and number learning. For instance, studies have shown that parents and their children use number words like one, two, and three in their spontaneous speech, which helps children's understanding of the meaning of number words (Bloom and Wynn, 1997).

Piaget and Inhelder (2013) proposed a cognitive theory of language, suggesting that language learning is associated with the development and maturation of the brain in interaction with experience. This theory proposes that people develop their language and thought through their own experiences as exposure to real-life allows the child's brain systems to develop, including the development of symbolic language. Piaget believed that language acquisition is directly related to cognitive skills.

Vygotsky (1962) proposed that language is based on social interactions. This theory suggests that infants from birth are continuously engaging in social interactions within cultural contexts that lead to cognitive function development, which includes language and thoughts (Robbins, 2001).

Influenced by Vygotsky's sociocultural theory, Bruner (1985) proposed that language learning combines both innate abilities like the Nativist theory and environmental-social factors; the basics of the language are present innately however, the structure of a language is learned through social interactions. Bruner stressed the importance of language in the learning process as it assists children in developing the ability to deal with abstract concepts.

The usage-based theory was proposed by Tomasello (2003). He claimed that language structure is learned from language use and what children hear around them; it focuses on children's ability to generalize from the input they receive. Tomasello and his colleagues acknowledge that the brain is hardwired for language, so to speak, but that in order for a child to develop their language, they need to be exposed to and receive direct input in the language/s of their parents/carers. Then, by using the language themselves in interaction, the child's acquisition progresses towards competency.

The current study is based on social interaction theory as it focuses on the importance of linguistic support in the interaction between the caregiver and the child in the learning process of language and numbers. For instance, research showed that children exposed to languages with dual case morphology, such as Arabic and Slovenian, accelerate learning of the number word “Two” when compared to languages that do not have dual case morphology (Almoammer, 2013).

2.1.2 Theories of bilingual development

Bilingualism theories are based on language acquisition theories.

Nowadays, a large number of the world population are bilinguals or multilingual. There are roughly 3.3 billion bilingual people worldwide, accounting for 43% of the population (Grosjean,2001). The question is whether learning two languages is the same as learning one language.

There are two main theories of bilingual language development, the Unitary System hypothesis and the hypothesis of the Separate System or the Dual Language System hypothesis.

Volterra and Taeschener (1978) proposed the Unitary System hypothesis, which states that bilingual children learn both languages simultaneously as a single language. It is composed of three stage model: first, children combine the lexicons and grammatical rules from the dual language input system. The next stage is building a separate vocabulary for each language; however, the grammar system remains the same for both languages. The last step of this hypothesis is that children around the age of three begin to differentiate the grammatical system, and the child is considered to have a separate language system as a bilingual adult. This theory was not supported as infants were able to separate between two languages early in learning which suggests the presence of separate language systems (Bosch & Sebastián-Gallés, 2001).

The Dual Language System Hypothesis was proposed by Fred Genesee (2001), which states that bilingual children build a separate linguistic system for each language that includes vocabulary and grammar for each language and that children learn the different rules for each language. They proposed different path for each language as well as not accepting the presence of cross-linguistic influence (Fromkin et al., 2019). What supports this theory the fact that bilingual children could differentiate between the two languages very early in life, from the earliest stage of language development (Bosch & Sebastián-Gallés, 2001).

The above theories could not explain cross-linguistic influence as they focused on separating or unifying the two language systems. The idea of one language system could not be correct as each language system consists of various subsystems (Müller, 2009), such as the dual nominal number system in Arabic.

It is important to note that although the two languages are separated, they still interact with each other (Yip & Matthews, 2007). Research concerning language and number learning suggests that number learning is language-specific and that children learn numbers in each language independently which supports the Dual Language System theory. However, the results showed item-specific transfer between languages, suggesting that if the number knowledge is learned in one language, children can transfer the knowledge to the other language (Wagner et al., 2015).

The current study will investigate the presence of transfer of number concepts between different languages in Arabic and English bilingual children.

2.1.3 Bilingualism and cognition

Understanding cognitive function is critical in the bilingualism literature. Number concepts are important cognitive constructs, which is the main purpose of this study; to examine the role of language in the development of number knowledge.

Bilingual children present an opportunity for researchers to investigate how language is represented in the brain, and it is important for us to understand whether growing up bilingually affects cognitive function positively or negatively. A large number of studies have considered language as a base for cognitive function. In general, most of the studies on bilingualism and executive function compare monolinguals to bilinguals, highlighting that they differ mainly in the executive domain rather than other cognitive functions, such as memory or visual-spatial skills (Bak & Alladi, 2014). Furthermore, executive domain studies have shown that bilinguals are more likely to be advanced in executive functioning with regard to inhibition, switching and monitoring, but not in other functions such as reasoning (De Bruin & Della Sala, 2015).

Bialystok (2001) reviewed the differences between bilingual and monolingual children’s cognitive development and concludes that certain aspects of executive function are improved in bilingual children. Accordingly, inhibitory control, which is the voluntary control of thoughts and actions, is more rapidly developed in bilingual children. Inhibitory control is a particularly important key in executive function and has an important role for language use in bilinguals. Children learn to inhibit attention to the stimuli of a certain language in order to attend or pay attention to another stimulus from another language, 'switching on/off' as both languages are activated during language processing (Guttentag, Haith, Goodman, & Hauch, 1984). Various studies also have shown that bilinguals outperform monolinguals in cognitive tasks that require inhibition and attention (Bialystok, 1999; Bialystok & Martin, 2004). For instance, Martin-Rhee and Bialystok (2008) have conducted three studies that included 31, 40 and 32 participants respectively. Age of participants differed in each study; the first study 4; 7 years, the second study 4; 6 -5 years and the last study examined older children with a mean age of 8; 0 years to observe if the performance of children will differ a few years later. All studies have concluded that the attention control that is used in selectivity is more advanced in bilinguals than matched monolinguals. Furthermore, a large body of research has supported the conclusion that the habitual use of two languages in pre-schoolers and young adults requires the ability to select and switch from one language to another, supressing inferences from the first language (Bialystok et al., 2005; Costa, Hernández, & Sebastián-Gallés, 2008; Miller & Cohen, 2001).

Kovács (2009) have proposed that bilingual children have separate linguistic systems for each language. Growing up bilingual, they must control which language they are employing during the production of speech; in this regard, they are accessing the linguistic system of the target language and supressing the system of the non-target language (Green, 1998) Also, Kovács' results contribute to the research that has documented that both languages are active when bilinguals use one language (Martin-Rhee & Bialystok, 2008). Furthermore, studies of early bilingualism by Kovács and Mehler (2009) have compared seven-month-old bilingual infants with matched monolinguals on three eye-tracking experiments that involved learning to respond to cues in one side of a screen to obtain rewards, and redirecting their focus to the other side of the screen. The results showed that bilingual infants have cognitive advantages and advanced domain general cognition.

On the contrary, other studies have reported no cognitive advantage for bilingual children, and any advantage in executive function could be present only in adults because of longer bilingual experience. For instance, Antón et al. (2014) found no bilingual advantage when testing 180 bilinguals and 180 matched monolinguals on attention network tests, the sample was ranging in age from 7 – 11 year-olds. Furthermore, Paap, Johnson and Sawi (2015) have reviewed studies that reported significant bilingual advantage and concluded that these studies could have small sample size, unmatched demographic and socioeconomic factors or use inappropriate tests and measures. They concluded that if bilingual advantage does exist it is limited to specific components of executive function.

2.1.4 Language acquisition in bilinguals compared to monolinguals

There are two theoretical questions that address the big debate of bilingualism theory. First, does dual language learning impose a burden on children compared to monolingual children? Second, whether bilingual children build one or two language systems?

The following section provides a description and comparison of bilingual and monolingual language acquisition.

There are conflicting studies regarding the pace of language development in bilingual children compared to monolinguals, particularly in vocabulary and grammar. Some studies reported that bilingual children follow the same language milestones as monolingual children (Houwer et al., 2014; Smithson et al., 2014). On the contrary, other studies have reported that bilingual children lag behind monolinguals when assessed in one language.

Studies on early speech perception found that monolingual children can differentiate their native language from a prosodically different language four days after birth. 44-day-old full-term monolingual infants were able to differentiate between French and Russian utterances suggesting that infants are biologically ready to acquire languages (Mehler et al., 1988). In contrast, monolingual infants could not distinguish between prosodically similar languages like Spanish and Catalan until the age of four months (Sebastián-Gallés & Bosch, 2009). Bosch and Sebastián-Gallés (2001) investigated whether four-month-old bilingual infants could differentiate between Catalan and Spanish as monolinguals, and they did. They concluded that bilingual infants could separate the two languages early in life as the monolingual infants, which suggests that learning two languages is not burdensome and that infants can potentially build separate systems for each language.

Regarding speech production, studies have proven that bilingual and monolingual infants share the same milestones; they start cooing around 6-8 weeks, babbling around the age of 6-8 months and complex babbling (a mix of consonants and vowels) around 10-12 months (e.g. Maneva & Genesee, 2002; Oller, Eilers, Urbano, & Cobo-Lewis, 1997).

Bilingual and monolingual children produce their first words around 12-13 months and combine words around 18-24 months (Petitto et al., 2001). The vocabulary size for bilinguals in each language might be smaller when compared to monolinguals since the child can learn only a certain number of words in one day, and a bilingual child has two languages to learn (Smithson et al., 2014). Vocabulary learning depends on the exposure and experience of each language (Pearson, Fernández, & Oller, 1993). Research has shown that even if bilingual children do not know the exact meaning of a word in one language, code-switching takes place when children substitute a word from their other language, which suggests that the Unitary system hypothesis is unlikely to be true (Fromkin et al., 2019).

Conboy and Thal (2006) tested 64 English-Spanish bilinguals aged 20-30 months. Their results indicate that the pace of grammar development in each language is in-line with the pace of the vocabulary size development of the same language. Also, they found a relation between the vocabulary and syntax within each language in bilingual children but a weak relationship across languages suggesting that children develop two different systems; bilingual children acquire a separate grammatical system for each language.

Furthermore, in each of their languages, young bilingual children show phonological processes similar to monolinguals, however they may show some cross-linguistic influence. For instance, 17 two-five-year-old French- English bilinguals were asked to repeat a non-sense word to test whether they can differentiate the different phonological systems, as English syllable templet is (SW) and French syllable template is (WS). Results showed that bilinguals have separate phonological systems; however, it is not entirely independent. (Paradis, 2001). Cross-linguistic influence in word order was also demonstrated by Yip and Mathews (2007) as they studied Cantonese-English bilingual children and they found that children made errors in word order influenced by Cantonese. Also, Döpke (1998) showed that German-English bilinguals demonstrated the influence of English word order in German. The cross-linguistic influence that bilingual children exhibit provide evidence that children are building different grammatical systems for each language making similar developmental errors to monolingual children (Yip & Mathews, 2007).

To summarise, bilingual children can differentiate between two languages from an early stage, start babbling and produce their first words at the same time as monolingual children and make similar errors to monolinguals. Additionally, the rate of language development depends on exposure to a particular language. From this comparison, we suggest that bilingualism does not cause a burden on children as the rate of language learning is the same in bilinguals and monolinguals. Moreover, it seems that bilingual children are potentially building two separate linguistic systems.

2.1.5 Cross linguistic influence and bootstrapping

The Dual Language System hypothesis is frequently supported in research studies (Conboy & Thal, 2006; Fromkin et al., 2019). These studies suggest that each language has its linguistic system, but this does not mean that these languages are separated and do not interact. Research has shown that young bilingual children show some form of cross-linguistic influence between their two languages in all language domains (Paradis, 2007; Yip & Matthews, 2007). For example, Yip and Matthews (2007) documented the cross-linguistic influence on the speech of Cantonese and English bilingual children. The English nouns proceed with the relative clause, whereas it is the opposite in Cantonese; relative clauses are placed before the nouns, and children were observed to change the order when speaking Cantonese.

Cross-linguistic influence could aid language development by facilitating the acquisition of certain concepts, which is known as bilingual bootstrapping (Paradis, 2011). Bootstrapping in the case of bilingual children refers to the idea that learning the second language can be accelerated due to knowledge of the dominant language. A more straightforward definition is learning new knowledge in one language using cues from the other language. Research has shown that cross-linguistic influence does not occur from the dominant language to the other language (Foster-Cohen, 2009). Cross-linguistic transfer depends on the complexity of the transferred concepts, as some grammatical domains are susceptible to cross-linguistic influence, whereas other domains, such as the syntactic properties, are acquired without cross-linguistic influence (Müller & Hulk, 2001).

2.1.5.1 Code-switching and transfer (code-mixing)

Code-switching and transfer are two linguistic phenomena that are very similar and considered as forms of cross-linguistic influence.

Code-switching is when a bilingual person speaks two languages within the same sentence or discourse, and it is considered a signal of linguistic competence (Fromkin et al., 2019). Also, it is considered a normal part of bilingual development as two to three- year-old bilinguals repeat a sentence in their second language if their speech was not understood in their first language (Ladberg, 1996). The most common word class for code-switching is a noun. On the contrary, transfer refers to "the influence of a person's knowledge of one language on that person's knowledge or use of another language" (Jarvis & Pavlenko, 2008, p. 1). The general meaning of transfer is the use of elements of the first language in the second language or vice versa, and that these cross-linguistic elements are facilitator of language learning. It could occur in any part of the language system - morphology, semantics, syntax, and pragmatics. Moreover, it can also be conceptual. Conceptual transfer is related to the meanings represented in one's mind, independent of their forms and structures (Jarvis, 2016). Odlin (2009) has defined the conceptual transfer as "those cases of linguistic relativity involving, most typically, a second language" (p. 5).

Transfer can be explained by the interdependence hypothesis (Cummins, 2000), which proposes that many linguistic skills that involve language learning, abstract linguistic concepts, and cognitive skills could be shared from the first to the other language. For example, Wagner and colleagues (2015) investigated the linguistic effects on number concept development by studying a bilingual sample. The researchers tested the prediction of cardinality concepts in the non-dominant language from cardinality concepts in the dominant language. The results varied according to the level of each participant's understanding of cardinality. For those classified as 'subset knowers' (children who showed understanding of number words 1, 2, 3, or 4), there was no effect of dominant on non-dominant, indicating linguistically independent acquisition. However, this was not true for 'cardinal principle knowers' (children who showed understanding of number words 5 and above). Their results showed the presence of transfer of conceptual understanding across linguistic boundaries. Studies in bilingualism have shown that transfer mutually occurs between languages and not necessarily only from the first language to the other (Pavlenko & Jarvis, 2002).

Odlin (2009) stated that the definitions of code-switching and transfer do not demonstrate the difference between them, and provides a discussion of the difference between them. He pointed out that transfer includes a more extensive range of linguistic behaviours and these behaviours are covert. It was proven that if the two languages are structurally similar, it may accelerate learning of L2, and if the structure is different, it may delay L2 learning (Melby-Lervag &

Lervag, 2011). For instance, research has shown that for children learning the Italian language as L1 and English as L2, which use the same alphabet, the level of proficiency in L1 can facilitate the learning of L2 (D'Angiulli, Siegall, & Serra, 2001).

On the other hand, code-switching is an overt behaviour. Marian (2009) holds that transfer and code-switching originate from lexical access phenomena, and that these phenomena are the results of cross-linguistic interaction that happens at different levels of cognitive processing. Furthermore, she pointed out that both languages must be activated during code-switching, whereas transfer depends on language mode activation, which is the state of activation of each language. In more general terms, the difference between code-switching and transfer is that code-switching is clear to the speaker, and s/he can decide when to switch or not, whereas transfer is not apparent and cannot be controlled (Grosjean, 2001).

The concept of transfer is present in code-mixing of the second language learner in which the structure of the first language is imposed on the other language as a result from lacking linguistic competence of the second language, which results in either violation of grammatical rules or learning new rules (Paradis, 2011).

The following is an example of a grammatical violation. In Arabic language, both word orders (SOV) and (VSO) are acceptable, whereas, in English, only (SVO) is acceptable. That is to say, in Arabic, there is a sort of flexibility as subjects can either precede or follow the verb. However, in English, the subjects must precede the verb.

In example (1. a), the subject “book” comes before the verb “was,” and the adjective “nice” comes after. This structure is acceptable in Arabic and English; therefore there was no rule violation in code-mixing.

In contrast, in example (1. b), the speaker spoke the sentence only in Arabic grammar. In this example, the verb “was” comes before the subject “book,” which makes the word order here (VSO). Such an order does not exist in English, which indicates a clear violation of English syntax, resulting in rule violation in code-mixing.

(e.g.1.a). *E.g. (SVO)*

Arabic ʔl-kitab kan ħelo
English the-book was nice

Code-mix ʔl-book kan ħelo → No rule violation

(e.g.1.b). *E.g. (VSO)*

Arabic kan ʔl-kitab ħelo
English *not applicable*

Code-mix kan ʔl-book ħelo → Rule violation

Code-switching and transfer raise an interesting question in children’s number learning. Is there an abstract transfer of language concepts from one language to the other that can help the representation of number knowledge? Wagner et al. (2015) suggested the transfer of conceptual understanding across linguistic boundaries. The next chapter will look in detail at grammatical number marking and its possible transfer across languages.

2.2 The Arabic language

2.2.1 Nature and variety

The Arabic language is Semitic, a branch of the Afroasiatic language family and a member of the south-western group (Holes, 2004). It has three primary forms: first, the Classical Arabic (CLA), which has a fixed and constructive form, and it is the language used in the “Quran” (Thackston, 1990). Second is the Modern Standard Arabic (MSA), a simplified form of the CLA. It is a unified language syntactically across the Arabic world; it is used in formal occasions, media, news, and education (Workman, 1979). Lastly, the non-standardized Arabic language, also called “Vernacular Arabic” (Smith, 1917) or “Colloquial Arabic” (Altoma, 1969), is influenced by the geographic region; various dialects that differ between and within different Arabic regions (Altoma, 1969). For instance, Badawi (1985) has reported five different Arabic Egyptian dialects based on socio-linguistic analysis.

All these language forms have only one written form. Furthermore, all these different forms of the Arabic language are used in daily life. Arabic language speakers exhibit diglossia, which is a phenomenon that includes understanding and speaking two forms of languages; the MSA and Colloquial Arabic (Ferguson, 1959). *Colloquial Arabic* is used on non-formal occasions and in daily communication. It does not have a defined syntax (Holes, 2004), and it is considered the children’s mother tongue, as they are introduced to the MSA later in life through education and formal media (Thompson-Panos & Thomas-Ruzic, 1983). *Colloquial Arabic* is the language form used in this study, and it is the form of Arabic spoken by the families taking part in this study. Henceforth the term used is “Arabic language”.

2.2.2 Morphological system

Spencer (1991, p. 21) states that in Arabic "Inflectional operations leave untouched the syntactic category of the base, but they too add extra elements. These are elements of meaning (for example, tense, aspect, mood, negation) and also grammatical function." The Arabic language, in all its forms, has a rich morphological system that plays a vital role in word formation (Gadalla, 2000; Holes, 2004; Watson, 2002). Arabic words are based on a system that is called "root-and-pattern" The root indicates meaning and pattern to provide the support, i.e., one or more vowels, to form a word. Word consists of a root that is usually formed by the attachment of three consonants, a pattern of vowel, and one or more affixes (suffix or/and prefix) (Gadalla, 2000). The vowels and affixes are used in many ways or patterns to make new meanings related to the root meaning.

In MSA, verbs agree in person, number (singular, dual, or plural), and genders.

2.2.2.1 Nominal number marking system

The nominal number morphological markings in the Arabic language are very important and valuable in investigating the relation of various linguistic concepts.

The Arabic language marks nominal number by inflection (affixes). It includes three categories: singular, dual, and plural. The singular form is used when the speaker refers to one entity; dual is used when the speaker refers to two entities, and the plural is used when to refer to more than two entities. These inflections can be attached to nouns and pronouns; they are always attached to the root and pattern to indicate the quantity (root-pattern+ suffix) “sayara-ten” for two cars or “sayara-aat” for cars.

The singular form of the noun forms the base as it is unmarked with number morphology inflections. However, the noun stem is represented for masculine referent, and feminine referent is represented by adding the suffixed /-a/.

Arabic noun morphology includes Nominative, Genitive, and Accusative cases, all of which vary according to number and gender. However, as is shown in Tables 1 and 2, the morphology of the dual, in contrast to singular and plural, does not vary according to gender.

Furthermore, in colloquial Arabic, dual markers occur only in nouns (Mitchell, 1962).

Table 2.1 Example, the masculine noun bayt ‘house’

Case	Singular	Dual	Plural
Nominative	bayt-tun	bayt-taan	bey-outun
Genitive	bayt-tan	bayt-tayn	bey-outun
Accusative	bayt-ten	bayt-tayn	bey-outen

Table 2.2 Example, the feminine noun tufaha 'apple'

Case	Singular	Dual	Plural
Nominative	Tufaha-tun	Tufaha-taan	Tufah-aatu
Genitive	Tufaha-tan	Tufaha-tayn	Tufah-aat
Accusative	Tufaha-ten	Tufaha-tayn	Tufah-aat

This thesis focuses on the influence of dual case comprehension on number knowledge in a bilingual context, therefore in I will focus on dual case morphology in Arabic. In a unique study of number marking in the speech of Saudi-Arabic parents and young children, Alquatani (2016) showed that parents' use of the dual case in child-directed speech is relatively sparse, and that children find dual case more difficult to learn than either singular or plural. Nonetheless, particular interest attaches to the dual case on account of its exactness, as distinguished from both singular and plural. Nouns marked with dual case, used in the context of their referents, are therefore likely to be optimally informative for the learner (Ramscar, Dye, Popick, & O'Donnell-McCarthy, 2011). It is important to highlight that there is a scarcity of studies on bilingual Arabic children and their parents' use of the dual case. Isolated results from small samples might be misleading. Because each study take place in a different city or region, therefore, more research is needed on this."

Dual nouns are formed by adding a suffix to the singular form of the noun, adding /-tain/ for feminine and /-en/ for masculine

(e.g.1). *E.g (1). kalb-en* *kalb-t-ain*

Dog-Dual.Masc Dog-Fem-Dual

'Two male dogs' 'Two female dogs'

Plural nouns have two different ways of formation; either suffix attachment or internal changes to a noun-stem structure. Suffix attachment is used to form regular plurals or what is called "sound plurals" by adding /-at/ for feminine or /-een/ for masculine forms for the human referents, in this type of plural, no changes are made to the stem of the word (e.g.2).

E.g. (2) Modarisa-at Modaris-een

Teacher-Plural-Fem Teacher-Plural-Mas

'Teacher' 'Teachers'

For non-human referents for plural forms, only the feminine plural can be used regardless of the gender referent. Internal changes are used to form irregular plural or what is called "broken plurals", this type of plural exhibits a range of forms in which the singular forms may be drastically different (e.g.3)

E.g (3) Kotob (Kitab) Aqlam (Qalam)

Book- plural Pen-Plural

Books Pens

2.2.2.2 The development of Arabic nominal-number markers

There are a small number of studies in the field of phonology, morphology, and syntax of the Arabic language (Al-Tamimi, 2011). It was claimed that research investigating the Arabic language is very challenging due to the lack of referenced grammar and normative data due to the presence of a large number of Arabic dialects. Therefore, few studies have looked into children's acquisition of Arabic and into the development of number marking in Arabic (Shahin, 2010).

The first study that investigated Arabic language acquisition was through a production language test involving 37 Egyptian Arabic children. A simple comprehension language test for a smaller sample (16 children) aged between 2; 8 and 7; 00 years was included. The comprehension test only examined singular and plural forms through the picture pointing task. Children were asked to point to either "ball" or "balls" according to the verbal stimuli presented by the researcher. The results showed that children demonstrated an understanding of singular-plural distinction around the age of three.

Furthermore, the study included an analysis of language production that included the dual forms and singular and plurals. The result showed children acquired regular plurals at the age of three. On the other hand, children acquire irregular plurals and duals around the age of five. Additionally, understanding numbers was examined by asking the children to give "one" to "five" stones. Results showed that all children were able to give "one" and "two". However, only children above the age of six could give numbers beyond “two”. The study concluded that the acquisition of nominal number marking seems to emerge early in children’s speech (Omar, 1973).

Nominal-number marking was also studied in Palestinian-Arabic through a cross-sectional study followed by a longitudinal study. Ravid and Farah (1999) studied 58 Palestinian children aged from three-eight year-old. Results showed that children started to produce irregular plurals which are used more frequently in their everyday speech, around the age of two; regular feminine plurals acquisition follow it around 2; 6, with the acquisition of masculine plurals emerging later. This series of acquisitions could result from the limited presence of masculine plurals only used for animate nouns. Nonetheless, it was concluded that regular plurals were fully mastered at the age of three, before the irregular forms, which required a longer time to be acquired. It was argued that these stages of acquisition and mastery could be delayed to a later age in life, up to the age of 12 (Moawad, 2006).

Similar results were found by Aljenaie, Abdalla and Farghal (2011), who examined dual and plural nominal marking in four to nine year-old Kuwaiti-Arabic speakers. Children were asked to provide the plural and dual forms of selected pictures of real and nonsense words. They found that children use the feminine regular plurals marker earlier and more frequently than the masculine regular plurals and irregular plurals. It was concluded that children use the feminine regular plurals as default and overgeneralize it to develop the other forms. Furthermore, they conclude that children tend to be more accurate in using the dual form when compared to plural.

Ravid and Hayek (2003) concluded that number inflections are learned between the age of three and five. They state that regular feminine plural is learned first, followed by dual, then irregular plural inflections. Al-Akeel (1998) examined language comprehension in Saudi-Arabic speakers. A systematic study that obtained data on the typical language acquisition process, including the pattern, rate, and the order of acquisition of morpho-syntactic structure of the Saudi Arabic language. He studied 120 three to six-year-old Child-Directed Speech. He found complete comprehension of the nominal number marking occurred between 4; 00- 4; 05 years. He claimed that children initially treat duals and plurals as one category because children cannot distinguish between them. However, children seem to draw this distinction gradually and fully understand it around the age of four.

It is essential to note that most of the findings of the mentioned studies concerning the development of Arabic nominal number marking cannot be generalized due to the presence of linguistic variations of different Arabic regions and different cultures and education. Furthermore, most of these studies included a small sample size and lacked longitudinal data that made examining the developmental trajectory of number marking impossible.

Overall, the findings of studies on the Arabic language (Omar, 1973; Ravid & Farah, 1999; Ravid & Hayek, 2003) emphasize the impact of the diverse language structures on language acquisition. As claimed by Ravid and Farah

(2009, p. 22): ‘what may seem irregular and “difficult” to speakers of one language might be in fact easily accessible to children who are very early on sensitive to the typological imperatives of their language’

In summary, the role of linguistic structures in the development of different cognitive processes, specifically the formation of number concepts, can contribute to understanding the relationship between language and numbers. Most of the evidence available on that topic is in the English language. On the other hand, with its rich morphological system, the Arabic language represents a further number-based distinction by comprising a dual case alongside singular and plural cases, offering in-depth insight concerning this argument. Furthermore, to avoid any linguistic variations, as there are different forms of Arabic languages, as mentioned, only Saudi Arabic children who speak Najdi dialects were included in this study.

2.3 The English language

2.3.1 Nature and variety

English language is a West-Germanic language of the Indo-European family language along with German, Dutch and Frisian (Hawkins, 2009). Currently the English language is considered a global language as 500 million speaks English as a first language (Zhu, 2001), and 950 million users as a second language (Saville-Troike, 2012). English language consists of numerous varieties which includes the different dialects of different regions of the British Islands, North America, Australasia, India, Africa, and various English-based areas in the Atlantic (e.g. Jamaica) and the Pacific (e.g. Hawaiian).

2.3.2 Morphological system

English words are root words that carry the basic meaning; it is a free morpheme that can stand alone. However, there are some exceptions where the root cannot be separated from their bound root (e.g.*, cran* in *cranberry*)

Derivational and inflectional morphemes are attached to the base and play a fundamental role in English word structure.

The inflectional morphology in the English language is very simple compared to other Germanic languages like German. Inflectional affixes can only be suffixes. They do not change the word's meaning or the grammatical category but instead mark various grammatical relations. For instance, the English nouns have only two variants; a mark for possessive singulars, e.g., /moon's/ and plurals, e.g., /moons/.

Derivational morphology changes the meaning of a word and the grammatical category. It can be either prefixes or suffixes. For instance, adding the prefix dis- to the base 'comfort' results in 'discomfort,' which is the opposite to the meaning of the word 'able', and adding the suffix -able to 'comfort' changes the form from noun to the adjective 'comfortable'.

In English, verbs agree in person, number (singular, dual, or plural), and genders. Nouns agree with number and gender, and adjectives are inflected as the nouns' properties.

Regarding the count-mass noun difference, only count nouns such as *cats* can be paired with indefinite articles, whereas the mass nouns like *water* cannot take the indefinite article. Mass nouns in English are paired with mensural classifiers and unitisers, for instance, *some water and much money*.

Regarding the numerals, only count nouns can be paired with numbers, for example*, one man, two cats.* On the other hand, mass nouns must be paired with mensural classifiers or unitisers before numbers, such as *one glass of water* (Gil, 2013).

English noun morphology includes Nominative, Genitive, Accusative, and Dative cases, all of which do not vary according to number and gender. Gender in English does not differ. However, sometimes gender distinction occurs when referring to specific nouns, for example, man/women, father/mother.

2.3.2.1 Nominal number marking system

The English language marks nominal numbers by inflection (affixes). It includes two categories: singular and plural. It can be attached to nouns. The plural in English is commonly formulated by adding the suffix *-s* for most countable nouns. This *-s* suffix has three different allomorphs, which is a morpheme that varies in sound and spelling without change in the meaning: /s/ (e.g. *hats*), /z/ (e.g. *boys*), and /əz/ (e.g. *buses*) (Carstairs-McCarthy, 2002; Ettlinger & Zapf, 2011). There are irregular suffixes to express plurals including */i/, /ae/, /en/* and */a/* (e.g.: *phenomena, children*) (Carstairs-McCarthy, 2002). Some English nouns are isomorphic which the singular and plural forms are the same, for example, *fish and shrimp.*

Having reviewed the nominal number marking structure in detail of the Arabic language and briefly in English, this section summarises the critical differences between these two languages and shows, among other things, the complexity of each of the systems the child has to learn simultaneously and eventually master. Table 2.3 summarise the similarities and difference.

Arabic has root-pattern morphology where the root is made of consonants, and the pattern is the vowel connected to the root, whereas the root in English must have vowels. Both Arabic and English verbs and nouns have inflectional affixes.

Nouns in Arabic are inflected for number, gender, case, and definiteness; nevertheless, English nouns are only inflected for number and case.

Arabic and English have singular and plural in their system of numbers. Arabic additionally has dual. In Arabic, the plural in Arabic has three types: masculine plural, feminine plural, and broken plural or irregular. In English, plural nouns are made by adding the suffix *-s* or modifications.

Arabic nouns commonly have gender, and most of the feminine nouns have gender suffix. In English, gender is not common; however it can be noted if the noun refers to human beings or animals.

It is important to note that it is not easy to compare Arabic language development and development in other languages due to the presence of various forms and dialects. Nevertheless, when comparing Arabic to the English language, English-speaking children seem to develop singular-plural distinction at the age of three years old (Kouider, Halberda, Wood, & Carey, 2006), where

Arabic Speaking children need more time to develop singular-dual-plural distinction (Al-Akeel, 1998).

Table 2.3. Summary of the similarities and difference between Arabic and English languages.

Aspect	**Arabic language**	**English language**
Root	Made of consonants.	Must have vowel.
Inflectional affixes	√	√
Nouns	- Inflected for number, gender, case, and definiteness. - Have gender.	- Inflected for number and case only. - Does not have gender.
NNM	Singular, dual and plural.	Singular and plural.

This chapter presented an overview of bilingualism, including the different definitions, theories of language acquisition, the phenomenon of cross-linguistic influence, and an overview of Arabic and English languages, including the difference between them.

Bilingualism offers an insightful perspective of the influence of language on cognition. How learning two languages can affect children's cognitive development, precisely on the concept of number knowledge which is the main topic in this study. The following chapter will look into number concept development, cardinality concepts, language and number relation, and lastly, transcoding.

Chapter 3: Number knowledge in a bilingual context

This chapter presents an overview of number concept development, including the core system of numbers: the pre-linguistic evidence and ANS vs. precise presentation. Also, present an overview of the general theories of the early development of numerical cognition, counting and cardinality; including the give-a-number task and transcoding. Furthermore, this chapter describes the language and number relation, bilingualism and number word development, including the transfer phenomenon.

3.1 Number concept development

Numbers are around us in every aspect of our daily activities: in our representation of time, in children's rhymes, in money and much more. Children learn the concept of numbers very early in life, even before their first words. For instance, six-month-olds can differentiate between two and three jumps of a puppet (Wynn, 1996). This suggests that children's number word learning is mapped onto an already existing concept.

Although number words like 'two' and 'three' are learned by children all over the world, this is not universal as some cultures do not have numbers, like the Pirahã in the Amazonian rainforest (Gordon, 2004), nor are number words easy to acquire. For instance, in the United States children learn the number word 'one' at the age of one, and it takes six to nine months for them to learn the number word 'two', and more months pass before they learn number word 'three' (Wynn, 1990; 1992).

Much research has attempted to identify the representations of numerosities on which early number word meanings are built and has debated whether these are better understood as continuous magnitudes (Wagner & Johnson, 2011; Wynn, 1992) or individuated small sets (Le Corre & Carey, 2007; Wagner, Chu, & Barner, 2019). To date, there is no definitive evidence one way or another.

Understanding the language input that children receive plays a major role in understanding number word development. Reviewing the language environment input of number words is considered an extension to research related to linguistic input as it is a child–parent interaction phenomenon. Children who receive more input containing number words appear to develop faster in their use of number words (Gunderson & Levine, 2011). However, children who are raised in cultures with languages where numbers are used infrequently tend to be late developers (Piantadosi, Jara-Ettinger, & Gibson, 2014). There is little research examining number word input, but most studies have supported the fact that the greater the adult input, the greater the impact on number knowledge development (Bloom & Wynn, 1997). Some research shows consistently that parents with a middle socioeconomic status (SES) provide more input that includes maths than those with a lower SES, which is reflected in child performance from kindergarten to adolescence (Blevins-Knabe & Musun-Miller, 1996; Saxe, Guberman, & Gearhart, 1987; Starkey, Klein, & Wakeley, 2004). A longitudinal study by Levine, Suriyakham, Rowe, Huttenlocher and Gunderson (2010) obtained a sample of interaction data from 44 preschool children between the ages of 14 and 30 months from five home visits. This showed a connection between early parent number input and pre-schoolers' acquisition of the cardinality principle. The results suggested that children's developmental trajectories can be positively influenced by input. Furthermore, Bloom and Wynn (1997) have examined the linguistic input that one- and two-year-old children received from their parents and the children's own speech. They concluded that linguistic cues have a major influence on the development of number word meanings as children 'bootstrap' their understanding of number through morphological and syntactic structures of the linguistic counting system. Further details will be discussed below regarding the relationship between language and number.

3.1.1 Core system of numbers

3.1.1.1 Pre-verbal evidence

Many research studies have proven that infants demonstrate some understanding of basic numerosity, which suggests that counting and number knowledge could be based on non-verbal innate representations. For instance, Wynn (1992a) showed that five-month-old infants, when presented with a set of two items, demonstrated increased attention when one item was removed or added relative to their response when the set was unchanged. Furthermore, it has been shown that infants exhibit an approximate understanding of numbers rather than specific representations. One study has shown that seven-month-old infants could differentiate between eight dots and sixteen dots, and sixteen versus thirty-two, but not eight versus twelve or sixteen versus twenty-four (Xu & Spelke, 2000).

3.1.1.2 Approximate number system vs parallel individuation system

Research has established evidence of the presence of core systems of number that are considered a source of early numerical information when it comes to numerical thinking. These core systems are present in humans and other animal species and present from birth (Gelman & Gallistel, 1978).

Furthermore, there is substantial evidence that numerical processing is present in animals, where language does not exist. For instance, a chimpanzee was trained to press a key with an appropriate Arabic number in response to objects presented in the display window (Matsuzawa, 1985). Similarly, Meck and Church (1983) trained a rat to press one lever in response to a sequence of two beeps and another lever in response to a sequence of eight beeps.

One of these systems is the approximate number system (ANS) (Gelman & Gallistel, 1978). The other is the parallel individuation system (PIS) (Hauser, Carey, & Hauser, 2000), also called the object tracking system (OTS). The representation of numbers can be identified through different modalities, either visually (Barth, La Mont, Lipton, & Spelke, 2005), auditorily or by touch (Plaisier, Bergmann Tiest, & Kappers, 2009). Although, these systems do not support complex mathematical concepts such as root squares and fractions, the systems are fundamental and may be considered the foundation of later mathematical concepts (Feigenson, Dehaene, & Spelke, 2004; Pica, Lemer, Izard, & Dehaene, 2004).

The ANS is a cognitive system found in humans and non-humans that is present from birth and continues to support numerical concepts in adulthood (Gelman

& Gallistel, 1978; Izard, Sann, Spelke, & Streri, 2009; Whalen, Gallistel, & Gelman, 1999). It is an approximate rather than exact representation of numerical magnitude, also called the analogue magnitude system, which follows Weber's law, in which the difference between two values is the function of their ratio. Dehaene (1997) and Moyer and Landauer (1967) have suggested that the process of understanding number relation and judgments of various numerical magnitudes is the same process that applies to perceptual judgments, such as loudness and temperature.

An important feature of this system is that the numerosity discrimination is abstract and presents a noisy representation of approximate numbers that captures the relationship between different quantities. This system does not provide precise discrimination but is related to ratio rather than numerical difference. It is believed that this system might have a significant role in the development of more advanced numerical concepts (Dehaene, 1997, 2001; Gelman & Gallistel, 1978, 2004; Wynn, 1992; 1996). Gilmore and Spelke (2008) investigated the role of the ANS on the understanding of addition and subtraction in preschool children. The results showed that children could successfully perform addition and subtraction on the symbolic and non-symbolic representations of large approximate numbers but not on the symbolic representation of exact numbers.

In contrast, the PIS has limited capacity as it focuses on small numbers of objects, and it deals with the precise presentations of distinct individuals. Children can represent and track items as a distinct individuals up to three to five items only (small number representation) (Feigenson, Carey, & Hauser, 2002; Hauser et al., 2000). It is important to note that the PIS and the term ‘exact numerosity’ are not identical. The PIS is a perceptual operator involving the processing of visual information in the brain. In contrast, the notion of exact numerosity occurs later in the cognition process. Gelman and Gallistel (1978) suggest that exact number concepts are cross-culturally universal and that each language can reveal a universal pattern during learning, even without instruction. On the other hand, Carey proposes that exact number concepts are inaccessible to young children and are acquired gradually (Carey, 2004).

Feigenson and colleagues (2004) and others (Spelke & Tsivkin, 2001) have adopted a moderate approach by suggesting that both systems, the ANS, which represents large approximate numerosity, and the PIS, which represents small exact numerosity, provide the basis for learning number words and counting. They also suggest that language serves as a link between these two representations.

Recent research has demonstrated that both systems – the ANS and the PIS – take part in the development of cardinality and therefore in the development of mathematical abilities in children, which will be discussed later in this chapter.

3.1.2 General theories of the early development of number words and counting

It is very important to note that the concept of number is regarded very differently by different researchers. We are talking about different stages in development, different cultures and languages. Broadly speaking, theories of children's acquisition of number word meanings can be divided into two camps: nativist and constructivist accounts.

Nativists, including Gelman and Gallistel (1978) and colleagues (Gelman & Greeno, 1989; Gelman & Meck, 1983) propose that an innate ability that is number specific underlies the counting ability of children; this ability unfolds as it is triggered by the experiences the child has whereby number word meanings are acquired.

According to Gelman and Gallistel (1978), children's counting processes can be defined through five universal "how to count principles":

1) <u>The one-to-one correspondence principle</u> states that each item in a counted set should be referenced with one specific number, and that number cannot be referenced to another item in that counted set.
2) <u>The stable order principle</u> states that the referenced number of an item in a set should be arranged in a fixed order.
3) <u>The cardinal principle</u> states that the final number in the counted set represents the property of that set or cardinality.
4) <u>The abstraction principle</u> states that counting applies to any group of entities (all kinds of physical objects or mental constructs).
5) <u>The order irrelevance principle</u> states that the order of different elements of the counted set is irrelevant and is mapped onto a total counting set.

Consistent with Gelman and Gallistel's (1978) view is the suggestion by Wynn (1992a) that infants have innate numerical concept abilities, her study showing that five-month-old infants could 'calculate' simple addition and subtraction of a small number of items. An alternative account to Wynn's – a constructivist account – was suggested by Sophian (1998) who stated that what Wynn observed in her study was not simple addition and subtraction happening in the child's brain but rather a behaviour that later becomes recognised as number concept knowledge. This numerical concept was suggested to provide the foundation of later arithmetical knowledge development.

Another constructivist view was proposed by Carey (2004), who stated that children learn the concept of the numbers 'one', 'two' and 'three' first, through the support of the PIS and the quantifiers of natural language, and that the meaning of the other number words is learned through the bootstrapping process.

Bootstrapping is a process that captures a human's ability to learn a set of symbols and their relation to each other, which fills these symbols with rich meaning. Carey (2004) has described how the bootstrapping process helps with learning how to count. Bootstrapping is the process by which learning novel concepts emerge from the assimilation of previous learned. Carey proposed that language can support bootstrapping of number concepts. She describes the learning of the first few number words as based on the association of small sets of items with number words provided by adults/older children. Children learn the first number word as a natural number quantifier, which is the number word 'one', as they know the singular determiner 'a'. They then learn the number word 'two' when the dual morphology (present in some languages) is learned. Furthermore, the number word 'three' is learned after a few months as the trial marker – a grammatical marker to refer to three items – is learned (present in rare languages) (Barner, 2012). By extension, where the meaning of any number words on the counting list is known, the following number words on the counting list refer to number words by adding one to the individual number, i.e. N + 1. In contrast, Rips and Bloomfield (2006) argue against this proposal, stating that if there is an innate ability for the numeral system, then the bootstrapping process may be unnecessary. They also argue that the bootstrapping process cannot pick out the natural number sequence from other non-standard sequence. The standard counting sequence is N + 1.

An additional constructivist view was proposed by Fuson, Secada and Hall (1983) and others (Briars & Siegler, l984; Fuson, l988), who claim that children's counting abilities are learned first as a routine activity. In this sense, counting has no meaning at first as it is modelled in their everyday lives by their parents and people around them. Children must learn different routine activities to become able to generalise counting, and then understanding of counting principles occurs.

3.2 Counting and cardinality

Cardinality refers to the number of members of a set. Understanding the cardinality principle entails an understanding of the use of number words as symbols to represent the cardinal value of a set. The activity of counting (e.g. reciting number words in order) does not necessarily imply understanding of cardinality. Most children do not understand cardinality until the age of three and a half to four (Wynn, 1990; 1992). However, it has been shown that children as young as two years and six months old show some behaviours displaying partial understanding of cardinality (Gelman & Gallistel, 1978). These behaviours include placing stress on the last word when they count, repeating the last word during counting or giving the correct response of the number word of a set without counting.

Le Corre and Carey (2007) investigated the relationship between analogue magnitude representations and cardinality and found that only children who reached the cardinal principle levels were able to map larger number words to large quantities.

3.2.1 Give-a-number task: knower levels vs cardinality

Studies of early number word learning by Wynn (1990; 1992) drew attention to the lengthy process by which children learn the meanings of the first words in the count sequence. In the initial ‘non-knower’ stage (starting around the age of two), children can point at objects and recite the count list (one, two, three, four…etc.) without understanding its quantitative meaning (Le Corre et al., 2006; Marušič et al., 2016). In the second stage (beyond the age of two) – the ‘one-knower’ stage – children understand the exact meaning of the number one (Barner & Bachrach, 2010; Le Corre et al., 2006). The third stage – the ‘subset-knower’ stage – occurs when subsequent number meanings are acquired gradually and in consecutive stages up to number four. However, even ‘four-knowers’ are unable to apply their knowledge of the count words to set sizes beyond their knower level (Le Corre et al., 2006; Spaepen et al., 2018). At this subset stage, children who have acquired the exact quantitative representation of number two are referred to as two-knowers, as they acquire the exact representation of three they are referred to as three-knowers, and as they acquire the exact representation of four they are referred to as four-knowers. Moreover, subset knowers usually demonstrate weak understanding of counting as they cannot count objects when asked for a specific number of objects (Wynn, 1990; 1992). The final stage in the process is called the ‘cardinal principle’ stage or ‘CP-knower’ stage; here children learn how counting represents number. Children are able to apply their understanding of the counting principles to quantify larger set sizes (Wynn, 1990; 1992; Le Corre & Carey, 2007; Lee & Sarnecka, 2010; Spaepen et al., 2018). The importance of this achievement was highlighted in a study by Geary et al. (2018) in which a child’s age on reaching CP-knower status was found to be a strong independent predictor of later number system knowledge and of broader mathematical skills.

Investigating the transition between these stages is crucial because it indicates what motivates number learning. Investigations have been carried out as a result of the following findings: first, that the frequency of number words in caregiver speech tends to affect the rate of transition between the stages; children who receive more speech containing number words appear to be faster in their development of number words (Gunderson & Levine, 2011); in contrast, children who grow up in a culture/language in which numbers are used infrequently tend to be late in their development (Piantadosi et al., 2014); second, that the grammatical structure of a language with reference to number has a major effect on the acquisition of number words, which is discussed in detail in the later section (e.g. Almoammar et al., 2013).

Numerous studies have used Wynn's give-a-number/give-N task (Wynn, 1990; 1992) and have provided extensive support for her proposal of stages of the acquisition of number words, or 'knower levels'. Wynn's give-a-number task has become the standard test of cardinality.

The give-a-number task allows children to use a 'last-word response' to indicate set size along with a precise understanding of quantity. Wynn (1992) used the following standard criteria to determine the knower level: the '*highest number children could consistently succeed at giving (p. 232):*

1. *On at least two-thirds of a child's trials for that numerosity, the child's response was either the correct number according to her own stably ordered count list or the correct number plus or minus one if the child had counted aloud from the pile to the number word asked for but had erred in the counting by either double counting or skipping one item or by repeating or skipping one number word.*
2. *The child responded with that number when asked for higher numerosities no more than half as often, percentage wise, as she did when asked for that number itself. For example, a child who gave two items 67% of the time (2 of the 3 trials) when asked for 2 was scored consistently correct on 2 only if she gave two items no more than 33% of the time when asked for three, four, and five items. This was to prevent children who had a preference for giving, e.g., two items no matter what*

they were asked for, from being considered to know the cardinal meaning of the word "two" (this happened on 12 of 58 trials).'

Various studies have used the give-a-number task to investigate number concepts and knower levels, but not all followed Wynn's criteria in order to determine the exact knower levels. There are two distinctive approaches to examining the knower level: conceptual and quantitative. The conceptual approach follows Wynn in aiming to establish conceptual (knower) levels, using with various probabilistic criteria, such as two out of three trials correct. Some studies present a fixed number of trials for all target numbers and provide quantitative data. Other studies skip some trials if the participant responds correctly. Appendix 1 summarizes the characteristics of different studies.

In contrast, the quantitative approach works with the total number of correct responses across the whole range of trials as a general indicator of understanding cardinality. Most studies have used the conceptual approach. The current study will contrast the conceptual and quantitative approaches by applying both approaches to the same data.

Wagner et al. (2015), Marušič et al. (2016) and Maruišiič et al. (2021) followed Wynn's exact criteria (criteria #1 and #2): children were defined as an N-knower (e.g. three-knower) if they correctly provided N (e.g. three blocks) on at least two out of the three trials when asked for N (e.g. three) and, of the times that the child provided N, two-thirds of those were in response to a request for N and not some another number. If N was five or higher, the child was classified as a CP knower.

Le Corre and Carey (2007) and Le Corre et al. (2016) adapted Wynn's (1990) give-a-number procedure and used similar scoring criteria but with precise criteria. The criteria were as follows: give N objects at least 67% of the time when asked for that number, and give N objects no more than half as often (50% of trials) when asked for a different number. The second criterion here is substantially less stringent than the 30% cut-off adopted by Wynn.

Some studies have taken a more straightforward approach to scoring. For example, Li, Ogura, Barner, Yang, and Carey (2009), Van Herwegen Costa, Nicholson, and Donlan (2018) and Wagner et al. (2019) used the same give-a-number procedure but with only one scoring criterion (criterion #1): responding to the two out of three trials. The scoring criterion was stated as the basic criterion; children were called *N*-knowers (e.g. two-knowers) if they correctly gave *N* items two out of three times when they were asked for *N* but failed to give the correct number two out of three times for *N* + 1. The studies did not take account of the number of responses of a given N across all target numbers.

Slusser and Sarnecka's (2011) and Lee and Sarnecka's (2011) scoring criteria were similar as they also used a straightforward method (criterion #1). Their scoring criterion defined knower levels based on the child having at least two successes at a given number N and at least two failures at N + 1. Three trials were completed for each tested number word. For example, children who responded appropriately for target number two but not for target number three were called two-knowers. Children who succeeded at the highest set sizes (five and six) were called CP knowers.

All the above-mentioned studies adopted a conceptual approach to test the understanding of cardinality.

In contrast, Mou, Berteletti and Hyde (2018) adopted a quantitative approach. They used a statistical modelling approach that evaluated the effects of a range of cognitive and linguistic variables on pre-schoolers' number knowledge. They used a computerised version of the give-a-number task in which participants were shown ten objects on a screen and asked to 'count out' two to eight items using the spacebar and counting aloud. The dependent variable derived from this task was simply the number of correct responses out of a total of 24 trials. Thus, Mou et al. (2018) took a quantitative rather than a conceptual approach to the evaluation of cardinality understanding.

There is considerable variability between studies in the application of criteria for establishing knower levels and measuring cardinality knowledge, which presents challenges for comparison across studies. The current study will examine individual patterns of response to the give-a-number task, apply both conceptual and quantitative analytic approaches and examine differences in outcome.

3.2.2 Transcoding

Transcoding refers to the ability to associate spoken and written Arabic numerals, e.g. 'thirteen' and 13, and it starts early; three-year-old children can match spoken-to-written Arabic multi-digit numerals (Yuan, Prather, Mix, & Smith, 2019). It provides an essential basis for early arithmetic skills and supports an understanding of place value (Cheung & Ansari, 2021; Malone et al., 2020). It is also considered a predictor of later mathematical skills in children (Malone et al., 2020)

A universal model of numerical cognition was suggested by Dehaene (1992), who proposed a triple-code model for numerical cognition. It presents three representations: the visual Arabic digits (e.g. '5'), the auditory-verbal number words (e.g. 'five') and the representation of non-symbolic magnitude (e.g. '•••••'), and each representation has its neural traits. Transcoding fits with the triple-code model (Habermann et al., 2020) as it involves the interaction between the visual and the auditory codes (see Figure 3.1).

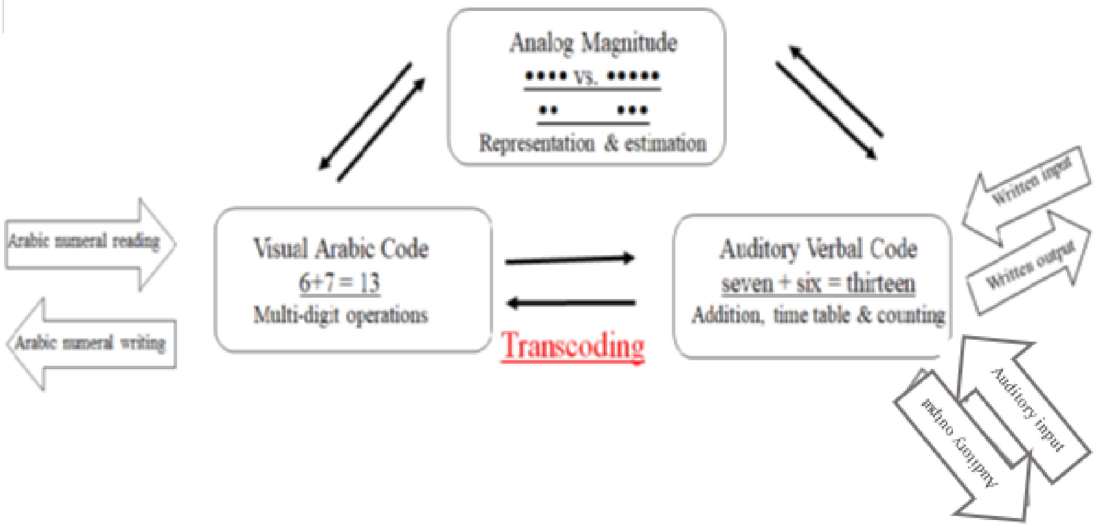


Figure 3.1 Dehaene's triple code model based on Dehaene, 1992; page 31

Children learn the numerical sequence through counting before acquiring the meaning of numerical symbols (number words). This creates what is referred to as the 'symbol-grounding problem' (Le Corre & Carey, 2007; Wynn, 1990). Numerical meanings may be derived from the ordinal relation between numbers (e.g. that three is larger than two because it comes later in the count list) as well as through the cardinal principle (the association between numerical symbols and the corresponding number of objects).

According to one account, understanding symbols for Arabic numerals is based on knowledge of the spoken number sequence (counting) combined with an understanding of the cardinality principle (Reynvoet & Sasanguie, 2016).

In transcoding, it can be very challenging to change from one notation to the other. There are cases where the number word expression follows the same sequence as the Arabic notation. For instance, in the English language, '31' is named 'thirty-one'. On the other hand, other languages present with number word inversion, that is, the sequence of numbers within number words is inverted with respect to the sequence of the Arabic notation. For example, in languages like Arabic, '31' is named 'one and thirty'. Research has shown that children exposed to languages with number word inversion are susceptible to typical inversion errors, whereas such errors are nearly absent in languages with no inversion (Zuber, Pixner, Moeller, & Nuerk, 2009). For example, when a child hears '/waħid wa θalaθe:n/' (one and thirty) in Arabic language and tries to translate this number word into Western Arabic notation, the child may mistakenly write down 13 or 130 instead of 31.

To understand the meaning of numeric symbols, place value needs to be understood. Place value is a system for written numeral presentation in Arabic digits that was developed in India and has two forms: the Western Arabic numeral (1, 2, 3) and the Eastern Arabic numeral (١, ٢, ٣). The Eastern Arabic numeral system is also called the Arabic-Hindu numerals. This system is expressed by Arabic alphabets.

The position of numbers in the Arabic numeral system is associated with a specific value. The first position from the right represents tens, the second position represents hundreds, etcetera. Except in cases of inversion, this is similar to the ordering of spoken number words (Cheung & Ansari, 2021). Research has shown that children acquire an understanding of the relationship between the place of numerical symbols and their value by the age of five (Yuan et al., 2019). Research has shown that preschool children know that small, single-digit numbers (e.g. one and two) denote a smaller quantity than larger single-digit numbers (e.g. seven and eight), even if children do not understand the precise meaning (Le Corre & Carey, 2007; Sarnecka & Gelman, 2004). This small association could be enough to help children understand numerical magnitude, that is, understanding that the digits on the far left matter more than the others (e.g. a number symbol XXX is greater than symbol XX) (Mix et al., 2014). Such understanding could be an essential step in children's understanding of place value.

Mix et al. (2014) showed that preschool children know how to map large spoken numbers to their written format and judge relative magnitudes. Furthermore, Göbel et al. (2014) investigated the influence of language on this aspect of number knowledge. They tested seven-to-nine-year-old German and Italian children on various symbolic numerical tasks. Their findings showed evidence of the influence of number word structure on the understanding of place value, as the place-value integration was more accessible when the mapping between number word structure and Arabic notation was compatible. In more detail, the word expression in Italian follows the same sequence as the Arabic notation. On the other hand, German language present with number word inversion, that is, the sequence of numbers within number words is inverted with respect to the sequence of the Arabic notation. Since the Italian children showed superior arithmetic skills the researchers conclude conclude that children’s ability to match Arabic numerals to their verbal names may be a strong indicator of their arithmetic skills development.

Cheung and Ansari (2021) have studied the relationship between the place and value of multi-digit Arabic numerals, and their results showed that age is clearly associated with the development of multi-digit understanding. Four-year-old children were able to understand that a multi-digit number is one whole number. However, the children had not yet acquired knowledge of the positional properties of multi-digits.

The current study investigates whether children’s concepts of cardinality at age three account for individual differences in their transcoding skills, independent of general language skills and knowledge of the spoken count sequence. The study compares cross-linguistic differences between Arabic and English languages in bilingual populations to investigate the relationship between transcoding and cardinality understanding. The main question is whether children’s understanding of cardinality influence their transcoding skills. The study will look into how different languages (Arabic and English) and different numeric symbols (Western and Eastern Arabic numerals) can influence cardinality understanding.

3.3 Language and number relationship

The theoretical and empirical associations between number knowledge and language have been explored as language is the principle medium for the communication of number word understanding. Moreover, it has been proposed that number development is shaped by language as number counting is embedded in natural language (Bloom, 1994).

Number words occur not only in verbal counting but also in contexts where semantic and syntactic cues are presented. For instance, in English language, using numeral *one* to indicate for singular noun “one car”. In Arabic language adding suffix to indicate for dual or plural forms, for example, adding /tain/ to indicate for duals “two balls” /kora-tain/, and /at/ to indicate for plurals “balls” /kora-at/. Such linguistic cues could facilitate understanding of a number word's meaning and properties, whether it is a set or a single item (Bloom & Wynn, 1997). Chomsky (1986) suggested that the sentence structures of language and the sequence of number counting have the same properties and share the same recursive device.

There is a continuous claim that language and number knowledge are connected. For instance, cross-cultural studies have shown that number knowledge is directly related to learning the verbal count list (Pica et al., 2004). Pica and colleagues (2004) investigated numerical cognition in Amazonian language speakers, which have a very small lexicon of number words. Their results showed that sophisticated and approximate numeral understanding could be present without the presence of a number words lexicon. However, the exact number concept is limited without the presence of a well-developed number words lexicon. Developmental studies have suggested that advanced abilities in numerical concepts accompany the onset of verbal counting (Gelman & Gallistel, 1978; Wynn, 1990). Moreover, advanced arithmetic skills are associated with the efficiency of number word articulation (Gathercole & Baddeley, 1993). Furthermore, it has been found that number representation disorders usually accompany language disorders (Cohen & Dehaene, 1991; McCloskey, 1992; Warrington, 1982).

While the combined evidence from these studies suggests that language plays critical role in acquiring number words, and that these are the basic building blocks for mathematical skills, there are significant objections to this position. In contrast, other studies believe that language is not an essential component of numeral development (Gelman & Butterworth, 2005). Gelman and Butterworth (2005) argue that neurogenic evidence imply that language and numerical concepts have different origins. However, they also suggested that language can facilitate number learning.

Spelke (2017) proposed that natural number development depends on acquiring the general rules of a certain language. She suggested a four-step process to learning numbers. First, children develop a profile of representation of the object kinds (nouns). In this profile, each object is linked to a function (if it is an animal), a possessor (if it is a body part) or a user (if it is inanimate).

Second, children learn ways of expressing individuals, including whether the individuals are of the same kind (*the fish/the hat*) and expression of their identities (*this fish/ that fish, my hat/ your hat*). They also learn to express these individuals through the use of conjunctions. These expressions support number words learning as the number words can occur simply in noun phrases (*e.g. Sara had three cats and one dog*). Third, children tend to link the expressions they have learned to the representations from the ANS. Children start to know that expressions like *two cats, and blue, green and black* refer to a set of large numerical magnitude. The final step is that children apply the grammatical rules of a certain language to refer to numbers. For example, in English, *one car or two cars.*

It appears that learning language production rules along with core knowledge allow children to develop numerical expression. If the number system were solely based on a core system such as the ANS or from learning the count list, it would be easier for children to solve arithmetical puzzles with number words only, and Spelke (2017) found this not to be the case. Preschool children were able to solve verbal, arithmetical problems when presented with a simple noun phrase (e.g. ‘If there are two bricks in this box and I put in two more, how many bricks are in the box altogether?’) before they could solve problems when presented with number words alone (e.g. ‘What do three and three make?’). Furthermore, preschool children’s number word learning can be predicted from their noun lexicon (Negen & Sarnecka, 2012).

Language structure affects children's acquisition of number words. Cross-linguistic comparison studies have shown that morphological bootstrapping aids in number word learning. The morphology structures of rich languages, such as Arabic and Slovenian, represent a further number-based distinction by including a dual case (marking two units) alongside singular and plural cases. For example, car (singular) in Arabic is /sajara/; to refer to two cars, dual case morphology is added /sajaraten/. Particular interest attaches to the dual case on account of its exactness, as distinguished from both singular and plural (Barner, 2012).

Barner and colleagues (2007) investigated the relationship between morphosyntactic cues (singular and plural) and children's ability to discriminate between a singular set (one item) and a plural set (four items) in 18-, 22- and 24-month-old English children. The authors emphasised that the conceptual understanding of 'one' and 'many' is needed to understand singular/plural grammatical number marking.

The results showed a correlation between singular/plural morphology comprehension and successful performance on a task involving searching for 'one' and 'four' balls in the 22- to 24-month-olds only. This correlation was not found in the youngest group of 18-month-olds. These results are consistent with the suggestion that plural morphemes start to develop in English children's speech around 24 months (Brown, 1973). Furthermore, these results indicate that both concepts are related – singular/plural grammatical marking and number word development. However, the question is how these concepts are related. The authors suggested that if there is a connection between language and number, it should co-occur across languages with the presence or absence of morphological distinction. This connection will develop earlier or later than that in English, according to the grammatical rules of the other language.

Cross-linguistic variation in number marking is substantial. Li and colleagues (2009) investigated the relationship between and among grammatical number marking (singular/plural) and number concept development in English and Japanese learners. The Japanese language differs from English as it does not distinguish between singular and plural nouns. English and Japanese children ranging in age from two to four years old were tested on a give-a-number task adapted from Wynn (1992) and a quantifier task where children were asked to place ‘some, few, most...’ items in a red circle. In addition, the testing included analysis of parents' speech directed to the children.

The results showed that two-year-old Japanese children outperformed their English-speaking peers in the quantifier task. However, they showed a delay in their number knowledge development. This delay in number knowledge faded as Japanese children aged, until they caught up with the English children.

Additionally, analysis of parent's language showed that quantifiers and numbers in Japanese do not follow a unique or special position relative to the noun in a sentence. The results of this study indicate a one-way causal relationship whereby the acquisition of grammatical morphology support the number concept understanding. Although it was suggested that the grammatical distinctions are not necessary for number word learning, it was acknowledged that they aid in the pace of learning. Furthermore, it was suggested that the role language plays in numerical development is not universal but rather language specific.

Further cross linguistic evidence was obtained by Almoammer et al. (2013), who investigated how the effects of grammatical morphology on number word learning. They tested Saudi Arabic and Slovenian children as these languages are exceptional in having dual case marking. The influence of dual case marking on number word acquisition was examined by comparing knower levels in Saudi Arabic and Slovenian preschool children to those of English preschool children. Results showed that, at 24 months, 42% of the Slovenian group were two-knowers, compared with 4% of the English group. Similar proportions were found at three and four years of age. In the Saudi Arabic group, overall, 41% of children were two-knowers compared with 11% of the English group. Again, similar proportions were observed within each age group. These findings support the proposal that grammatical number marking aids the formation of number concepts.

Almoammer identifies the influence of dual case comprehension on knower levels, this raises a question of the process of number learning, as one study reported difficulty of dual case learning relative to singular and plural learning (Alquatani, 2016).

This phenomenon has not been widely studied, there are numerous ways in which the dual case may influence children’s number development.

It is important to note that Almoammer et al. (2013) only observe the knower levels of children in dual case and non-dual case languages, they do not observe the wider numeracy development of children; for instance, the cardinality concepts on its development from knower level 0 to 5.

Sarnecka and colleagues (2007) investigated the role of singular/plural morphology distinction on cardinality concept development in relation to number words ‘one’, ‘two’ and ‘three’ by testing English-, Russian- and Japanese-speaking children between the ages of 30 and 42 months.

The study compared English and Russian children because these languages have obligatory singular/plural number marking. For example, singular nouns (boy, woman) are morphologically distinguished from plural nouns (boys, women). These groups differed to the Japanese-speaking children, as the Japanese language does not have obligatory singular/plural marking. The singular/plural distinction is developed at 24 months in English children and 15 months in Russian children (Leushina, 1991).

The children were tested on a counting task and the give-a-number task. The results showed that English and Russian children presented with more understanding than the Japanese children of the number words ‘one’, ‘two’ and ‘three’. Approximately 90% of English- and Russian-speaking children aged between 33 and 42 months knew at least the meaning of the number word ‘one’, whereas nearly 50% of the Japanese group did not, which suggests that linguistic cues play an essential role in the development of the cardinality concept of ‘one’, ‘two’ and ‘three’. The researchers claimed that the initial understanding of number words in a language is linked to the grammatical categories the number words align with, i.e. number word ‘one’ is perceived as singular, ‘two’ as dual, ‘three’ as trial and any larger numbers are perceived as a plural category without any particular magnitude, depending on the availability of the grammatical category in a language. Around the age of four, children’s development of number words changes as they learn the cardinal principle. The study’s results highlighted that, if the understanding of number words ‘one’, ‘two’ and ‘three’ is reinforced by the understanding and development of singular-plural morphemes, children speaking languages with richer grammatical number morphemes show earlier understanding of number word meanings.

These findings form part of a growing body of evidence that grammatical number marking supports the formation of number concepts (Almoammer et al., 2013; Barner et al., 2009; Le Corre et al., 2016; Marušič et al., 2016; Sarnecka et al., 2007). In contrast, others believe that language and numbers are independent of each other (Gelman & Butterworth, 2005). An alternative suggestion is that number concept is universal (Gelman & Gallistel, 1978). Nevertheless, cross-linguistic evidence suggests that variations in language play a role in variations in the development of number concepts (Almoammer et al., 2013; Li et al., 2009). Nevertheless, when cross-linguistic comparison is used to evaluate the effects of language on number concepts, the confounding effects of cultural variation cannot be fully controlled.

In order to investigate developmental process, it is important to study number concepts in younger children. Sarnecka and colleagues (2018) looked into the influence of the socioeconomic (SES) status of dual language learners on the number development of preschool children. They compared high and low SES dual language learner households, with high and low SES English monolinguals. Their main finding suggests that basic numerical development is influenced by poverty and not by dual language learning. This could result from the limited resources in low SES households.

It is clear that there is widespread debate regarding the role of linguistic cues in number concept development. The Arabic language could provide a suitable context for evaluating this proposal due to it having a rich morphological system, where numbers are marked in a three-way system (singular, dual and plural) with morphological endings on verbs, adjectives and nouns. As noted above, where cross-linguistic comparison is used to evaluate the effects of variation in number marking, the confounding effects of cultural variation cannot be fully controlled. In order to address this concern, the current study examines number-marking variation among bilingual participants attending one school in Saudi Arabia.

3.4 Bilingualism and numbers

Whilst many studies of number word development are conducted with monolingual language learners, studying children who are bilingual presents a unique view of the role of linguistic competence in number development. Various studies have suggested that bilingual children have advantages in numeric development, for instance, in understanding the arbitrary nature of numeric symbols (Saxe, 1988). Further evidence suggests advantages in number concept tasks. Studies have demonstrated that bilingual children perform better in problem-solving tasks, which suggests parallel development of language and number (Bialystok & Codd, 1997).

Macizo, Herrera, Roman and Martin (2011) have suggested that bilingual children process numbers differently in each language, making research in this domain crucial because findings could highlight the nature of numerical representation. This may provide clarification of whether numerical knowledge is stored in an abstract form, as suggested by McCloskey (1992), or in a verbal-linguistic form, as suggested by Cohen and Dehaene (1995) and Campbell (1994).

It has been observed that bilingual speakers tend to use numbers for counting and arithmetic in their first or dominant language in which they originally learned numbers (Van Rinsveld, Brunner, Landerl, Schiltz, & Ugen, 2015). However, this may not hold in all cases, as children's circumstances may change. A child could become dominant in their second language, and the language they use for numbers could also change (Dehaene, 1997). This may occur if children attend school in a language environment that is not their home/heritage language. Additionally, research has indicated that bilingual children resolve arithmetical problems with higher speed and accuracy when presented in their dominant or first language (Frenck-Mestre & Vaid, 1993; Gonzalez & Kolers, 1987). These results can be explained by children needing more time for translation if the number is not presented in their dominant language.

The influence of language on number-related tasks was investigated with Chinese-English bilinguals. Participants were asked to respond verbally, either in English or Chinese. The tasks included number naming and simple arithmetic in both Arabic numerals and Chinese symbols. Results showed that performance in the number-naming task was more efficient when the response was presented in Chinese symbols compared with Arabic numerals. However, performance in the simple arithmetic was more efficient when presented in Arabic numerals (Campbell, Kanz, & Xue, 1999).

Frenck-Mestre and Vaid (1993) conducted an experiment to investigate the influence of language on numeric representation by testing Russian–English bilingual adults. Their understanding of exact numbers was tested through addition tasks in both languages. The results showed that participants responded to the items efficiently when the stimuli matched the language of instruction, regardless of whether the language was L1 or L2. It was suggested that numerical facts are language sensitive, if not language dependent.

A recent study (Bonifacci, Tobia, Bernabini, & Marzocchi, 2017) investigated the relationship between language and early numeracy skills in bilingual preschool children. The early maths skills of 156 Italian children aged between 50 and 77 months from diverse language backgrounds (Arabic, Russian and South American (Spanish-speaking)) were examined. Monolinguals and bilinguals were compared through a structural-equation model that included two different types of latent variables: first, variables that included early numeracy skills with a linguistic component; second, variables that included early numeracy skills with no linguistic component. In monolinguals, effects of language (phonological awareness and grammatical abilities) were found on non-verbal aspects of numbers. In contrast, in the bilingual sample, no such effects were found. The authors conclude that the role of language in bilingual maths development is unimportant. However, the argument the authors presented is inadequately supported as the language skills of the bilingual sample were not measured, and the diversity of language backgrounds was not included in the analysis. Furthermore, there was no measurement of linguistic and number knowledge in the first language. These measures are essential to fully assess the role of language on number development in bilinguals.

3.4.1 Transfer

Wagner et al. (2015) extended the field of enquiry to the role of language in the formation of number concepts. They examined the linguistic specificity of knower levels in 147 English/French and English/Spanish bilingual children aged two to five. The dominant number learning language (NL1) was identified by measuring the highest count list that the children could produce in each language. Results indicated that children learn numbers in each language independently for each subset knower level. Knower levels in the non-dominant number learning language (NL2) were not predicted either by NL1 counting ability or by NL1 knower level, indicating linguistically independent acquisition. However, this was not true for the CP- knower level. Children who were CP knowers in NL1 were most likely to be CP knowers in NL2, suggesting transfer of conceptual understanding across linguistic boundaries.

Wagner et al. (2015) conclude that transfer is item-based, that is number knowledge is parallel within a language and between languages. For example, children know that *five* in English and *khamsa* in Arabic represent the same number, as *six* in English and *sitta* in Arabic are the same. Therefore, when children know that *five* plus *six* equals *eleven,* they already infer that *khamsa* plus *sitta* equals *heda'ash.* This notion of transfer is understood to have occured in the older age group of Wagner et al.'s sample (i.e. in CP knowers), while the younger children showed independent language-based learning. Although Wagner et al.'s (2015) study is highly informative in a new field of research, there are weaknesses in the design of the study, particularly concerning the examination of language abilities. The dominant language was examined through the highest count task, yet it is not evident that this is a measure of exposure. However, linguistic influence varies as a function of exposure.

Nonetheless, important general conclusions are drawn from these findings: the lengthy process of acquisition of number word meanings may be attributable to language-specific mapping processes. However, at the CP-knower stage, conceptual understanding may no longer be linguistically determined.

Wagner et al.'s (2015) conclusions draw attention to the possible distinction between linguistically specified elements of number vs those concepts whose format is non-linguistic. Grammatical number marking was not in variation in the sample studied by Wagner et al. (2015). However, a different bilingual sample (English/Arabic) affords the opportunity to examine the ways in which differential experience of grammatical number marking may be influential.

In a computational model developed by Piantadosi, Tenenbaum and Goodman (2012), the singular/plural distinction is realised as a combination of primitive elements, in interaction with others, in the ‘language of thought’ and is learned relatively early, corresponding with evidence that the singular/plural distinction in English is learned around 24 months (Kouider et al., 2006). Under such an interpretation, inputs from dual number marking might facilitate a general concept of ‘twoness’ that precedes number word development and operates at an early stage across languages. An alternative account, consistent with the proposal of Wagner et al. (2015), might predict binding of the dual meaning to its co-occurring number word, with consequent linguistic specificity, before the CP-knower stage.

In conclusion, understanding of the concept of ‘two’ supported by dual case marking may be transferred in abstract form between languages. Our bilingual sample allows the investigation of the presence of abstract transfer across languages.

In the current study, we are asking whether the grammatical structures that represent numbers in natural language have specific effects on the formation of number concepts. In particular, whether dual case marking affords enhanced access to the concept of ‘two’, and if so, how this influence operates in a bilingual context, where the structures of number marking vary across languages.

This chapter has presented an overview of number concept development, including the core system of numbers and different theories of the early development of numerical cognition, counting, cardinality, knower levels and transcoding. Furthermore, an overview of the language and number relationship has been given, including the influence of linguistic structures on number concepts and the transfer phenomenon. The following chapter will focus on the methodology section of the study.

Chapter 4: Methodology

Research approval has been obtained from the UCL Research Ethics Committee (Project ID: 2012/014) and the Ministry of Education of Saudi Arabia. Informed consent was obtained from participants' parents prior to testing.

4.1 Design

This is a correlational study in which the contribution of dual case comprehension to cardinality concepts and transcoding is evaluated in young Saudi children bilingual in English and Saudi Arabic. Age, general language skills and number sequence knowledge are treated in regression analyses as concurrent predictors.

4.1.1 Measures

Five tasks were developed to meet the aims of this research. First, parallel language assessments in English and Arabic were designed to provide an estimate of general language skills. Second, the Nominal number marking comprehension test was designed by the researcher for the current study to assess children's understanding of dual case marking in Arabic. Third, the cardinality test, a modified version of the Give-a-number task (Wynn 1990), to assess children's understanding of cardinality in both languages. Fourth, the count word sequence production task was designed as a proxy for count sequence word input in each language. Finally, the number identification task was designed to assess transcoding in both languages. The language questionnaire was designed for use by parents to capture the possible differences in the children's background and home environment, but was not taken up by the majority of parents.

4.1.2 Statistical methods

The analyses were carried out using the R Studio version 1.2.1335 for Windows. Different statistical analysis methods were used to address the research hypotheses and aims, including descriptive statistics, Pearson and Kendall's correlation, simultaneous multiple regression (including both linear and logistic models), and *t*-tests and Wilcoxon tests. Furthermore, analysis of frequencies of individual responses to the cardinality test was performed. Alpha level was set at $p < 0.05$.

The following role of thumb was used as an indicator for the correlation size: (.9 to 1.00) very high correlation, (.70 to .90) high correlation, (.50 to .70) moderate correlation, (.30 to .50) low correlation, and (.00 to .30) negligible correlation. (Mukaka, 2012).

4.2 Participants

There were 78 participants. All participants were bilingual Saudi children exposed to Arabic and English languages. They ranged in age from 3;00 years to 3;11 years, (mean 3;07, s.d. 0;04). This age was selected because it was reported that at the age of three, children can understand how the counting system determines numerosity (Wynn, 1990). There were 43 girls and 34 boys. One child was excluded due to symptoms of language delay, and the school was informed to perform the necessary actions. Table 4.1. summarizes participant information.

Table 4.1 Demographic information for participants

Participants			
Total	77		
Age in months	*Min*	*Max*	*Mean (SD)*
	43	48	42.65 (3.932)
Gender	*Female*		*Male*
	43		34

4.2.1 Recruitment procedure

Participants were recruited from one private school in central Riyadh, Saudi Arabia. The school is committed to a bilingual approach, delivering teaching in both Arabic and English across the curriculum.

Recruiting from one school can eliminate major differences in bilingual exposure. Furthermore, the school selected is based in the centre of Riyadh, the capital, and includes a broad range of social classes.

The head of the school was informed about the study design and objectives. Information sheets, consent forms, and parental language surveys were distributed to parents by school staff. The number of parents who refused to participate in the study is not known due to school rules and regulations. The birth dates were provided from the school records.

4.2.2 Inclusion criteria

- Bilingual children who are exposed to Arabic and English language.
- The absence of developmental disorder, autism, or a neurological disorder.
- No evidence of severe visual impairment.
- No evidence of hearing impairment.
- No evidence of cognitive impairment.
- No motor impairment.

4.2.3 Socioeconomic status

The sample's socioeconomic status (SES) was broadly homogeneous as all participants were recruited from a single fee-paying school. Any possible differences were intended to be captured and controlled by asking about the parent's educational level within the language questionnaire (see 4.4.1. below).

4.2.4 The educational system in SA

The Ministry of Education directs education in Saudi Arabia, and children are enrolled in school from the age of three. There are two types of schools: government and private. There are similarities and differences between the two, but, most significantly, they share the same primary content. They differ concerning the presence of additional materials in most subjects in the private schools and at the time of the introduction of English as a second language. Private schools introduce English from kindergarten, and therefore a bilingual community exists, whereas government schools introduce English in sixth grade, meaning that their students are in a monolingual environment in pre-school and primary years. The majority of private schools base their learning on the Arabic language with the addition of English language classes that are introduced from pre-kindergarten. This implies that early maths skills are primarily taught in Arabic language. The current study recruited children from these schools

4.3 Procedures

All participants were tested on Arabic and English versions of the test battery. Each language was tested on a separate day and the order of languages to be tested was counterbalanced across participants. The time window between the testing of the two languages was three weeks. Each session took between 10-20 minutes depending on the cooperation of the tested child. The order of the testing was fixed: Language assessment, dual case comprehension test, cardinality test, knowledge of the number word sequence task and finally the transcoding task. All tests were carried out receptively where children do not have to give a spoken response, except for the counting task.

Testing was carried out individually in a quiet corner in the classroom, with children seated at a table or the floor sitting in front of the researcher. Verbal positive reinforcement was used for encouragement when needed. Results were recorded manually in a form developed by the researcher.

4.3.1 Scoring criteria for the cardinality task

Two scoring approaches were used; conceptual and quantitative approaches. The conceptual approach is based on Wynn's Give-n-task criteria, children were defined as an N-knower (e.g. three-knower) if they correctly provided N (e.g. three blocks) on at least two out of the three trials when asked for N (e.g. three) and, of the times that the child provided N, two-thirds of those were in response to a request for N and not some another number. If N was five or higher, the child was classified as a CP knower.

The quantitative approach takes the total correct responses across the whole range of trials as a general indicator of understanding of cardinality.

4.4 Material

4.4.1 Parental language survey

The parental language survey was developed and designed by the researcher to have better insight about the language environment of the child in the home and at school. The questionnaire was to be filled by parents or a caregiver.

The development of this questionnaire went through several steps. The first step was browsing the literature about child language input questionnaires and looking for items related to the objectives of the research. The second step was conceptualization; formulating the test items of the questionnaire (variables). This included 13 items, covering the level of use of Arabic and English languages at home and school. Items were scored on a 4-point Likert scale (never, rarely, sometimes, always). The third step was questionnaire formatting, stating the question in a clear appealing manner and making it easy to understand and to respond. The fourth step establishing validity; content validity was attained by two professional review and five consultative parents' review. All have agreed that the questionnaire is easy to fill in and the questions are clear and the language used is appropriate. Furthermore, one person proficient in Arabic language examined the language used and made minor changes to the structure of Arabic Language to make it more accurate. The final step was questionnaire reliability. The questionnaire was administered for validity and reliability to 20 parents living in central Riyadh, Saudi Arabia in a piloting exercise. Parents were asked to read the questionnaire carefully and check the box that best describe the language environment. All parents stated that the questionnaire easy and appropriate, therefore no changes were made.

The questionnaire is available in Appendix 2.

4.4.2 Language assessments

English and Arabic language skills were assessed using equivalent items selected from the Clinical Evaluation of Language Fundamental-Preschool, Second Version (CELF-P2; Wiig et al., 2004) and the Comprehensive Arabic Language Test (CALT; Altaibb & Althukair, 2014), with modifications to accommodate cultural differences. There were 17 items in each test. See Appendix 3.a for full details.

From the CELF the following categories were included; from the linguistic concept subtest: coordination (item number 17), inclusion/exclusion (item number 1), spatial (item number 8), temporal relation/order (item 2, 6, 12, 19), and quantitative (item number 15). From basic concept subset: attribution (item number 5, 12), dimension/size (item number 6), number/quantity (item number 3, 8, 9, 10), and equality (item number 14, 17). (Appendix 3.b)

From the CALT the following category was included; from following commands and basic concepts subtest: commands and understanding of quantity, commands and attribute, commands and concept of “different”, command and the concept of size ‘longest’, command and the concept of equality ‘same’, commands and concepts of temporality, location, and inclusion/exclusion, two level commands and concepts of temporality and temporal + size. One test item was added to the original CALT as a first testing item that already existed in the CELF as a first testing item. This item is an easy question to start with ease (item number 1: Point to one of the bears)

Children were presented with a coloured binder picture booklet and asked to point to the correct picture that answer a simple question provided verbally by the researcher.

Example:

The researcher said the instruction in English or Arabic Saudi dialect (Najdi). No repetition or prompting was used, self-correction was accepted. If the child did not hear the question or was distracted, the researcher repeated the question. Verbal reinforcement was employed systematically; after 5 items were presented the experimenter would say “good or you are doing well”. When the testing is finished the child received stickers as a reinforcement for completion of the rest of the test battery

Two scoring sheets for this task were developed; one for each tested language. The response of the child is recorded immediately during testing and any additional observation was noted. Children will be given 1 point for correct answer and 0 point for incorrect answer, no response “NR” is considered incorrect answer and 0 point was given (See Appendix 3.c)

Split half reliability was tested using Pearson’s r. There was one set of trials for each language, each having a fixed order of presentation. Items were divided into odd vs. even items according to order of presentation. The total of correct odd trials and the total of correct even trials were calculated for each participant in each set, and the correlation between odd and even trials for each set are in Table 4.2.

Table 4.2 Split-half reliability test for the language tests

Sets	Pearson's r
English lang test	.59
Arabic language test	.62

4.4.3 Nominal number marking comprehension test.

This task was designed for the current study in order to assess children's understanding of singular, dual and plural marking in Arabic.

Pictures of six objects were selected for testing (car, chair, tree, spoon, pencil, bag). These items were selected for high frequency and familiarity to young children growing up in Saudi Arabia. Each single page in the booklet had three similar pictures (same object) but differed in quantity, each included singular set with one item, dual set with two items and plural set with either three, four or five items. We note that this approach highlights the contrast in set size (i.e. by having a set of 1, 2, and 3 items on the same card.

The plural sets included different numbers to represent a range of plural meaning. The arrangement of sets (singular, dual, plural) in one page was counterbalanced. Each object had 3 different pictures that differ in size and colour. One additional card picture of a non-tested item (ball) was used to familiarize the children with the task.

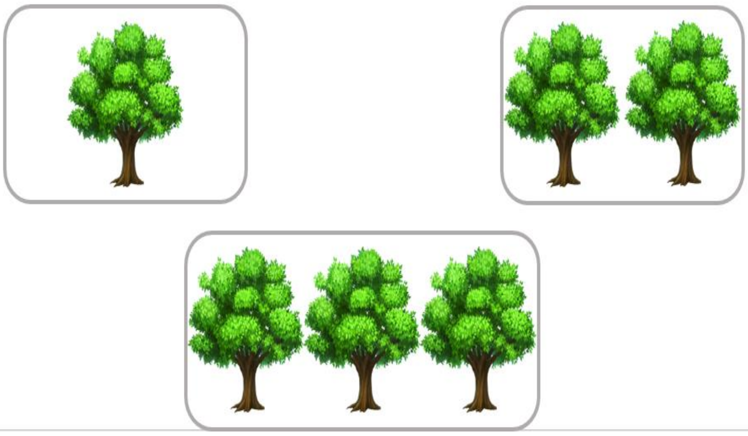
Figure 4.1 Examples of three stimulus cards from the dual case comprehension test

A total of 18 testing cards and 1 training card were used. Six trials were used to test comprehension of each nominal number category (singular, dual, plural). Based on the binomial distribution, the probability of 5 or 6 correct responses in any number category is less than 5% (for 4/6 correct p = .08; for 5/6 correct p = .02; for 6/6 correct p = .001)

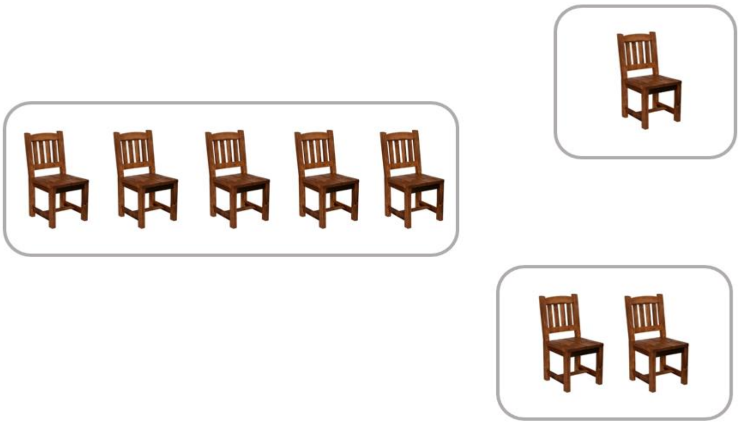
Two testing sets were developed; half of the children were presented with a pseudo-random presentation of the cards and the other half were presented with another pseudo-random presentation, such that neither the same nominal number marking nor the same objects were presented on consecutive cards. See Appendix 4.a for full details.

Example:

1- Testing the Dual (two trees) →



2- Testing singular (one chair)



Children were presented with one card at a time and asked to point to the picture that matches the verbal stimuli presented by the researcher. Support was given when needed; e.g. repeating the question. The verbal stimuli were in the form of “Can you show me the picture of the object-plural Questions were limited to one set in each card (either, singular, dual, plural) to avoid practice effect and boredom. No number words were used in presentation of the task.

Two scoring sheets for this task were developed; one for each set. The response of the child was recorded immediately during testing and any additional observation was noted. The total score was out of 18; one point for each correct response. The nominal number category (singular, dual, plural) was reported, 6 points for each category (See Appendix 4.b)

4.4.4 Cardinality test

This task was adapted from Wynn (1990) and aimed to determine cardinality knowledge tested in English and Arabic languages. Small wood blocks and a puppet were used. Forty blocks were placed in a bowl in front of the child. In each trial children were asked to feed a lion puppet. The researcher said “the lion is hungry and you will feed him”. The child is asked to take a particular number of blocks and hand them to the researcher, and then the researcher would feed them to the puppet. The researcher would say “Give me N and tell me when you are finished”. The researcher avoided any nominal number marking while giving these instructions. It was evident that singular/ plural marking can help children to predict the number asked for independently from understanding the number words (Carey, 2004). No following questions were asked. If the child lost attention the researcher would repeat the requested number (e.g. ‘give me two’, or would say only ‘two’). In a case where the child was afraid of the puppet, the researcher would not include the puppet and simply ask the child to give her X blocks.

The following numbers were tested (2, 3, 4, and 5). Each number word was presented three times, giving a total of 12 trials. This procedure was different from that of Wynn (1990) in that each trial was independent of the success of the previous one. The order of testing was pseudo-randomized; no number word was- tested twice consecutively. Two testing sets were developed; half of the children were presented with the pseudo-random presentation of numbers and the other with a reversed order of the same set. Children who were tested on Set 1 in one language, they were tested on Set 2 with the other language. The order of testing in Arabic vs English was counterbalanced. A familiarization trial was administered in which participants were asked to give “one” (a non-tested number). The researcher asked the child to give her one block. If the child failed to give one block, the researcher will show that child how to do it. The response of the child was recorded immediately during testing and whether the child is a counter or a grabber, and any additional observation was noted. The total of correct responses (out of 12) was used as the score for this test, three out of three for each tested number (See Appendix 5.a).

Two scoring sheets for this task were developed (See Appendix 5.b)

It is important to highlight that in contrast to many studies (e.g. Le Corre et al., 2006; Lee & Sarnecka, 2010; Wynn, 1992) we tested all participants on all trials at all target numbers. We examine patterns of error across the performance range. We compare conceptual scoring (based on estimation of the child’s conceptual level or knower-level), with quantitative scoring based on the total number of correct trials.

Split half reliability was tested using Pearson’s r. There were four different sets of trials, each having a fixed order of presentation (English Set 1 & Set 2, Arabic Set 1 & Set 2). Trials were divided into odd vs. even trials according to order of presentation. The total of correct odd trials and the total of correct even trials were calculated for each participant in each set, and the correlation between odd and even trials for each set is in Table 4.3.

Table 4.3 Split-half reliability test for the Cardinality tests

Sets	Pearson's r
English – Set 1	.83
English – Set 2	.84
Arabic – Set 1	.64
Arabic – Set 2	.84

4.4.5 Knowledge of the number word sequence (counting)

Children were asked simply to produce the number word sequence as far as they could to test their knowledge of the sequence. Children were asked to count in Arabic and English. Prompting was used for the first number "one" with rising intonation to encourage children to start counting if needed. The researcher would say "count in a loud voice as high as you can". The last correctly sequenced number was recorded. Scoring sheet in Appendix 5.b.

4.4.6 Number identification task

This task was designed to assess transcoding, that is, to investigate if children are able to map numeral names to numerals. It was tested in English using Western Arabic numerals and in Arabic using both Western and Eastern Arabic numerals.

In a forced-choice method, children were presented with two numbers presented on A4 size white paper, side by side in Calibri font, size 170 with black line between them (Figure 4.2).

Example:

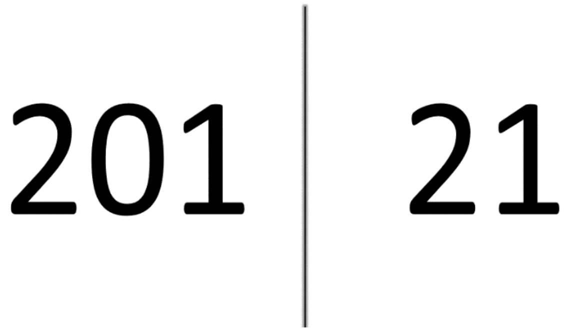


Figure 4.2 Example from the number identification task

Children were asked to point to the numeral that matched the presented target number verbally, this included single -double- and triple digit numbers. Ten trials were included. The probability of achieving 8, 9, or 10 correct responses by chance is less than 5%.

The researcher said “I will show you a card with two numbers and I want you to point to the one I say”. Training was initiated with a non-tested card to familiarize the children with the procedure.

Three pairs of number items were selected randomly including single digits (1 vs 9, 3 vs.7, 4 vs. 6) and seven items included single, double and triple digits that were selected from Mix et al. (2014). These seven were selected because they presented with the highest performance level among 3:5 year-old participants. The items from Mix et al. (2014) and their percentage of correct responses are as follows: (2 vs.8 -73%-, 12 vs. 22 -73% -, 202 vs, 21 -73% -, 11 vs, 24 -62% -, 64 vs, 604 -69% -, 15 vs.5 -58% -, 36 vs. 306 -54%) (Appendix 6.a)

The order of the testing of numbers was randomized. Three testing sets were developed; set 1 and 2 with Western Arabic numeral; set 2 used the reversed order of set 1. Set 3 used a random order of Eastern Arabic numeral equivalents.

Children were tested in week one on set 1 (the western Arabic numeral), either in spoken English or Arabic. In week two they were tested on set 2 (the western Arabic numeral), either in spoken English Arabic. (The spoken language of the stimuli were counterbalanced). Also, in week two children were tested on set 3 (the Eastern Arabic numeral).

Scoring sheets for each set were developed. The response of the child was recorded immediately during testing and any additional observation was noted. The total score was out of 10; one point for each correct response. (Appendix 6.b)

When testing is finished the child received a sticker as a thank you for the test battery completion.

Chapter 5: Results

The following assessments were carried out: English and Arabic language tests were administered to have an estimate of the linguistic input, using the CELF-5 and CALT, the Give-a Number task to test cardinality in both languages, the test of comprehension of nominal number marking in Arabic, the test of number sequence knowledge in both languages used as a proxy for count word input in each language. Finally, the number identification task was used to test transcoding skills in both languages.

5.1 Language Tests

5.1.1 Descriptive statistics of language testing are shown in Table 5.1

Figures 5.1 and 5.2 present the distribution of the English and Arabic language tests. From the figures, we can conclude that English and Arabic language tests score were normally distributed. The normality of the distributions reflects the sensitivity of these tests. Paired *t*-test was administered to test the difference between Arabic and English language abilities. Results showed that Children's performance in English and Arabic languages significantly differs, the children’s performance is better in Arabic language.

No children scored 0 (floor level) in the English or Arabic language tests.

Table 5.1 Descriptive statistics for language tests

	Mean	***sd***	***Median***	***Max***	***Min***
Arabic	8.13	2.58	8	14	3
English	6.98	2.84	7	14	2

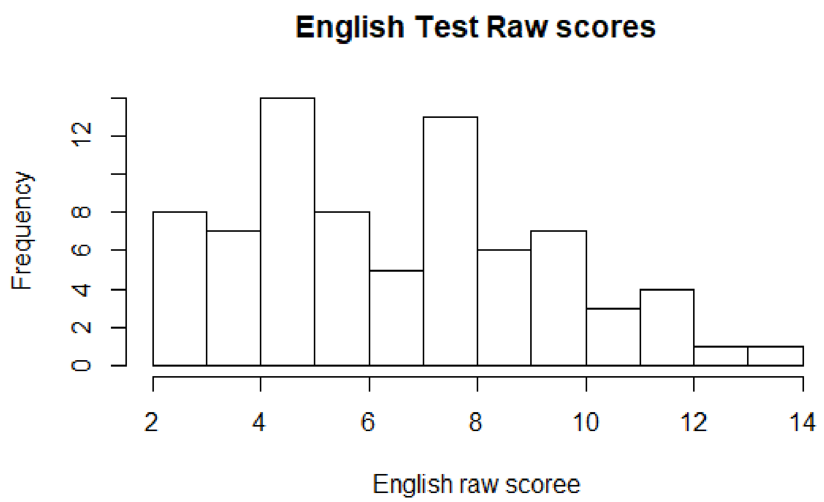


Figure 5.1 The distribution of scores on the English language test

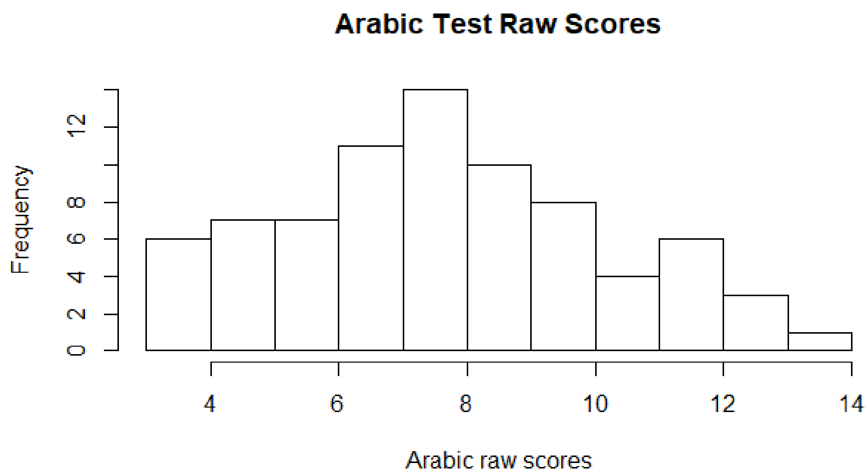


Figure 5.2 The distribution of scores on the Arabic language test

5.1.2 Language tests item analysis

Item analysis of language test performance shows appropriate sensitivity of test items across the range of ages tested (see Appendix 7 for details). In the absence of standardization data, it is not possible to infer with any precision the extent to which exposure to Arabic vs. English language varied across the sample. However, given the careful matching of stimuli between the language tests, and the efforts made to accommodate cultural differences, it appears that levels of performance across languages were broadly equivalent.

5.1.3 Correlation between language tests and age

Parametric Pearson tests of the correlation between the Arabic test and the English language tests and age are shown in Table 5.2.

Table 5.2 The correlation between language tests and age

	r	***df***	***p***
Arabic	0.35	75	<.001
English	0.16	75	0.15

The correlation between Arabic language score and age is significant and stronger than the non-significant correlation between English language score and age, indicating that exposure to English is less consistent across age than is exposure to Arabic.

5.1.4 Correlation between Arabic and English language tests

Parametric test of the correlation between the Arabic test and the English language tests is shown in Table 5.3.

Table 5.3 The correlation between Arabic and English language tests

r	***df***	***p***
.3	75	<.001

We conclude that there is a significant positive relationship between Arabic and English language test in our sample. However, it is not a strong correlation.

5.2 Nominal number marking task

5.2.1 Descriptive statistics of all nominal number marking tests are shown in Table 5.4

Table 5.4 NNM descriptive statistics

	Mean	***sd***	***Median***	***Max***	***Min***
Singular	2.87	1.78	3	6	0
Dual	2.98	1.97	2	6	0
Plural	2.60	1.95	2	6	0

The number of children who scored 0 (floor level) in the singular comprehension test are 7, the dual comprehension test are 7, and the plural comprehension test are 15.

Figure 5.3, 5.4 and 5.5 show the distributions of scores on each of the grammatical categories in the NNM task.

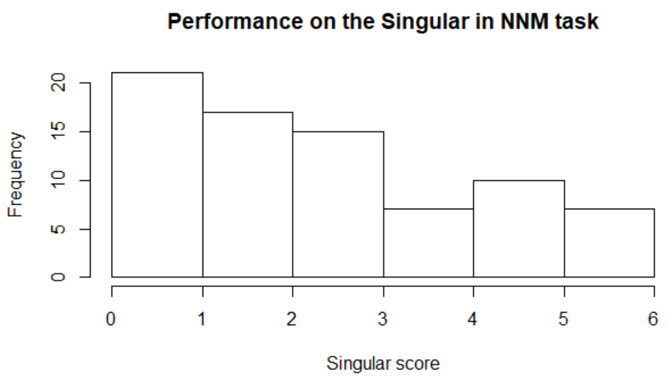


Figure 5.3 The distribution of scores for singular number marking in the NNM task

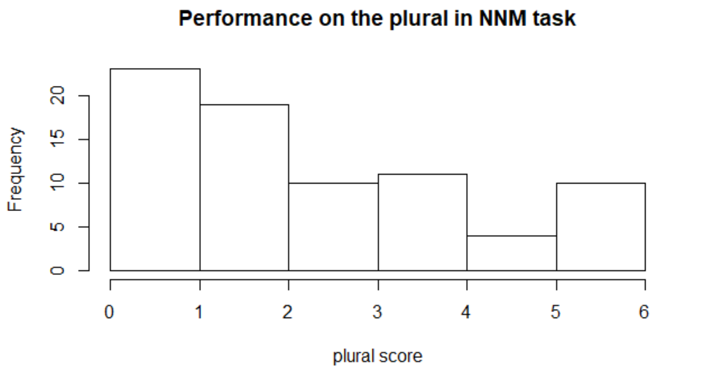


Figure 5.4 The distribution of scores for plural number marking in the NNM task

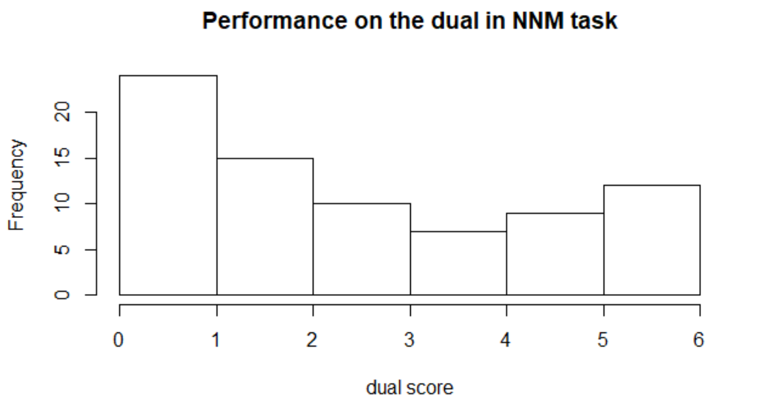


Figure 5.5 The distribution of the performance of dual number marking in the NNM task

From the table and figures, we can see that the performance of children across the different nominal number marking categories is similar, with a clear tendency towards minimum scores. Many participants score at floor level.

5.2.2 Correlation between NNM score for singular, dual and plural.

Non-parametric Kendell's test of the correlation between the different scores of NNM is shown in Table 5.5.

Table 5.5 The correlation between the different scores of NNM tasks

	NNM Singular	***NNM Dual***	***NNM Plural***
NNM Singular	1	-0.07	-0.19*
NNM Dual	-0.07	1	-0.01
NNM Plural	-0.19*	-0.01	1

* *p < .05*

** *p < .01*

We conclude that there is significant positive relationship between the NNM singular scores and NNM plural scores. However, it is weak correlation.

5.2.3 Grammatical categories in NNM and age

The responses were grouped according to binomial probabilities. For each trial there is a 0.33 probability of giving the correct response by chance. Over six trials, scoring 1 or 2 correct indicates greater than chance responding. 3 or 4 correct indicates random responding. 5 or 6 correct indicates greater than chance responding.

Table 5.6 presents the performance of children on different grammatical categories in NNM task according to the age range.

Table 5.6 The percentage of children responded correctly according to age range in NNM task

Response category	1- 2 correct response	3- 4 correct response	5-6 correct responses	Total (77)
Age range	**SINGULAR**			
34-38	67% *(n =10)*	27% *(n = 4)*	7% *(n = 1)*	15
39-43	48% *(n = 10)*	38% *(n = 8)*	14% *(n = 3)*	21
44-48	44% *(n = 18)*	24% *(n = 10)*	31% *(n = 13)*	41
	DUAL			
34-38	73% *(n = 11)*	13% *(n = 2)*	13% *(n = 2)*	15
39-43	38% *(n = 8)*	29% *(n = 6)*	33% *(n = 7)*	21
44-48	49% *(n =20)*	22% *(n = 9)*	29% *(n =12)*	41
	PLURAL			
34-38	47% *(n = 7)*	33% *(n = 5)*	20% *(n = 3)*	15
39-43	62% *(n = 13)*	38% *(n = 8)*	0	21
44-48	54% *(n = 22)*	20% *(n = 8)*	24% *(n = 10)*	41

Younger age group (34-38) and the older age group (44-48) tend to have similar performance across different grammatical categories. At all ages and in all grammatical categories the highest percentage of participants is found in the group ‘1-2 correct responses’. There is a general trend for the percentage of participants in the ‘5-6 correct responses’ group to increase between the youngest and oldest participants, but the overall influence of age within this group is inconsistent. A relatively high proportion of participants (between 13% and 38%) respond randomly (3-4 correct responses) throughout.

5.3 Knowledge of the number word sequence (counting)

5.3.1 Descriptive statistics for the highest correct number reached in each language are shown in Table 5.7

Table 5.7 The number sequence task descriptive statistics

	Mean	***sd***	***Median***	***Max***	***Min***	***Effect size***
Arabic	7.06	3.00	6	14	1	
English	7.53	3.53	9	19	1	

There is no significant difference between languages, t = 0.88, df = 148.17, p value = 0.37.

5.3.2 Correlation between counting and age

Parametric Pearson test of the correlation between counting and age is shown in Table 5.8.

Table 5.8 The correlations between counting scores and age

	t	**R**	**p- value**	**d**
Arabic	1.99	0.22	0.04	.04
English	1.94	0.21	0.05	.04

We conclude that there is a significant positive relationship between children's performance on the Arabic and English counting tasks and age, however, the effect size is relatively small.

5.4 Give a number task

This is the central task of the study, used to assess participants' understanding of cardinality.

Two distinctive approaches were used to score children's responses: conceptual and quantitative. The conceptual approach aims to establish conceptual (knower) levels (with various probabilistic criteria, such as two out of three trials correct). In contrast, the quantitative approach works with the total number of correct responses across the whole range of trials as a general indicator of understanding cardinality. The current study will contrast the conceptual and quantitative approaches by applying both approaches to the same data.

5.4.1 Conceptual approach (Knower level)

The first approach is the conceptual approach. Here we note that the range of target numbers tested is from 2 to 5 (1 is not tested), with three trials of each target number presented in pseudo-random order, in each language.

Our first conceptual analysis treats knower level as a binary variable, dividing children into those who were either non-knowers or 1-knowers (i.e. children who did not respond with at least two trials correct for any target number) from those who were "at least" 2-knowers (i.e. children who were able to respond correctly on at least two out of three trials correct on target number 2). This allowed us to identify children who have already transitioned to the 2-knower stage. Following that, we carry out an additional analysis treating knower level as an ordinal variable, identifying participants as 2, 3, 4 or 5 knowers, according to whether they gave at least two out of three correct responses for targets 2, 3, 4 or 5, and applying Wynn's additional criterion, i.e. that the child responded with the same number when asked for a non-target numerosity on no more than one third of trials. An example of the criterion from Wynn (1992) page 232:

" For example, a child who gave two items 67% of the time (2 of the 3 trials) when asked for 2 was scored consistently correct on 2 only if she gave two items no more than 33% of the time when asked for three, four, and five items."

5.4.1.1 Descriptive statistics

Table 5.9 Descriptive statistics for knower level

	Mean	***sd***	***Median***	***Max***	***Min***
English knower level	2.13	1.52	2.00	5	0
Arabic knower level	1.83	1.52	2.00	5	0

The mean of English knower level is slightly higher than Arabic knower level. The median, maximum and minimum are identical across the two languages.

5.4.1.2 Comparison of knower levels in English and Arabic

Histograms of the distributions of scores in the English and Arabic cardinality knower level are shown in Figures 5.6 and 5.7.

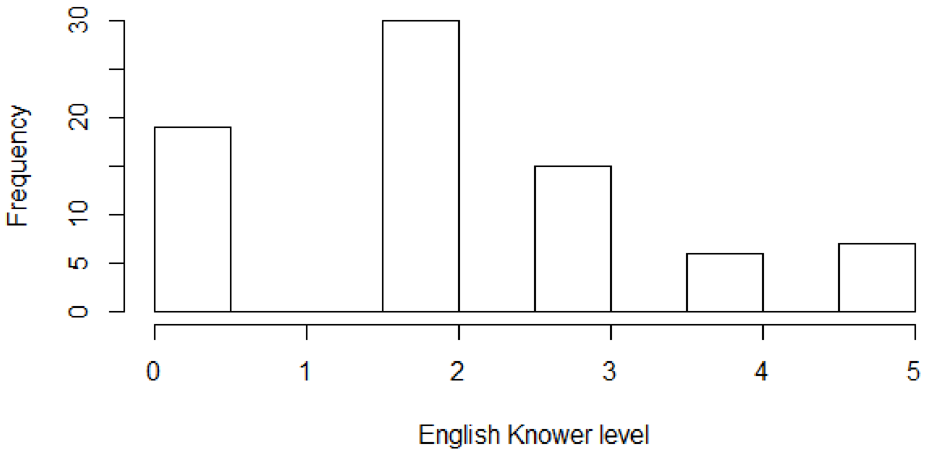


Figure 5.6 Distribution of English knower level

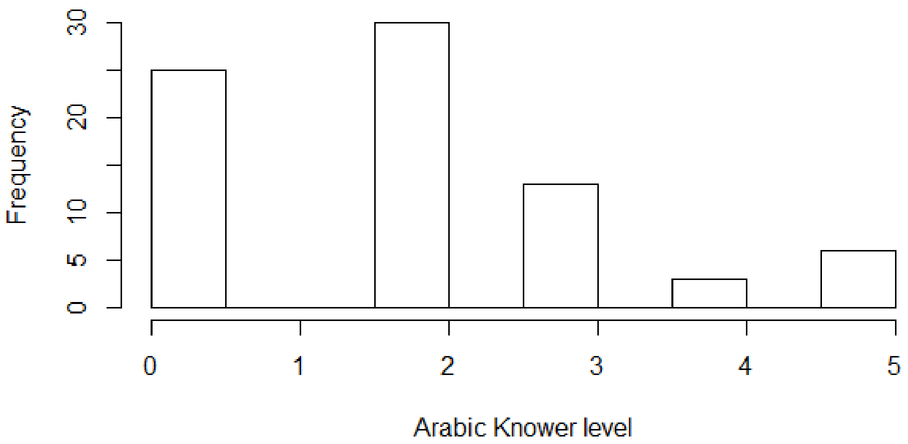


Figure 5.7 Distribution of Arabic knower level

5.4.1.3 Frequency of knower levels in English and Arabic

The frequency of knower levels achieved in the Give-a- number task in each language were examined and distributed into binary categorization. (See Table 5.10).

Table 5.10 The frequency of knower level as a binary variable

	Pre-2 knowers	*2 knowers and above*	*Total*
English	37	40	77
Arabic	46	31	77

A McNemar test comparing binary knower levels in English and Arabic gave W = 2.78, p = 0.09. No significant difference in binary knower levels was found.

A detailed table of frequency of knower levels Pre-2 to 5 in English and Arabic is shown in Table 5.11.

Table 5.11 The frequency of knower levels Pre-2 to 5

	Pre-2 knowers	**2-knower**	**3-knower**	**4-knower**	**5-knower**	**Total**
English	37	14	13	6	7	77
Arabic	46	10	12	3	6	77

Wilcoxon test comparing the knower levels in English and Arabic showed W = 3.30, p = 0.17. There is no evidence of a difference in knower levels between languages.

The relation between participant's performances on binary knower levels in each language is shown in Table 5.12.

Table 5.12 The frequency of shared binary knower levels in English and Arabic

Arabic / **English**	**Pre-2 knowers**	**2-knowers &above**	**Total**
Pre-2 knowers	**30**	7	37
2-knowers & above	16	**24**	40
Total	46	31	77

NB Frequencies of participants who have the same knower level in each language are shown in bold

As seen in Table 5.12, 30 children are pre-2 knowers in both languages. Furthermore, 54 out of 77 have the same binary knower level on both languages, indicating equal or balanced number knowledge across languages in more than 70% of participants.

The frequency of shared multiple knower levels in English and Arabic is shown in Table 5.13.

Table 5.13 Frequencies of knower levels in English and Arabic

		Arabic Knower Level					
		pre-2	Two	Three	Four	Five	Total
English Knower Level	pre-2	**30**	5	2	0	0	37
	Two	7	**2**	4	0	1	14
	Three	4	3	**6**	0	0	13
	Four	3	0	0	**3**	0	3
	Five	2	0	0	0	**5**	7
	Total	46	10	12	3	6	77

NB Frequencies of participants who have the same knower level in each language are shown in bold

Although there is no statistical difference between Arabic and English knower levels, it can be seen that more children are 2-knower and above in English than in Arabic.

5.4.1.4 Correlations between variables

Kendall’s rank correlations between all variables are shown in Table 5.14.

Table 5.14 Correlation matrix for all variables

	English knower level	Arabic knower level	English lang. test	Arabic lang. test	Dual case comp.	English Max. count	Arabic Max. count
English knower level							
Arabic knower level	z = 4.72** tau= 0.46						
English lang. test	z = 2.94** tau= 0.26	z = 1.51 tau= 0.14					
Arabic lang. test	z = 3.25** tau= 0.29	z = 3.37** tau= 0.31	z = 2.73** tau= 0.23				
Dual case comp.	z = 1.68 tau= 0.15	z= 3.65** tau=0.34	z = 2.30* tau =0.19	z= 3.70** tau =0.32			
English Max. count	z = 2.77** tau =0.25	z = 3.07** tau= 0.28	z = 2.91** tau= 0.25	z = 3.02** tau=0.26	z = 1.76 tau= 0.15		
Arabic Max. count	z = 1.92* tau= 0.17	z = 3.04** tau= 0.78	z = 1.33 tau= 0.11	z = 2.57** tau =0.22	z = 0.90 tau= 0.07	z = 3.84** tau= 0.33	

* *p* < .05

** *p* < .01

Notable patterns within the correlation matrix include: strong association between dual case and Arabic, but not English, knower levels; high levels of correlation between language measures; high levels of correlation between language measures and knower levels in both languages; significant correlations between highest count in English and all other variables except dual case; significant correlations between highest count in Arabic and all other variables except English language test and dual case comprehension.

5.4.1.5 Regression analysis

I. Binary logistic regression with knower level as a binary dependent variable

We used binary logistic regression to estimate the unique influence of dual case comprehension on knower levels, independent of age, language skills and count sequence production. Here knower level is a binary variable dividing children into those who were either non-knowers or 1-knowers (pre 2-knowers) from those who were at least 2-knowers.

1. The first model in Table 5.15, (non-transfer model) evaluates prediction of Arabic knower levels. We see that age, Arabic max count score and dual case comprehension have significant independent effects on Arabic knower levels. The Akaike information criterion (AIC) is 88.01. This metric is based on the number of independent variables in the model, and a maximum likelihood estimate of model fit. AIC can be used to compare the fit of different regression models based on the same dependent variable (lower AIC indicates for a better fit model). There have been suggestions about using a correction. Burnham and Anderson (2002) suggest that if the number of predictors variables in the analysis is more than 2% or 3% of

the sample size (ratio n/K -i.e. sample size/number of parameters) then AICc is preferred to AIC. However, the original demonstration of the utility of AICc (Hurvich & Tsai 1989) used sample sizes n=10 and n=20, with seven predictor variables. Critical to the current study, Wagner et al. (2015) used AIC and not AICc in their work with the main analyses based 147 children and 4-5 predictor variables, and subsequent analyses based on smaller subsets of the sample, still including 4-5 predictors. Given all these indicators the decision was made to use AIC in the following analyses."

Regarding the statistical analysis, it is not clear in the literature that it is appropriate to conduct a statistical analysis of AIC values. Wagner et al (2015) did not do any statistical analysis on the AIC; they only commented on whether it is higher or lower, and if lower the model is preferred.

AIC takes account of the effect size observed and the number of parameters; so the more parameters the analysis has, the higher the AIC will be. In the case of our models, with the addition of one parameter (the dual case), the AIC was lower even though the number of parameters has increased. This is a powerful demonstration of the superiority of the second model.

Table 5.15 Binary regression model: Arabic knower level

	coefficient	std.error	z	p
Intercept	-11.39	3.72	-3.05	<.001
Age	0.18	0.08	2.15	0.03
Arabic language	0.05	0.12	0.46	0.63
Arabic max count	0.21	0.10	2.09	0.03
Dual case comp.	0.35	0.15	2.32	0.01

	Min	*Median*	*Max*
Stnd. Res.	-2.24	-0.41	2.14

AIC	**88.01**

We addressed the question of transfer between English knower levels and Arabic knower levels (transfer-model). In Table 5.16 we examined the influence of English knower level on Arabic knower level, independent of age, Arabic language skills, Dual case comprehension and Arabic counting score, and we see that English knower level has a significant independent effect on Arabic knower level, and that age, dual case comprehension and Arabic max count have further independent significant effects. The addition of English knower level as a further predictor increases model efficiency (AIC is reduced to 82.31 from 88.10 for the non-transfer model).

Table 5.16 Binary regression model testing transfer from English to Arabic knower level

	coefficient	**std.error**	**z-value**	**p-value**
Intercept	-12.51	4.33	-2.88	<.001
Age	0.19	0.09	2.05	0.04
Arabic lang. test	-0.01	0.13	-0.12	0.90
Arabic max count	0.24	0.11	2.17	0.02
Dual case comp.	0.33	0.16	2.11	0.03
English knower level	1.66	0.62	2.64	<.001

	Min	***Median***	***Max***
Stnd. Res.	-2.10	-0.31	2.42

AIC	**82.31**

The model in Table 5.17 (non-transfer model), evaluates prediction of English knower levels. We see that none of the variables is a significant predictor of the outcome (though the effect of English Language is marginal). The AIC is 104.11.

Table 5.17 Binary regression model: English knower level

	coefficient	Std.error	z-value	p-value
Intercept	-6.03	2.85	-2.11	0.03
Age	0.09	0.06	1.43	0.15
English lang. test	0.18	0.09	1.82	0.06
English max count	0.05	0.07	0.78	0.43
Dual case comp.	0.12	0.13	0.91	0.36

	Min	*Median*	*Max*
Stnd. Res.	-1.90	0.60	1.93

AIC	**104.11**

We addressed the question of transfer of Arabic knower levels (transfer-model). In Table 5.18 we examined the influence of Arabic knower level on English knower level, independent of age, English language skills, dual case comprehension and English counting score. We see that Arabic knower level has an independent significant effect on English knower level, and that English language has a further independent significant effect. The AIC is 98.49, lower than the value of 104.11 shown in Table 5.16, indicating that the transfer model is superior.

Table 5.18 Binary regression model testing transfer from Arabic to English knower level

	coefficient	std.error	z-value	p-value
Intercept	-4.16	3.02	-1.38	0.16
Age	0.04	0.07	0.65	0.51
English lang. test	0.20	0.10	1.95	0.05
English max count	0.02	0.07	0.32	0.74
Dual case comp.	0.01	0.14	0.11	0.91
Arabic knower level	1.60	0.60	2.66	<.001

	Min	*Median*	*Max*
Stnd. Res.	-2.15	0.42	1.98

AIC	**98.49**

II. Ordinal logistic regression for knower level as an ordinal dependent variable

We used ordinal logistic regression to provide a more detailed analysis regarding the unique influence of dual case comprehension on knower levels, independent of age, language skills and counting score. Here knower level is a dependent variable with a children categorised as either pre-2 knowers or those who were 2-knowers, 3-knowers, 4-knowers or 5-knowers.

The first model evaluates prediction of Arabic knower levels (non-transfer model). In Table 5.19 we see that dual case comprehension and age are significant predictors of outcome.

Table 5.19 Ordinal regression model: Arabic knower level

	coefficient	**std.error**	**t-value**	**p-value**
Age	0.23	0.08	2.73	0.01
Arabic lang. test	0.12	0.11	1.11	0.27
Arabic max count	0.13	0.08	1.58	0.11
Dual case comp.	0.41	0.14	2.87	<.001

AIC	**165.17**

We addressed the question of transfer of English knower levels to Arabic knower level (transfer-model). In Table 5.20 we examined the influence of

English knower level on Arabic knower level, independent of age, Arabic language skills, dual case comprehension and Arabic counting abilities. We see that English knower level and dual case comprehension has a significant effect on Arabic knower level, independent of age, Arabic language skills and Arabic counting abilities**.** The AIC is 154.4, lower than the value of 165.17 shown in Table 5.19, indicating that the transfer model is superior.

Table 5.20 Ordinal regression model testing transfer from English to Arabic knower level

	coefficient	std.error	t-value	p-value
Age	.20	0.08	2.43	0.01
Arabic lang. test	0.11	0.12	0.93	0.93
Arabic max count	0.13	0.09	1.46	0.14
Dual case comp.	0.39	0.15	2.64	0.01
English knower level	0.84	0.23	3.60	<.001
AIC	**154.4**			

The model in Table 5.21, evaluates prediction of English knower level (non-transfer model). We see that English language is a significant predictor of outcome, independent of age, English highest count and dual case comprehension.

Table 5.21 Ordinal regression model: English knower level

	coefficient	std.error	t-value	p-value
Age	0.10	0.06	1.64	0.10
English lang. test	0.16	0.08	1.98	0.05
English max count	0.09	0.06	1.37	0.17
Dual case comp.	0.08	0.11	0.67	0.50
AIC	**212.05**			

We addressed the question of transfer of Arabic knower levels to English knower level (transfer-model). In Table 5.22 we examined the influence of Arabic knower level on English knower level, independent of age, English language skills, dual case comprehension and English counting ability. We see that Arabic knower level has a significant effect on English knower level, independent of age, English language skills and English counting abilities. The AIC is 192.48.49, lower than the value of 202.05 shown in Table 5.21, indicating that the transfer model is superior.

Table 5.22 Ordinal regression model testing transfer from Arabic to English knower level

	coefficient	**std.error**	**t-value**	**p-value**
Age	-0.00	0.06	-0.13	0.89
English lang. test	0.19	0.08	2.23	0.03
English max count	0.04	0.07	0.66	0.50
Dual case comp.	-0.13	0.13	-0.98	0.32
Arabic knower level	1.08	0.24	4.42	<.001
AIC	**192.48**			

The results of the binary and ordinal regression models are entirely coherent. Across languages the effects of age, language scores, counting and dual case comprehension vary consistently. The transfer models showed improvement in comparison to the non-transfer models throughout.

5.4.2 Quantitative approach (Cardinality analysis)

The second approach is the quantitative approach, which evaluates cardinality knowledge based on total correct response in core analysis. We tested all participants on all trials at all target numbers. We examined patterns of error across the performance range, and based our analyses on the total number of correct trials (score out of 12), thereby capturing individual differences in participants' understanding of cardinality in a way that lends itself to parametric analysis.

Given the particular interest attaching to the distinction between CP knowers and children who have not yet reached the CP knower stage and to make contact with previous literature we also used standard criteria to identify individuals who have reached CP knower level. We calculated the number of CP knowers (defined as five-knowers according to criteria used by Le Corre et al. (2006))

The average level of power that was achieved overall in the following regression analyses was .96 (range .92 to .99).

5.4.2.1 Descriptive statistics are shown in Table 5.23

Table 5.23 Descriptive statistics for cardinality scores

	Mean	*sd*	*Median*	*Max*	*Min*
English cardinality	4.19	3.36	3.00	12	0
Arabic cardinality	4.05	3.05	3.00	12	0

The mean of English cardinality is slightly higher that Arabic cardinality. The median, maximum and minimum are identical across the two languages.

The number of children who scored 0 (floor effects) in the English cardinality test are 10, and the Arabic cardinality test are 8.

5.4.2.2 Comparison of cardinality scores in English and Arabic

Histograms of the distributions of scores in the English and Arabic cardinality tests are shown in Figures 5.8 and 5.9. Both distributions show a positive skew.

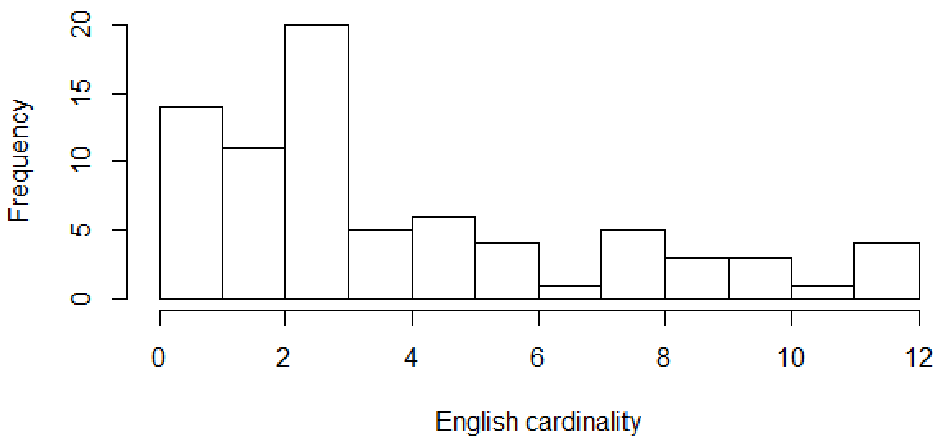


Figure 5.8 Distribution of English cardinality scores

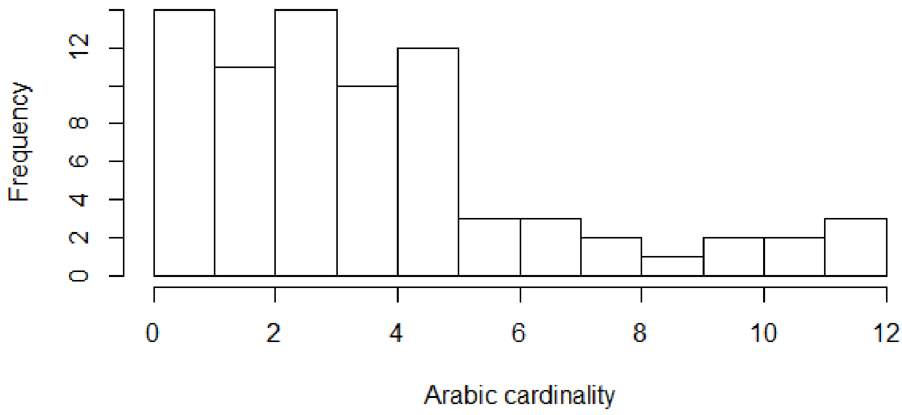


Figure 5.9 Distribution of Arabic cardinality scores

English and Arabic cardinality have the same max and min scores and the cardinality score “three” is the most frequent score in both languages.

A paired sample t- test comparing cardinality in English and Arabic showed t (76) = .455, p = 0.65. No difference in cardinality scores was found. Kendall’s rank correlations between Arabic and English, z= 5.01, tau= 0.42, p-value < 0.001, which indicates for a strong positive correlation between cardinality scores.

5.4.2.3 Frequency examination of individual responses

An item-level analysis of variation between participants’ performance in the cardinality test was carried out.

The patterns in the responses each individual gave to each trial in the data are shown in Appendix 8.

It is observed that children who give one object for all trials are not necessarily consistent across languages.

The number of children who responded 1 to all trials in both languages is equal (10 children). Eight children responded “1” to all trials in one language but not in the other. 16 children responded “2” to all trials in one language but not in the other. There is a slight increase in the number children who responded two in all trials on Arabic (18 children) when compared to English (14 children). These observations indicate differences across languages in the very early stages of number word learning.

All response patterns were captured within the following independent categories:

- <u>Category 1 Generalizers:</u>

Participants give one object on at least 9/12 trials, OR participants give two objects on at least 9/12 trials, OR participants give three objects on at least 9/12 trials.

- <u>Category 2 Varied responders:</u>

Participants do not give the same response on more than 8/12 trials AND do not give 3/3 correct responses to any target number.

- <u>Category 3 Varied responders, correct on target number 2 or 3:</u>

Participants do not give the same response on more than 8/12 trials AND give 3/3 correct responses to target number 2 or to target number 3.

- <u>Category 4 Varied responders, correct on target numbers 2,3 and more:</u>

Participants do not give the same response on more than 8/12 trials AND give 3/3 correct responses to target numbers 2, 3 and may give 3/3 correct on one or more additional target numbers.

It is important to note that seven out of 77 participants were classified as CP knowers in English, six out of 77 participants were classified as CP knowers in Arabic. Of these, five were classified as CP knowers in both languages.

Table 5.24 Frequencies of cardinality categories in English and Arabic by age and test score

	English Cardinality mean score: 2.39 sd: 1.17			Arabic Cardinality mean score: 2.14 sd: 1.09		
	Frequency of participants	**Mean test score**	**Mean age**	**Frequency of participants**	**Mean test score**	**Mean age**
Category 1	24	1.71	40.7	29	2.17	40.7
Category 2	18	2.06	42.6	20	2.75	42.2
Category 3	16	4.38	43.6	16	5.19	44.7
Category 4	19	9.21	44.6	12	9.25	45.3
Total		**77**			**77**	

As shown in Table 5.24, the frequency of participants, the mean age of participants and the mean cardinality test scores achieved by participants are all closely matched across languages. A consistent gradient of increase in test scores and age is observed across categories.

5.4.2.4 Correlations between variables

Kendall's rank correlations between all variables are shown in Table 5.25.

Table 5.25 Correlation matrix for all variables

	English cardinality score	Arabic cardinality score	English lang. test	Arabic lang. test	Dual case comp.	English Max. count	Arabic Max. count
English cardinality score							
Arabic cardinality score	z = 5.01** tau= 0.42						
English lang. test	z = 4.28** tau= 0.36	z = 3.14** tau= 0.26					
Arabic lang. test	z = 2.92** tau= 0.25	z = 3.15** tau= 0.26	z = 2.73** tau= 0.23				
Dual case comp.	z = 1.67 tau= 0.14	z = 2.86** tau=0.24	z = 2.30* tau =0.19	z = 3.70** tau =0.32			
English Max. count	z = 3.19** tau =0.27	z = 2.37** tau= 0.20	z = 2.91** tau= 0.25	z = 3.02** tau =0.26	z = 1.76 tau= 0.15		
Arabic Max. count	z = 2.37** tau= 0.20	z = 2.18* tau= 0.18	z = 1.33 tau= 0.11	z = 2.57** tau =0.22	z = 0.90 tau= 0.07	z = 3.84** tau= 0.33	

* *p < .05*

** *p < .01*

Notable patterns within the correlation matrix include: strong association between dual case comprehension and Arabic cardinality, but not English cardinality; high levels of correlation between language measures; high levels of correlation between language measures and cardinality in both languages; significant correlations between highest count in English and all other variables except dual case comprehension; significant correlations between highest count in Arabic and all other variables except English language and dual case comprehension. These correlation patterns are identical across both conceptual and quantitative approaches.

5.4.2.5 Regression analysis

We used simultaneous multiple linear regression to estimate the unique influence of dual case comprehension on cardinality scores, independent of age, language skills and count sequence production.

The first model in Table 5.26 (non-transfer model), evaluates prediction of Arabic cardinality. Dual case comprehension and age have significant independent effects on Arabic cardinality**.** The results is identical to the ordinal regression of the conceptual approach. The adjusted R Squared for the model is .27 ($p<.001$). The AIC is 152.09.

It should be noted that there is one observation whose standardized residual (3.48) exceeds 3, indicating minimal distortion within the model.

Table 5.26 Simultaneous multiple regression predicting Arabic cardinality

	coefficient	std.error	t-value	p
Intercept	-9.04	3.26	-2.46	<.001
Age	0.22	0.08	2.75	<.001
Arabic lang. test	0.13	0.13	0.99	0.32
Arabic max count	0.17	0.10	1.65	0.10
Dual case comp.	0.38	0.16	2.32	0.02

	Min	Median	Mean	Max
Stnd. Res.	-2.96	-0.16	0.00	3.48

AIC	152.09

We addressed the question of transfer of English knower levels (transfer-model). In Table 5.27 we examined the influence of English cardinality on Arabic cardinality, independent of age, Arabic language skills and Arabic counting score. We see that English cardinality and age has a significant effect on Arabic cardinality. Compared to the other approach, Arabic max count is additional predictor of the outcome in the conceptual approach. The standard residuals are not more than three or less than minus three, which is considered a good model with no outliers. The adjusted R Squared for the transfer model is .47, R Squared change (.20) is significant (p<.001). The AIC is 127.46, which is a better fit than the model in Table 5.26.

Table 5.27 Multiple regression model testing transfer from English to Arabic cardinality

	coefficient	std.error	t-value	p-value
Intercept	-6.23	2.90	-2.14	0.03
Age	0.15	0.07	2.16	0.03
Arabic lang. test	0.04	0.372	1.21	0.71
Arabic max count	0.06	0.09	0.69	0.48
Dual case comp.	0.33	0.14	2.41	0.01
English cardinality	0.46	0.08	5.39	<.001

	Min	Median	Mean	Max
Sntd. Res.	-2.08	0.02	0.00	2.55
AIC	127.46			

The model in Table 5.28 (non-transfer model), evaluates prediction of English cardinality. Dual case comprehension does not have significant independent influence on English cardinality. Age, English language skills and English max count score have a significant independent effect on English cardinality. The standard residuals are not more than three or less than minus three, which is considered a good model with no outliers**.** The adjusted R Squared for the model is .25 ($p<.001$). The AIC is 168.88.

Compared to the conceptual approach (see Table 5.21), the quantitative approach identified numerous significant predictors; including age, English language score and English max count.

Table 5.28 Simultaneous multiple regression predicting English cardinality

	coefficient	std.error	t-value	p-value
Intercept	-6.57	3.64	-1.80	0.07
Age	0.17	0.08	1.97	0.05
English lang. test	0.38	0.12	3.07	<.001
English max count	0.20	0.10	2.01	0.04
Dual case comp.	0.03	0.17	0.18	0.85

	Min	Median	Mean	Max
Stnd. Res.	-1.79	-0.16	-0.00	2.97
AIC	168.88			

We addressed the question of transfer of English knower levels (transfer-model). In Table 5.29 we examined the influence of Arabic cardinality on English cardinality, independent of age, English language skills and English counting score. We see that Arabic cardinality and English language have a strong significant effect on English cardinality. The result of this approach is identical to the conceptual approach. The standard residuals are not more than three or less than minus three, which is considered a good model with no extreme outliers. The R Squared for the transfer model is .46. R Squared change (.20) is significant (p<.001). The AIC is 144.13, which is a better fit than the model in Table 5.28.

Table 5.29 Multiple regression model testing transfer of cardinality from Arabic to English

	coefficient	std.error	t-value	p-value
Intercept	-1.81	3.26	-0.55	0.58
Age	0.02	0.07	0.28	0.77
English lang. test	0.29	0.10	2.67	<.001
English max count	0.14	0.08	1.61	0.10
Dual case comp.	-0.20	0.15	-1.28	0.20
Arabic cardinality	0.60	0.11	5.43	<.001

	Min	Median	Mean	Max
Stnd. Res.	-2.43	-0.12	0.00	2.85
AIC	144.13			

Both conceptual and quantitative approach resemble similar results which reflects the coherence of both measures of cardinality.

5.5 Transcoding

5.5.1 Descriptive statistics for transcoding tasks are shown in Table 5.30

5.5.2 Table 5.30 Descriptive statistics for transcoding score

	Min	*Median*	*Mean*	*Max*	*sd*
Western Arabic numeral presentation and English language response	2.00	6.00	5.79	9.00	1.81
Western Arabic numerals presentation and Arabic language response	2.00	5.00	5.24	9.00	1.68

Eastern Arabic numerals presentation and Arabic language response	2.00	5.00	5.37	9.00	1.58

Figures 5.10, 5.11 and 5.12 show the distribution of performance on different transcoding scores.

No children scored 0 (floor effects) in any of the transcoding tests.

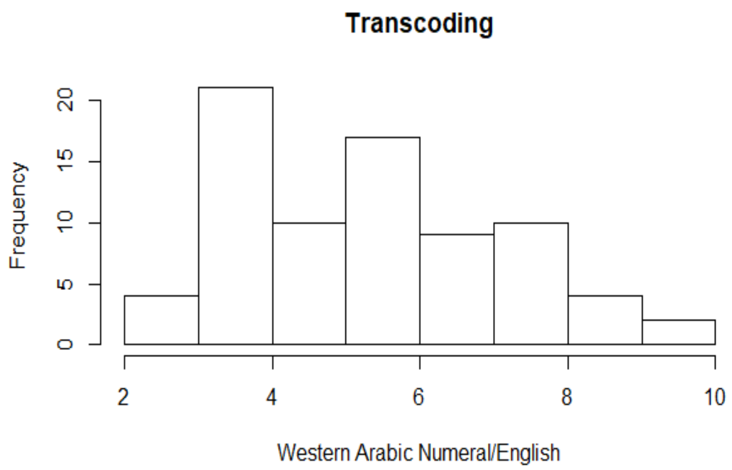


Figure 5.10 Distribution of Western Arabic numerals presentation and English language response

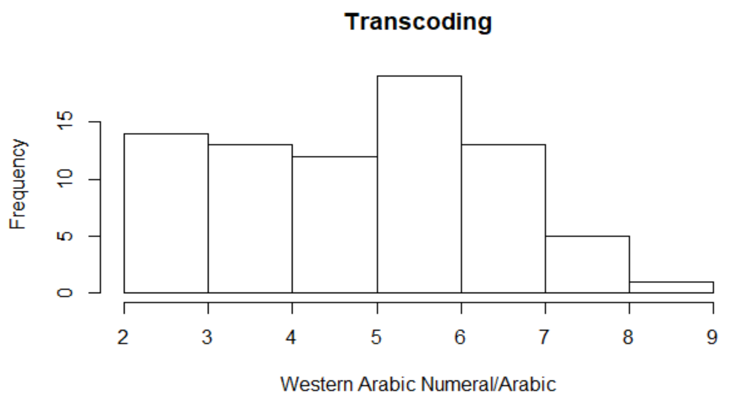


Figure 5.11 Distribution of Western Arabic numerals presentation and Arabic language response

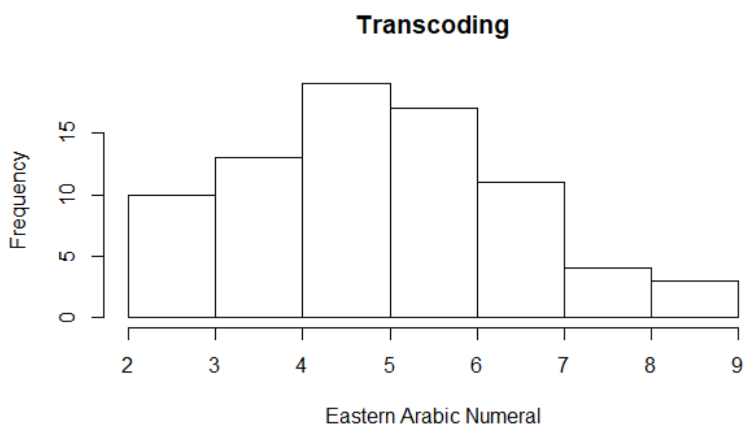


Figure 5.12 Distribution of Eastern Arabic numerals presentation and Arabic language response

The distribution of scores across the different transcoding tasks is consistent and approximately normal.

5.5.3 The difference between the transcoding scores

Paired t-tests between transcoding variables are shown in Table 5.31.

Table 5.31 Tests of difference between transcoding scores

	Western Arabic/ Arabic presentation	Eastern Arabic/ Arabic presentation
Western Arabic/ English presentation	t= 2.321* df= 76 Mean diff.= 0.545	t= 1.732 df= 76 Mean diff.= 0.415
Western Arabic/ Arabic presentation		t= -0.505 df= 76 Mean diff.= -0.129

* *p < .05*

** *p < .01*

Children's performance between Western Numeral English *(M= 4.97, SD= 1.81)* and Arabic *(M= 4.24, SD= 1.68)* presentations_significantly differs, the children's performance is better in western Arabic numeral with English presentation.

The performance of children between the Western Numeral English presentation and Eastern Numeral Arabic presentation is marginally different, with better performance on the Western Numeral English presentation.

5.5.4 Transcoding item analysis

5.5.4.1 The frequency of correct responses to transcoding test items is shown in Table 5.32

Table 5.32 The frequency of items of transcoding tests

(Number of participants getting correct answer in each item)

N=77	**201vs. 21**	**15vs. 5**	**4 vs. 6**	**8 vs. 2**	**12vs. 22**	**9 vs. 1**	**11vs. 24**	**64 vs. 604**	**7 vs. 3**	**36 vs. 306**

Western Arabic/ English presentation	31 40%	44 57%	57 74%	53 69%	41 53%	51 66%	44 57%	42 55%	59 77%	25 32%
Western Arabic/ Arabic presentation	28 36%	41 53%	48 62%	49 64%	40 52%	45 58%	27 35%	52 68%	53 69%	20 26%
East Arabic/ Arabic presentation	35 45%	30 39%	48 62%	51 66%	38 49%	47 61%	42 55%	45 58%	54 70%	24 31%

For all items, children's best performance is in west Arabic numeral with English presentation. The best item performance in all transcoding sets is 7 vs. 3 (single digit). The worst item performance in all transcoding sets is 36 vs. 306 (triple digit).

5.5.4.2 Analysis of digit forms in the transcoding tests

Analysis of digit forms of the transcoding test are shown in Table 5.33.

Table 5.33 The frequency of items of transcoding tests

(Number of correct responses selected in each item; single, double and triple)

	Western Arabic/ English presentation	**Western Arabic/ Arabic presentation**	**East Arabic/ Arabic presentation**
Total single digits (out of 308)	223	196	198
Total double digits (out of 308)	150	127	135
Total triple digits (out of 154) →	74	80	79

The contingency Table shows a clear common pattern of increasing difficulty from single to double and then triple digits.

5.5.5 Correlation between transcoding sets, language scores and cardinality scores

Pearson correlations between transcoding sets, language scores and cardinality scores are shown in Table 5.34.

Table 5.34 Correlation of transcoding tests and cardinality scores

	English card.	**Arabic card.**	**English Max-count**	**Arabic Max-count**	**English language test**	**Arabic langua ge test**	**Western Arabic/ English pres.**	**Western Arabic/ Arabic pres.**	**Eastern Arabic/ Arabic pres.**
Western Arabic/ English presenta tion	t= 4.67** r= 0.47	t= 1.99* r= 0.22	t=0.56** r= 0.06	t=3.08** r= 0.33	t= 468** r= 0.47	t=1.88 r= 0.21		t= 2.81** r= 0.30	t= 2.15* r= 0.24
Western Arabic/ Arabic presenta tion	t= 3.68** r= 0.39	t= 3.90** r= 0.41	t= 1.77 r= 0.20	t= 0.17 r= 0.15	t= 1.37 r= 0.15	t= 1.57 r= 0.17	t= 2.81** r= 0.30		t= 0.46 r= 0.05
Eastern Arabic/ Arabic presenta tion	t= 3.04** r= 0.33	t= 2.87** r= 0.31	t= 0.58 r= 0.06	t= 0.45 r= 0.05	t= -0.28 r= -0.03	t= 1.03 r= 0.11	t= 2.15* r= 0.24	t= 0.46 r= 0.05	

* *p < .05*

** *p < .01*

5.5.6 Regression analysis

5.5.6.1 Quantitative approach (Cardinality score)

The first model (Table 5.35) is a simultaneous multiple regression mode to investigate the predictive value of age, English language scores, English maximum and English cardinality on Transcoding (English presentation on Western Arabic numeral).

This model has one outcome variable, Transcoding, and four predictor variables age, English language, English maximum count and English cardinality score. We see that English cardinality, English language, and English max count have a significant independent effect on the outcome. The adjusted R Squared for the model is .32, is significant ($p<.001$).

Table 5.35 Simultaneous multiple regression predicting transcoding score (English presentation of Western Arabic numeral)

	Estimate	std.error	t-value	pr (<|t|)
(intercept)	2.36	1.93	1.22	0.22
Age	0.04	0.04	0.89	0.37
English lang. test	0.23	0.06	3.44	<.001
English max count	-0.10	0.05	-2.00	0.05
English cardinality	0.19	0.06	3.23	<.001

Standardised residuals:

Min	**Median**	**Mean**	**Max**
-2.43	-0.13	0.00	2.61
AIC	67.20		

We addressed the question of transfer between English and Arabic transcoding (transfer-model). In Table 5.36 we examined the influence of Transcoding score (Arabic presentation of Western Arabic numeral) on Transcoding score (English presentation of Western Arabic numeral) independent of age, English language skills, English cardinality score and English counting score. We see that English cardinality, English language, and English max count have a significant independent effect on the outcome.

The addition of Arabic Transcoding as a further predictor did not increases model efficiency. The adjusted R Squared for the transfer model is .32. R Squared change is .020, not significant (p = .140).

Table 5.36 Simultaneous multiple regression testing transfer from Arabic transcoding score to English transcoding

	Estimate	std.error	t-value	pr (<|t|)
(intercept)	2.09	1.92	1.08	0.28
Age	0.03	0.04	0.65	0.51
English lang. test	0.23	0.06	3.51	<.001
English max count	-0.11	0.05	-2.09	0.04
English cardinality	0.16	0.06	2.66	0.01
Transcoding (Arabic presentation of Weste rn Arabic numeral)	0.16	0.11	1.49	0.14

Standardised residuals:

Min	Median	Mean	Max
-2.43	-0.09	0.00	2.51
AIC	66.82		

In Tables 5.35 and 5.36, the English max count appears significant with a significant negative relation to the dependent variable. Though, in the correlation matrix, there was no correlation between the English max count variable and transcoding of English presentation. This is an abnormal finding; it suggests that the English max count is disturbing the model. Furthermore, it is not interpretable that English max count is a significant negative predictor.

This abnormal result could occur when a simultaneous model is constructed. Therefore, a build-up model (See Appendix 9) was administered to investigate the model's efficiency.

The build-up model shows that the English transcoding model is disturbed by the inclusion of the English max count variable, which produced anomalous results. Therefore, we ran the model (Table 5.37) without the English max count variable.

Furthermore, a scatter plot was run (See Appendix 10) to investigate the presence of outliers. One outlier was noted; even when the outlier was excluded from the analysis (Seen Appendix 10) still, the results were not consistent. The English max count turned out to be insignificant; nevertheless, it has a high negative t-value, which is considered a disturbing model.

This model (Table 5.37) is identical to the model in Table 5.35 but the English max count score was excluded. Therefore, it has one outcome variable, Transcoding, and three predictor variables age, English language and English cardinality score. We see that English cardinality and English language have a significant independent effect on the outcome. The adjusted R Squared for the model is .29, is significant ($p<.001$).

Table 5.37 Simultaneous multiple regression predicting transcoding score (English presentation of Western Arabic numeral) without English max count

	Estimate	**std.error**	**t-value**	**pr (<|t|)**
(intercept)	2.30	1.97	1.16	0.24
Age	0.03	0.04	0.665	0.51

English lang. test	0.20	0.06	3.05	<.001
English cardinality	0.16	0.06	2.78	0.01

Standardised residuals:

Min	**Median**	**Mean**	**Max**
-2.43	-0.13	0.00	2.61
AIC	69.37		

We addressed the question of transfer here again, after the removal of English max count, between English and Arabic transcoding (reduced transfer-model). In Table 5.38 we examined the influence of Transcoding score (Arabic presentation of Western Arabic numeral) on Transcoding score (English presentation of Western Arabic numeral) independent of age, English language skills and English cardinality score. We see that English cardinality and English language have a significant independent effect on the outcome.

The addition of Arabic Transcoding as a further predictor did not increases model efficiency. The adjusted R Squared is .029, R Squared change is 0.16, is .020, not significant (p = .180).

Table 5.38 Simultaneous multiple regression testing transfer from Arabic transcoding score to English transcoding, without English max count

	Estimate	**std.error**	**t-value**	**pr (<|t|)**
(intercept)	2.05	1.97	1.04	0.30
Age	0.02	0.04	0.42	0.67
English lang. test	0.21	0.06	3.10	<.001
English cardinality	0.14	0.06	2.22	0.02
Transcoding (Arabic presentation of Western Arabic numeral)	0.15	0.11	1.35	0.18

Standardised residuals:

Min	Median	Mean	Max
-2.43	-0.09	0.00	2.51
AIC	69.43		

The next model (Table 5.39) is a simultaneous multiple regression, it was conducted to investigate the predictive value of age, Arabic language scores, Arabic maximum count and Arabic cardinality score on Transcoding (Arabic presentation of Western Arabic numeral).

This model has one outcome variable, Transcoding, and four predictor variables age, Arabic language scores, Arabic maximum count and Arabic cardinality.

We see that only Arabic cardinality has a significant independent effect on the outcome. The adjusted R Squared for the model is .13, is significant ($p<.001$).

Table 5.39 Simultaneous multiple regression predicting transcoding score (Arabic presentation of Western Arabic numeral)

	Estimate	std.error	t-value	pr (<|t|)
(intercept)	2.29	2.06	1.11	0.27
Age	0.04	0.05	0.93	0.35
Arabic lang. test	-0.01	0.07	-0.01	0.98
Arabic max count	0.01	0.06	0.17	0.86
Arabic cardinality	0.19	0.06	2.88	<.001

Standardized Residuals:

Min	Median	Mean	Max
-2.43	-0.13	0.00	2.61
AIC	74.23		

We addressed the question of transfer between English and Arabic transcoding (transfer-model). In Table 5.40 we examined the influence of Transcoding score

(Arabic presentation of Western Arabic numeral) on Transcoding score (English presentation of Western Arabic numeral) independent of age, Arabic language skills, Arabic counting score and English transcoding score.

We see that Arabic cardinality and English transcoding score have a significant independent effect on the outcome. The addition of English transcoding score as a further predictor increases model efficiency (AIC is reduced to 71.82 from 74.23 for the non-transfer model). The adjusted R Squared for the transfer model is .17. R Squared change is (.046) not significant (p=0.074).

Table 5.40 Simultaneous multiple regression testing transfer from English transcoding score to Arabic transcoding

	Estimate	**std.error**	**t-value**	**pr (<|t|)**
(intercept)	1.84	2.03	0.90	0.36
Age	0.03	0.05	0.75	0.45
Arabic lang. test	-0.01	0.07	-0.13	0.89
Arabic max count	-0.02	0.05	-0.35	0.72
Arabic cardinality	0.18	0.06	2.79	0.01
Transcoding (English presentation of Western Arabic numeral)	0.21	0.10	2.04	0.04

Standardised residuals:

Min	**Median**	**Mean**	**Max**
-2.43	-0,09	0.00	2.51
AIC	71.82		

The next model (Table 5.41) is a simultaneous multiple regression, it was conducted to investigate the predictive value of age, Arabic language scores, Arabic maximum count and Arabic cardinality score on Transcoding (Arabic presentation of Eastern Arabic numeral).

This model has one outcome variable, Transcoding, and four predictor variables age, Arabic language scores, Arabic maximum count and Arabic cardinality score. We see that only Arabic cardinality has a significant independent effect on the outcome. The adjusted R Squared for the model is 0.052, not significant (p=0.096).

Table 5.41 Simultaneous multiple regression predicting transcoding score (Arabic presentation of Eastern Arabic numeral)

	Estimate	**std.error**	**t-value**	**pr (<|t|)**
(intercept)	5.000	2.037	2.455	0.01
Age	-0.004	0.051	-0.092	0.92
Arabic lang. test	0.012	0.075	0.162	0.87
Arabic max count	-0.028	0.064	-0.449	0.65
Arabic cardinality	0.172	0.067	2.550	0.01

Standardized residuals:

Min	**Median**	**Mean**	**Max**
-2.43	-0.13	0.00	2.61
AIC	72.08		

We addressed the question of transfer between English and Arabic transcoding (transfer-models). In Table 5.42 we examined the influence of Transcoding score (English presentation of Western Arabic numeral) on Transcoding score (Arabic presentation of Eastern Arabic numeral) independent of age, Arabic language skills, Arabic counting score and English transcoding score.

We see that only Arabic cardinality have a significant independent effect on the outcome. English transcoding score is marginal (.07). The addition of the English transcoding score as a further predictor did not increase the model efficiency. Although there is an increment in the adjusted R square and a reduction in the AIC, it appears that this change is marginal as the model turned out to be insignificant. The adjusted R Squared for the transfer model is 0.081. R Squared change (.03) is not significant (p=.074).

In Table 5.43 we examined the influence of Transcoding score (Arabic presentation of Western Arabic numeral) on Transcoding score (Arabic presentation of Eastern Arabic numeral) independent of age, Arabic language skills, Arabic counting score and Arabic transcoding score.

We see that only Arabic cardinality have a significant independent effect on the outcome. The adjusted R Squared for the transfer model is 0.04. R Squared change 0.007, is not significant (p= 0.467).

Table 5.42 Simultaneous multiple regression testing transfer from English transcoding (Western numeral) score to Arabic transcoding (Eastern numeral)

	Estimate	std.error	t-value	pr (<|t|)
(intercept)	4.60	2.01	2.28	0.02
Age	-0.01	0.05	-0.26	0.79
Arabic language	0.00	0.07	-0.15	0.98
Arabic max count	-0.05	0.06	-0.09	0.36
Arabic cardinality	0.16	0.06	2.46	0.01
Transcoding (English presentation of Western Arabic numeral)	0.18	0.10	1.81	0.07

Standardised residuals:

Min	Median	Mean	Max
-2.43	-0.09	0.00	2.51
AIC	291.11 70.60		

Table 5.43 Simultaneous multiple regression testing transfer from Arabic transcoding (Western numeral) score to Arabic transcoding (Eastern numeral)

	Estimate	std.error	t-value	pr (<|t|)

(intercept)	5.19	2.06	2.52	0.01
Age	-0.00	0.05	-0.01	0.99
Arabic language	0.00	0.07	0.12	0.90
Arabic max count	-0.02	0.06	-0.43	0.67
Arabic cardinality	0.18	0.07	2.64	0.01
Transcoding (Arabic presentation of Western Arabic numeral)	-0.08	0.11	-0.73	0.44

Standardised residuals:

Min	**Median**	**Mean**	**Max**
-1.86	-0.12	0.00	2.49
AIC	73.50		

We expected a mutual transfer between the transcoding concepts of Arabic and English languages. The results were not as expected; Arabic transcoding (Western numerals) score was not a significant predictor. On the other hand, English transcoding (Western numerals) was marginal.

Chapter 6: Discussion

This study has addressed the role of language in the development of number concepts through a focus on the grammatical structures that represent number in natural language. It aimed to examine the effects that number-marking variation had on number concepts used by bilingual participants attending pre-school in Saudi-Arabia, exploiting the contrastive forms of number marking in English and Arabic. In addition, it aimed to investigate whether cardinality concepts are transferred across languages in abstract non-linguistic formats, and to explore the relationship between cardinality and transcoding. Examining these aspects has added to the evidence showing that the linguistic context within which children learn to count can substantially modify the learning process, and has provided further understanding of the development of early number concepts in bilingual and multilingual populations more widely.

A specific question concerned cardinality concepts tested in English speakers. Would the comprehension of dual-case (in Arabic) show cross-linguistic effects, independent of age, general language skills, and exposure to the number word sequence?

We also aimed to investigate the relationship between three-year-old children's concepts of cardinality and their transcoding skills, exploring whether this relationship is independent of general language skills and knowledge of the spoken count sequence, and if it is based on an abstract conceptual understanding and asking in particular, does a child's understanding of cardinality influence their transcoding skills?

6.1 Cardinality discussion

We addressed the above questions by assessing cardinality, as indicated by the Give-a-number task (Wynn, 1990), in 3-year-old children who have been exposed to both Arabic and English language. This is a central task of the study, used to assess participants' understanding of cardinality.

We used a modified version of this task. We tested children on the following numbers: 2, 3, 4, and 5. In the give-a-number task, we did not have the opportunity to perform a longitudinal analysis. However, we had the opportunity to have single cross-sectional observations to look at the different ways in which people have used this data in order to score, perform analysis, and understand how children differ in this.

Two different analytical approaches were used: the first approach is the conceptual approach analysis and the second is the quantitative approach analysis. Each section starts with examining the first part of the study – investigating whether dual-case marking comprehension supports young children's understanding of number concepts. Following that, each section answers the question: whether transcoding is related to an understanding of the cardinality concept. For both Arabic and English languages, separate regression analyses were used to address these questions.

In the conceptual approach, based on previous findings (Almoammer et al., 2013; Wagner et al., 2015; Marusic et al., 2016) it was predicted that number concepts tested in Arabic would be more advanced than those tested in English. This prediction was not borne out. Knower-levels were closely matched across languages, they have the same maximum and minimum scores and the majority of participants were below CP knower level.

Based on these findings, we investigated further questions concerning the mechanism by which the understanding of number concepts had developed. To look at the distribution of cardinality scores and cardinality concept development. Furthermore, to what extent does comprehension of dual-case predict knower-levels, independent of age, general language skills, and exposure to the number-word sequence (as indicated by production of the count sequence).

As previously mentioned, separate regression analyses were used to address these questions for each language. In Arabic (non-transfer model), the effect of dual-case on knower-levels was significant, and independent of the effect of age. The fact that this effect was independent of the effect of age indicates its contribution to development, over and above simple maturation. Also, age is significant predictors of outcome. No effect of language or number sequence knowledge was found. In English (non-transfer model) by contrast, the effect of dual-case on knower-levels was not significant. The effect of language was significant, but no effect of age, dual-case and number sequence knowledge was found.

The contrasting findings between Arabic and English could be a result from that English Language skills are likely to be unevenly distributed within the sample; some families are more likely than others to provide English language experience. Without this experience, it's likely to be harder for children to learn number concepts in English. Therefore, we should expect that language skills will show strong effects in English models. In Arabic, however, language exposure is likely to be consistent across the sample, and therefore variation in language skills is likely to be subsumed (concealed) under the effect of age.

We concluded from these findings that the positive effect of dual-case on knower-levels was specific to Arabic. However, this conclusion was in clear contradiction to the earlier finding that knower-levels (including a high frequency of ‘two-knower’ status) were closely matched across languages. We therefore conducted another regression analysis to test whether the Arabic knower-level itself had an effect on the English knower-level, and vice versa, independent of the effects of age, English/Arabic language, and English/Arabic number sequence knowledge. This was confirmed. These regression models were designated as ‘transfer’ models.

We found that the Arabic knower-level was indeed a significant independent predictor of the English knower-level. Consistent with the previous analysis, we found that the effect of English language was significant, but there was no effect of age or number sequence knowledge. Also, we found that English knower-level was indeed a significant independent predictor of Arabic knower-level. Consistent with the previous analysis, we found that the effect of both age and dual-case comprehension were also significant. Taken together, these findings may indicate an indirect effect of dual-case comprehension on English knower-levels. This would imply that the conceptual understanding developed in the linguistic context of Arabic is represented at a supra-linguistic or abstract level, and is then transferable to the linguistic context of English.

To summarise, the statistical analysis shows that if we look at the variation in Arabic knower-levels, we find effects of age and dual-case comprehension in the non-transfer model. The addition of the English knower-level to the model (transfer model) is also significant. The dual-case variable continues to be significant independent of the other effects. Thus, we can account for variation in Arabic knower-levels in a complex model that includes independent effects of age, dual-case comprehension and English knower-levels. It's essential to highlight that the effect of dual case and English knower levels are independent of the effect of age. If not, it could be argued that both dual case and English knower level effects were significant only because of their association with age.

In the quantitative approach, which is based on the simple quantity of correct responses. In Arabic (non-transfer model), the effect of dual-case comprehension on cardinality was significant, and independent of the effect of age. No effect of language or number sequence knowledge was found. By contrast, in English, the effect of dual-case comprehension on cardinality was not significant. The effects of age, language, and number sequence knowledge were all significant.

From these findings we can again conclude that the effect of dual-case on cardinality concepts was language-specific. And again, the fact that this effect was independent of the effect of age indicates its contribution to development, over and above simple maturation. Further light is thrown on the developmental process by the contrast between zero-order correlations and the results of simultaneous regression analysis. The strong associations between Arabic language scores and cardinality, and between Arabic counting scores and cardinality, are not present in the regression model, indicating the primacy of dual-case comprehension and age as developmental drivers. Of interest is the distinctive pattern of prediction in the English model, where age, language, and number sequence are all significant. A possible interpretation of this finding is that, in this sample, the exposure to English language and to the English number-word sequence varied in a way which is independent of age. This implies that both make independent contributions to cardinality concepts. On the other hand, the influence of language and number sequence in Arabic may be more consistent with age-related maturation.

Again, we examined the extent to which cardinality concepts are mutually influential across languages. Previous research by Wagner et al. (2015) studied bilingual samples, including both French/English and Spanish/English bilingual groups. Children's dominant number learning language (NL1) was identified by measuring the highest count list that the children could produce in each language. The researchers then tested the prediction of cardinality concepts in NL2 through the cardinality concepts in NL1. The results varied according to the level of each participant understanding of cardinality. For those classified as 'subset knowers' (children who showed understanding of number words 1, 2, 3, or 4), there was no effect of NL1 on NL2, indicating linguistically independent acquisition. However, this was not true for 'cardinal principle knowers' (children who showed understanding of number words 5 and above). Results indicated transfer of concepts across linguistic boundaries for children whose foundational understanding of cardinality was already established. Wagner, Kimura, Cheung and Barner (2015) concluded that the initial stages of understanding of number-word meanings are language-specific. The foundations of cardinality are established independently as children learn to use count words to quantify small sets. This understanding is subsequently transferable across languages.

In the current study, we asked: to what extent are concepts of cardinality mutually transferable from Arabic to English and from English to Arabic? There was no difference in cardinality scores between Arabic and English. Also, no difference was found between the two languages in the maximum count score, indicating equal exposure. Despite the accelerator effect of the dual-case on the Arabic language, English and Arabic cardinality are still equivalent.

We found that, independent of any other influence, Arabic cardinality was a significant and powerful predictor of English cardinality. Consistent with earlier analysis, we found that the effect of English language was independently significant. The effect of number sequence knowledge was now marginal, and the effect of age was abolished. As noted above, in this sample the development of Arabic cardinality is consistent with general maturation, and therefore this change might indicate an age-related component.

The main finding from the regression analysis described above is the strong cross-linguistic contribution of Arabic cardinality to English cardinality. Similar findings emerge from the regression analysis examining the influence of English cardinality on Arabic cardinality. The significant independent effect of age, and the lack of effects of language and number sequence knowledge, are consistent with earlier analysis; the simultaneous multiple regression predicting Arabic cardinality (non-transfer model). The main finding is the strong cross-linguistic contribution of English cardinality to Arabic cardinality. Taken together, these analyses demonstrate powerful mutual influence of cardinality concepts across languages.

In addition, there is a correlation between the Arabic and English language tests. However, this correlation is not strong, and could be due to the fact that age is not correlated with English but is correlated with Arabic, which shows that Arabic and English languages are mapping to different developmental pathways as the exposure to English differs in the sample. Furthermore, it could be due to a lack of sensitivity and validity in the language tests; the Arabic language test is not standardised, and the English language test is standardised for English speakers as a first language.

With regard to the analysis of the nominal number marking (NNM) task, the high percentage of 0-1 responses to the NNM task found across the different ages and different NNM categories (singular, dual, and plural), indicates the level of uncertainty in children’s understanding of the concepts at this very early stage in their grammatical knowledge development. However, the responses are not random because it is unlikely to occur by chance that such a low level of correct responses is recorded. Rather this pattern indicates a consistent failure to process nominal number marking.

In the age range of our sample, there is an indication of increased understanding with age, concerning the singular nominal number marking. On the other hand, regarding the dual and plural nominal number marking, the developmental challenges continue through the age range.

Altogether, we have a sample of the early stages of development, as some children showed some understanding, while others demonstrated challenges, in nominal number marking. It is important to note that singular number marking is easier and comes first in language development, (Alquatani, 2016), which could explain the developmental trajectory.

In regards to our findings from the analysis of the number word sequence task, we note from all regression analyses that the influence of number sequence knowledge was inconsistent across languages. Also, there is only a weak correlation between maximum counting and knower levels/cardinality in both languages, which provides no independent prediction of knower levels or cardinality once language skills and dual-case comprehension are taken into account. This finding supports the critical role of language in the development of early number concepts, even when specific numerical inputs are taken into account. It is important to note that the number word sequence knowledge is a developmental function; as children age, their counting skills improve (getting further in the counting sequence). However, many factors including social and educational factors are operating as well as the child develops.

Earlier, we presented three theoretical models of number concepts development in young children who are bilingual in English and Arabic (Figures 1.1, 1.2, 1.3).

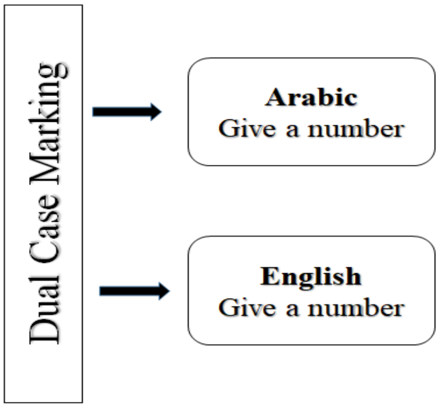


Figure 1.1 Dual Case has direct effect on knower levels in both languages

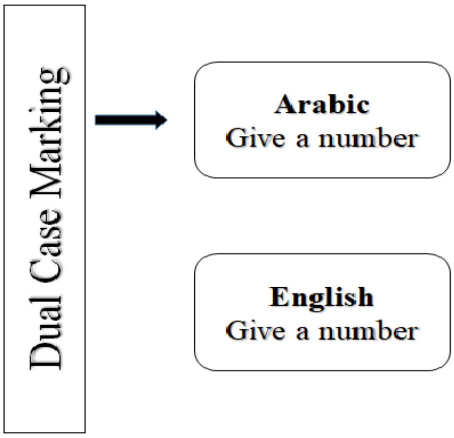


Figure 1.2 Dual Case has direct effect on Arabic knower levels, but not on English knower levels

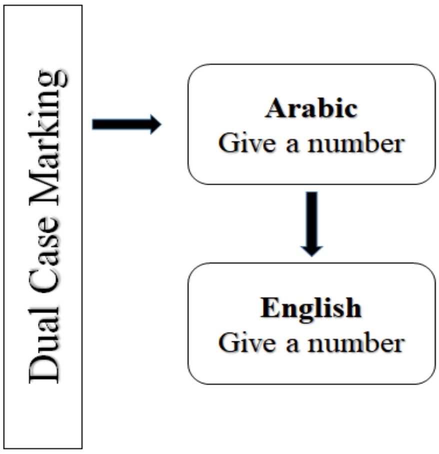


Figure 1.3 Dual Case has direct effect on Arabic knower levels, with subsequent transfer of abstract concept from Arabic to English knower levels

Our first research question concerned the proposal that exposure to dual-case marking may guide the development of early number concepts by foregrounding the occurrence of paired entities in the child's environment. In the first model (Figure 1.1.a) the foregrounding property of dual case has an early and direct effect on cardinality concepts in both languages. This proposal is not supported by our results. Although cardinality scores were closely matched across languages, and there was a direct effect of dual-case comprehension on Arabic cardinality, no such effect of dual- case comprehension was found on English cardinality.

The second theoretical model (Figure 1.1.b) proposes that the inputs from dual-case marking are contained within the Arabic language context. This model is broadly consistent with the proposal of Wagner et al. (2015) that the early developmental stages of cardinality concepts entail an extended process of mapping number concepts to language-specific number words, which, in the case of bilingual children, are learned independently in each language. In this account, the transfer of concepts across languages does not occur until children show evidence of understanding the principle of cardinality, usually associated with CP-knower status. In the current sample, only six out of 77 children achieved this status in Arabic, and seven out of 77 in English (five of these were CP-knowers in both languages). Therefore, according to the combined findings of Almoammer et al. (2013) and Wagner et al. (2015), it would be predicted that there should be a direct effect of dual-case comprehension on Arabic, but not English, knower-levels. This was confirmed.

The third theoretical model (Figure 1.1.c) proposes that the transfer of number concepts occurs mutually between languages. The analyses reported above show strong effects consistent with this model. Consistent with the parameters of the regression models, a detailed item-based examination of scores in our cardinality task showed age-related patterns of performance which are entirely consistent across languages. These findings run counter to the suggestion of Wagner et al. (2015) that transfer of conceptual understanding is only possible for children who are CP-knowers. Less than ten percent of our sample achieved this level. A number of factors related to differences in sampling might explain these discrepant conclusions. Wagner et al. (2015) recruited from a much broader age-range (2; 2 to 5; 6, compared with ours which was 3; 0 to 3; 11). The majority of their sample were CP-knowers. Wagner et al. (2015) included children bilingual in English-Spanish and English-French, none of whom had been exposed to dual-case marking. Our sample, and our analyses focussed attention on the particular characteristics of children exposed to English and

Arabic. Our observations indicated a broad equivalence of performance levels across measures of linguistic and numerical skills. Nonetheless, while these factors; the age and languages of the children in the sample may be responsible for differential findings, our data and analyses indicate that the early stages of number concept development in bilingual children may be shared across languages, before children fully understand the cardinality principle.

On one hand, the results of our study show the language-specific influence nominal number marking has on the early understanding of number concepts, while, on the other, they demonstrate a high level of mutual influence across languages on the same concepts. These findings need not be contradictory. It is reasonable to propose, along with Piantadosi et al. (2012), that numerous factors in early development support a ‘language of thought’ which precedes understanding of number-word meanings. From the current study we might propose two specific mechanisms which may be at play. First, an abstract system of number representation which, in the case of bilingual inputs, is enhanced through a cross-linguistic experience of the procedures of object counting. This cross-linguistic experience could entail transfer of elements of the first language in the second language or vice versa. These cross-linguistic elements may facilitate conceptual development.

Second, a language-specific system which exploits the information provided by nominal marking to parse the environment in numerical terms.

Our findings extend those of Almoammer et al. (2013) by showing that the previously reported influence of Arabic dual-case knowledge on early number concepts is replicated in a bilingual, within-participant design. We also extend the findings of Almoammer et al. (2013) and Marušič (2016) by showing that dual-case influence operates independently of age and general language skills. Our results add to a growing body of research demonstrating the importance of grammatical number marking, and wider linguistic factors, in shaping early number concepts (e.g. Barner et al., 2009; Le Corre et al., 2016; Sarnecka et al., 2007).

An important new proposal emerges from our study. The evidence of a strong, mutual, cross-linguistic influence on early emerging concepts of cardinality suggests the possibility that early emerging abstract representations of number provide the basis through which bilingual children's initial understanding of number-word meanings is shared across languages. Furthermore, there is evidence of closely matched knower levels in English and Arabic in the conceptual approach; the finding of a direct effect of dual-case comprehension on Arabic, but not English knower-levels; and the further finding of a direct effect of Arabic knower levels on English knower levels, are all consistent with a theoretical model in which early number concepts (early knower levels), acquired in a language-specific context, are subsequently represented in abstract form and capable of transfer between languages. This proposal runs counter to the suggestion of Wagner et al. (2015) that such transfer is only possible for children who are "five-knowers" or above (i.e., cardinal principle or "CP-knowers"). What might explain these discrepant conclusions? As noted above, there are important differences in sampling between the two studies, including age range, proportion of CP knowers, language backgrounds. While these factors may be responsible for differential findings, nonetheless our data and analyses indicate that abstract transfer of early number concepts between languages is possible, specifically before children understand the cardinality principle.

We propose that dual-case morphology could facilitate or enhance the development of concepts of cardinality, which results in the presence of transfer at the sub-set knower stage. We can interpret this finding in relation to the widespread observation that the period of acquisition of early number concepts is prolonged, and the proposal that this is due to the process of mapping concepts to number words. We suggest that grammatical number marking may play a facilitative foregrounding role in the mapping process, but that this process may still be prolonged and language specific, preceding an abstract concept formation.

6.2 Transcoding discussion

Transcoding is the ability to map spoken numbers to symbolic numerals. Transcoding provides an essential basis the understanding of place value (Cheung & Ansari, 2021; Malone et al., 2020). Also, it predicts later arithmetical skills (Göbel et al., 2014; Habermann et al., 2020).

There are several factors that could possibly influence transcoding skills: language, number sequence knowledge and cardinality. According to one account, understanding symbols for Arabic numerals is based on a knowledge of the spoken number sequence (counting) combined with an understanding of the cardinality principle (Reynvoet & Sassanguie, 2016). Habermann and colleagues (2020) have shown a relationship between children's counting skills and transcoding.

We are asking whether cardinality is important to transcoding. We know from the first part of the study the importance of cardinality knowledge. However, we also propose that the children in our sample may have an abstract, non-linguistic representation of number concepts. This could suggest that the contribution of cardinality to transcoding might be limited.

This is the first study that we are aware of that compares Western and Eastern Arabic numerals. The descriptive statistics of the transcoding task show that the performance of bilingual children in Western Numerals with English presentation is significantly better than Arabic presentations. Moreover, there is no difference in the children's performance between Western Numeral English and Eastern Numeral Arabic presentation.

Two factors may account for superior performance in English. Research has shown that place-value integration is more accessible when the mapping between number-word structure and Arabic notation was compatible. The English presentation matches the visual presentation of Western Arabic Numerals, whereas the Arabic presentation was presented with word-inversion which makes them more susceptible to inversion errors (Zuber et al., 2009). Furthermore, it is essential to highlight those differences in input, i.e. greater exposure to English transcoding, may explain superior performance. This was not controlled.

Item analysis showed children performed best when single digits were presented followed by double digits and then triple digits. Research has shown that preschool children know that small, single-digit numbers (e.g., one and two) denote a smaller quantity than larger single-digit numbers (e.g., seven and eight), even if they do not understand the precise meaning (Le Corre & Carey, 2007; Sarnecka & Gelman, 2004). This small association could be enough to help children understand place value, that is, understanding that the digits on the far-left matter more than the others (e.g., a number symbol XXX is greater than symbol XX), which also entails understanding of cardinality. Most children enter school with counting sequence skills and a conceptual understanding of numbers up to 10 (Mix et al., 2014). Such understanding could be essential in children's understanding of place value.

Regression models were used to assess to the influence of age, language skills, number sequence knowledge and cardinality concepts on transcoding. Separate regression analyses were used to address these questions in each language.

6.2.1 Findings of English transcoding of Western numerals

Although, the English max count is correlated with English transcoding, the regression model became unstable when the English number sequence variable was introduced, therefore this variable was discarded and a simpler model based on age, English language and English cardinality was used. The effects of English language, English max count, and cardinality were all independently significant. Age was not significant, which was predicted as

English language skill is not necessarily related to age but more about exposure. The influence of the English language is predictable because English language exposure is essential to number word knowledge. English cardinality is also significant, suggesting that children need to understand the concept of cardinality to understand numerical symbols (Reynvoet & Sasanguie, 2016).

Our previous results suggested that when children are exposed to the foregrounding effect of Arabic's dual case, the abstract representation of number concept allows crossover between languages. This brings us to the question of whether understanding transcoding is transferred between languages. We therefore conducted another regression analysis to test whether there is significant independent effect of Arabic transcoding on English transcoding. No such effect was found, in contrast to the presence of abstract transfer of cardinality concepts. This is consistent with Dehaene's triple-code model (Dehaene, 1992), as cardinality understanding, learned through counting objects aloud, is primarily involving the auditory code; when children learn cardinality concepts expressed in the spoken form, they are linking it with abstract representation (Analog Magnitude or ANS). On the other hand, transcoding understanding involves more components of the triple code mode: the visual and auditory codes are central to the process. Involvement of abstract magnitude is possible but not central (Figure 6.1). Linking the spoken number words to visual code places strong emphasis on specific spoken language inputs.

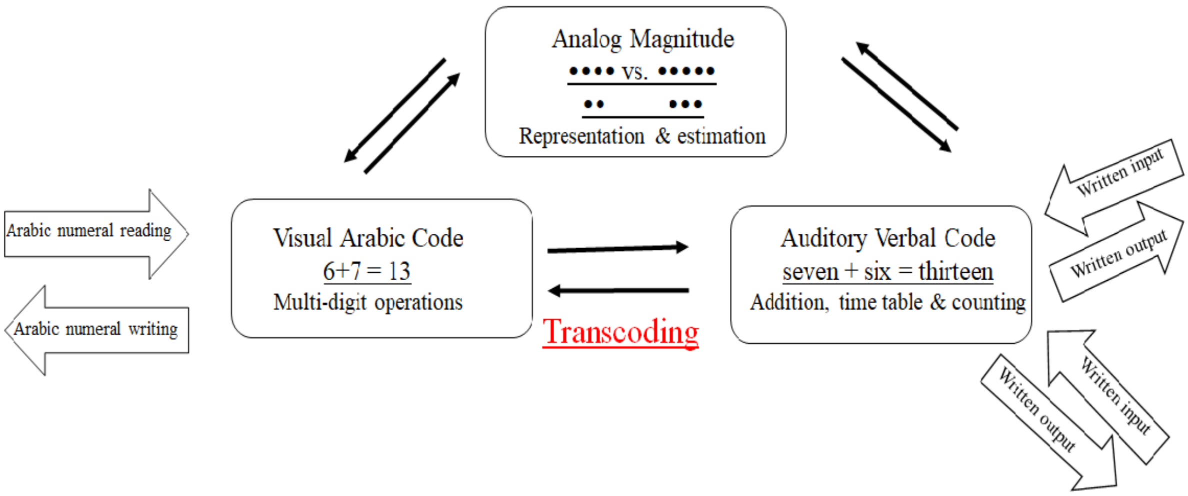


Figure 6.1 Dehaene's triple code model based on Dehaene, 1992; page 31, modified to highlight the transcoding pathway

6.2.2 Findings of Arabic transcoding of Western numerals

The regression model for Arabic transcoding of Western numerals is not explained by age, Arabic language score, or Arabic max count score; the only significant predictor is Arabic cardinality score.

Compared to the Arabic cardinality model (in Table 5.26), we did find an effect of age; the older children are, the more experience they get. Also, they have increased dual-case comprehension, which helps them understand Arabic cardinality. In the model of transcoding, the situation is different, as age is not a significant predictor. Only the Arabic cardinality score is a predictor of Arabic transcoding. We suggest that the learning process of Arabic transcoding is different from the learning process of cardinality, and maybe more dependent on school experience.

We conducted another regression analysis to test whether there is a transfer between English and Arabic transcoding of Western Arabic Numerals. An identical model was created which included age, Arabic language score, Arabic max count score and Arabic cardinality score, with the addition of English transcoding. There is an influence of English transcoding on Arabic. However, the reverse effect (influence of Arabic on English transcoding) was not found. This indicates English transcoding has primacy in the learning process. This could result from the broader exposure to Western Arabic Numerals in English language in the children's environment and culture.

Primacy may be related to the input the children receive and thus may be related to multiple factors. For instance, the education level of the parents, the presence of the elderly in the house, and the presence of English/Arabic speaking caregivers, which may have a substantial influence on number learning.

The questionnaire would have been a good indication of the input, but it was unfortunately dismissed in the study."

6.2.3 Findings of Arabic transcoding of Eastern numerals

The regression model for Arabic transcoding of Eastern numerals, as in the previous model, transcoding is not explained by age, Arabic language score, or Arabic max count score; it can only be explained by the Arabic cardinality score.

The Arabic presentation has a similar influence on transcoding skills as the results of Eastern and Western numerals are identical. This could be a result of the place value argument (that English number word structure fits Western Arabic numeral structure better than Arabic word structure) (Göbel et al., 2014) also applied to Eastern Arabic numeral structure.

We expected a mutual transfer between the transcoding concepts of Arabic and English languages. The results were not as expected; Arabic transcoding (Western numerals) score was not a significant predictor. On the other hand, English transcoding (Western numerals) was marginal. As mentioned, this could indicate that English transcoding has primacy in the learning process.

6.2.4 Summary of findings concerning transcoding

Taken together, the findings of the transcoding study suggest the following conclusions: Cardinality concepts play an important role in transcoding skills in both languages. However, the pattern of mutual transfer of cardinality concepts between languages in not found for transcoding skills. English number transcoding has primacy for the children in our sample, based on more robust representation than in Arabic. The relative weakness of Arabic transcoding may be related to the fact that children learn two different notations in the Arabic language, which may be a cause of confusion.

The best item performance in all transcoding sets is 7 vs. <u>3</u> (single digit). The worst item performance in all transcoding sets is <u>36</u> vs. 306 (triple digit). From the analysis of the number of correct responses selected in each item; single, double and triple, the results show a clear common pattern of increasing difficulty from single to double and then triple digits

Conclusion was drawn that children's best performance is in west Arabic numeral with English presentation.

From the analysis of performance on different types of test items, we can see there is inconsistency in the performance across presentation types. No developmental pattern was observed.

The marginal findings in relation to the influence of English transcoding on both Western Arabic transcoding and Eastern Arabic transcoding, in the absence of transfer between Arabic forms, provide a suggestion that a language-specific process may be in operation. This strengthens the case for replication of findings, especially in a longitudinal study. If confirmed longitudinally, this finding might suggest that the representation of written numerals is not underpinned by abstract transfer, with consequent implications for teaching and learning. Under these circumstances early educators might wish to provide consistent language-specific inputs to pre-school learners, in order to establish a stable basis for later cross-linguistic learning.

6.3 Summary and conclusion

We investigated the relationship between grammatical morphology and number concepts, examining the contrast between Arabic and English languages. In particular, exploring whether or not dual-case marking comprehension can improve access to the concept of cardinality. And if so, how does this operate in a bilingual context, where the structures of number-marking vary between languages? Also, to what extent are concepts of cardinality mutually transferable between languages?

In comparison to the conceptual and quantitative analysis approaches of the give-a-number task, the quantitative approach appears to show more sensitivity than the other approach, as the quantitative approach (linear regression) identified a greater number of significant variables. The binary and logistic regression models in the conceptual approach fail to register the variations that occur when we use multiple scaled measurements. However, it is important to note that both the conceptual (knower level) and quantitative approach (cardinality score) presented the same overall pattern of results, suggesting that knower levels and cardinality scores provide complementary indicators of number concept knowledge. Lastly, we have shown the influence of cardinality on transcoding, which is likely to influence arithmetic skills in later years.

We acknowledge important limitations in our study. Concerning the give-a-number task, we tested only numbers two to five we recognise that without data on number word “one”, we cannot differentiate between non-, one-, and two-knowers. Furthermore, it is not possible to define a child as a two-knower without first ensuring that they don’t give two items when asked for one. We acknowledge the limitation of this paradigm. Therefore two forms of data scoring were used for the analysis to provide an in depth look at the understanding of number concepts. Furthermore, the cross-sectional nature of our design limits the extent to which we can infer developmental process. Also, the lack of a monolingual comparison sample limits the extent to which we can generalize our findings. Our original design included both longitudinal observation and monolingual comparison, but was unavoidably truncated by the COVID-19 crisis. Lastly, the parental language questionnaire was aimed to capture the possible differences in the children's background and home environment, but was not taken up by the majority of parents. Therefore, it was excluded from the study.

Despite these limitations our findings have implications for understanding the development of number concepts more widely. First, we have added to the evidence showing that the linguistic context within which children learn to count may substantially modify the learning process. We go further than previous research in demonstrating this effect within participants, thereby excluding the possible confound of cultural influence. Second, we have shown that the effects of dual-case marking on early number concepts are independent of age and general language skills. We have also shown that dual-case marking is capable of exerting greater influence on children's acquisition of early number concepts than specific numerical inputs (as indicated by knowledge of the number word sequence *per se*).

We interpret our findings as demonstrating the powerful foregrounding role of dual-case marking in the child's experience of the world around them, with consequent effects on concept formation. Contrary to previous research findings (Wagner et al., 2015). Our findings indicate that, very early number concepts, developed within a specific set of linguistic contexts, may be represented at an abstract level, capable of transfer across languages. However, the pattern of mutual transfer of cardinality concepts between languages is not found for transcoding skills. This may have general importance for understanding the development of early number concepts in bilingual and multilingual populations more widely. Is it also necessary to acknowledge the implications of these findings for education professionals – e.g. assessment of children's skills, moderation of expectations and encouragement of bilingualism at the earliest stages of number learning, while at the same time understanding the linguistic specificity of early transcoding skills.

The next step regarding this research is to conduct a longitudinal study with a similar sample. The longitudinal method will allow us to evaluate the longitudinal effect of initial status of dual case and cardinality on outcomes including transcoding and early arithmetic skills. Furthermore, it will allow us to look for the contributions of all measured variables in time 1 to the outcomes of time 2 (after 12 months). Longitudinal study would allow evaluation of the developmental drivers of children's nominal number marking skills. Particularly, it would allow us to examine whether cardinality concept actually drives singular/dual/plural marking ability, which cannot be tested with data only from one timepoint. Overall, helps in broader understanding of the mechanisms underlying the association between nominal number marking in Arabic and number development, alongside comparison similar processes in English.

Additionally, we will present the standard method of the Give-a-number task by including number 1, allowing us to compare the full knower level score analysis with the cardinality score analysis. Lastly, collecting parental questionnaire data to evaluate to some extent the contribution of factors that are based in the home. We will also seek specification about the language of numeracy teaching in the schools.

In regards to expanding the study; testing an Arabic monolingual sample will allow us to compare the developmental trajectory of number knowledge of monolinguals to that of bilinguals; comparing children’s performance in cardinality concept and evaluate the influence of exposure to a second language.

Furthermore, we will examine bilingual children who were not exposed to languages that include dual case marking to evaluate the developmental trajectory of cardinality concepts and to evaluate the nature of abstract transfer, and whether it is has linguistic or numerical base.

Additionally, comparing bilingual children who are not exposed to the Arabic language but exposed to languages that include dual case marking such as German language.

In the future plan, it would be beneficial to use language measures to create groups with low versus high English proficiency to resolve the issue of the uneven distribution of English proficiency in the sample to have an in-depth interpretation of the results.

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Appendices

1. Summary of the characteristics of different studies used the Give-N task

Study	procedures used to score the Give a Number task
Wynn, 1990-92	Children were asked to give a puppet one to five items, and the highest number word they could succeed at consistently was determined. They were first asked for 1 item and then for 2 items; depending on their success, they were then asked for 3 items, or asked again for 1 or 2 items. Children who failed on a trial were next asked for a numerosity at which they had previously succeeded. This served to determine the consistency of a child's performance on a particular numerosity. Children were asked three times for each of these numerosities. The experimenter followed up children's responses by asking questions such as "Is that three?" and then "Can you count and make sure? Scoring criteria: 1- On at least two-thirds of a child's trials for that numerosity, the child's response was either the correct number according to her own stably ordered count list,' or the correct number plus or minus one if the child had counted aloud from the pile to the number word asked for, but had erred in the counting by either double counting or skipping one item or by repeating or skipping one number word. 2- The child responded with that number when asked for higher numerosities no more than half as often, percentage wise, as she did when asked for that number itself. For example, a child who gave two items 67% of the time (2 of the 3 trials) when asked for 2 was scored consistently correct on 2 only if she gave two items no more than 33% of the time when asked for three, four, and five items.
Le Corre and Carey, 2006	Adapted from (Wynn, 1990) small bowl with plastic toys placed on a table in front of the child and asked, "Could you take *one* elephant out of the bowl and put it on the table?" After the initial demonstration, the experimenter proceeded to ask for larger numbers of toys. On trials where the experimenter asked for 2 or more toys, children were always asked, "*Can you count and make surethis is X*?" If children counted and the last number of their count did not match the number of objects requested, the experimenter then probed with "*But I wanted X elephants – can you Wx it so that there are X*?" If children succeeded at giving X

	dinosaurs, the experimenter requested X+1 on the next trial. If they then failed to give X+1 dinosaurs, X was requested on the subsequent trial. Children were tested up to the smallest number that they could *not* give correctly at least two out of three times. Scoring criteria: 1- Give *n* objects at least 67% of the time when asked for that number; and 2- Give *n* objects no more than half as often when asked for a different number.
Barner et al, 2009	Adapted from Wynn (1992) Stimuli were presented to children and asked, ‘‘Oh, there are strawberries. How many do you think there are? Could you count them for me?”. Then the experimenter asked them to give a certain number of strawberries. When children successfully gave N strawberries (e.g., 3), they were then asked to give N + 1 strawberries (e.g., 4). When they failed with N, they were tested on N – 1 (e.g., 2). When they initially failed to give a correct amount, they were asked, ‘‘Are you sure there are N strawberries?” Following their response, they were asked, ‘‘Can you count to make sure?” If children counted and the last number of their count did not match the number requested, they were asked again, ‘‘Is that N strawberries? Can you fix it to make it N strawberries?” If they failed to correctly fix the set, they were tested with N – 1. If they succeeded, they were tested with N again. Scoring criteria: Children were called N-knowers (e.g., two-knowers) if they correctly gave N strawberries two of three times when they were asked for N but failed to give the correct number two of three times for N + 1. Children were credited as cardinal principle
Slusser and Sarnecka, 2011	Materials for this task included a stuffed animal, a red plastic plate, and 15 small plastic bananas. The experimenter asked the child, ‘‘Can you give Peter one banana?’’ After the child slid the plate over to Peter, the experimenter asked the follow-up question, ‘‘Is that one?’’ If the child said ‘‘yes,’’ the experimenter said, ‘‘Thank you!’’ and placed the bananas back in the tub. If the child said ‘‘no,’’ the experimenter restated the original prompt (‘‘Okay, can you give him one?’’) and continued with the follow-up question as before. Children were always asked for 1 or 3 bananas on the first and second trials, respectively. If a child succeeded on both of these, the next request was for 5 bananas. If not, the next request was for 2 bananas. Subsequent requests depended on the child’s responses. If the child succeeded at giving a number

	N, the next request was for N + 1, with 6 being the highest number requested. If the child failed to give N, the next request was for N _ 1, with 1 being the lowest number requested. Scoring criteria: The child had at least two successes at a given number N and at least two failures at N + 1. A child was given credit for ‘‘knowing’’ a number if he or she produced at least twice as many correct responses as errors for that number (including both types of error, as described above). Each child was then assigned a number-knower level, reflecting the highest number reliably generated. For example, children who reliably generated sets of 1 or 2 objects, but not 3 objects, were called two knowers. Children who succeeded at the highest set sizes (5 and 6) were called CP-knowers.
Lee and. Sarnecka, 2011	Each child was given 21 trials: three trials each of the numbers 1, 2, 3, 4, 5, 8 and 10. Materials included a stuffed animal, a plastic plate, and three sets of 15plastic counters each (fish, dinosaurs and oranges). The experimenter began the task by saying ‘‘The way we play this game is, I will tell you what to put on the plate, and you put it there and sli-i-i-de it over to Pig, like this (demonstrating). OK, can you give one fish to Pig?’’ After the child slid the plate toward the stuffed animal, the experimenter asked one or more follow-up questions. On low-number trials (those asking for one, two, three or four items), there was only one follow-up question, repeating the original number word (e.g., ‘‘Is that one?’’) If the child said ‘‘yes,’’ then the experimenter said, ‘‘Thank you!’’ and placed the item(s) back in the bowl. If the child said ‘‘no,’’ then the experimenter restated the original request, starting the trial over. On high-number trials (those asking for five, eight or 10 items), the follow-up questions encouraged the child to count. (For children who had spontaneously counted out the items already, the follow-up was the same as on low number trials.) For children who had not counted the items, the first follow-up question was the same (e.g., ‘‘Is that five?’’). If the child said ‘‘yes,’’ the experimenter said, ‘‘Can you count and make sure it’s five?’’ If the child counted and ended with a number other than five, the experimenter said ‘‘Can you fix it so it’s five?’’ If the child answered no’’ to the original follow-up question, the experimenter said ‘‘Can you count and fix it so it’s five?’’ The child’s final response (after counting and fixing) was the response used for the analysis. Scoring criteria:

	1- A child is counted as 'knowing' a number N, if that child successfully generated sets of N for at least two of the three trials asking for that number. 2- Did not generate a set of N more than once.
Wagner, 2015	Two version: 1- Twenty-one trials, consisting of three trials for each of the seven numbers tested (i.e., 1, 2, 3, 4, 5, 8, and 10). 2- Stair-cased version of the Give-a-Number task; for each trial thereafter, if the child succeeded in giving the correct quantity (i.e., n), the experimenter proceeded by asking for one more on the subsequent trial (i.e., n + 1) up to the number eight. If the child failed to provide the correct quantity, the experimenter then asked for one fewer (i.e., n _ 1). Scoring criteria: Children were defined as an n-knower (e.g., three-knower) if they correctly provided n (e.g., 3 fish) on at least two out of the three trials that was requested and, of those times that the child provided n, two-thirds of the times the child did so it was in response to a request for n. If n was five or higher, the child was classified as a CP-knower.
Maruˇsiˇc et al, 2016	Children were presented 10 buttons, and were asked, "Can you put N in the box?" where N was 1, 2, 3, 4, 5, 8, or 10. Once the child had placed objects into the box, the experimenter asked, "Is that N?" If the child said "no" or if they provided an incorrect answer, they were given an opportunity to count the items and fix their response, "Can you count and make sure?" Children were asked for each number three times, in fixed pseudorandom order. Scoring criteria: 1- Provided n items 2/3 of the time when asked for n. (b) 2- On 2/3 trials on which they gave n, it was in response to a request for n, and not some other number. 3- In order to be classified as a non-,1-, 2-, 3-, or 4-knower, children were required to demonstrate failure on higher numbers.
Le Corre et al, 2016	Children were asked to give of one to six small toys out of a pile of twelve to fifteen. In a staircase procedure, the first number requested was one and the highest was six. Whenever children gave a number correctly, the experimenter asked for the next higher number, stopping when she reached a number that

	children could not give correctly at least twice out of a maximum of three trials. Children were always asked to check whether they had given the correct number of toys by counting the set they had given. If children counted and the last number of their count did not match the number of toys requested, the experimenter then asked children to fix their answer by saying: ‘‘But I wanted N strawberries – can you fix it so that there are N?’’ Scoring criteria: 1- Give N objects on at least two out of a maximum of three trials when asked for ‘‘N” objects. 2- Give N objects no more than half as often when asked for a different number. 3- Satisfy conditions 1 and 2 for all numbers less than N.
Wagner et al, 2018	Adapted from Wynn (1990). The experimenter began by presenting the child with a plate and ten similar objects. For each trial, the experimenter sked the child to place a quantity on the plate, “Can you put *N* on the plate? Put *N* on the plate and tell me when you’re all done”. Once the child responded, the experimenter asked, “Is that *N*? Can you count and make sure?” and encouraged the child to count. If the child recognized an error, the experimenter allowed the child to change their response. Children completed up to twenty-one quasi-randomized trials, consisting of three trials for each of the seven number words tested (*one*, *two*, *three*, *four*, *five*, *eight*, and *ten*). Scoring criteria: 1- Children were defined as an *n*-knower (e.g., three-knower) if they correctly provided n (e.g, three fish) on at least two out of the three trials that *n* was requested. 2- The child provide *n,* two-thirds of the times.
Mou et al, 2018	Children were presented with 10 items located in a row at the top of the computer screen and heard the computer request a given number (e.g., ‘‘five”). Children were asked to give the number of items as requested by pressing the spacebar, with each press moving one item from the top to the center of the screen. Children were encouraged to count aloud when pressing the spacebar or to count the items moved down. Only for this practice trial did children receive verbal feedback from the experimenter. Children received seven test numbers from ‘‘two” to ‘‘eight” that were requested in a random order. Then, children received two more test blocks, each having eight test numbers from ‘‘one” to ‘‘eight” presented in a random order. Children were allowed to restart a

	trial if they thought they had given a wrong number and wanted to correct it regardless of whether the answer was really wrong. The total percentage of correct responses (out of 24 trials) was used as the score for the test. It is important to note that some studies use knower level, or the highest number the child shows evidence of understanding, as the dependent variable on the Give-N task. Operational definitions of knower level vary tremendously by task context and research group, making it challenging to definitively compute and compare across studies. Instead, we chose percentage correct because it can be objectively computed and directly compared across studies.
Schneide et al, 2020	The experimenter provided children with 10 plastic objects (e.g., buttons, bananas, apples, or bears), and a small plastic plate. The experimenter asked them to put *N* items on the plate (trials included 6, 9, 7, and 5, in that order). After the child finished placing a set on the plate, the experimenter asked, "Is that *N?* Can you count to make sure?" If the child answered in the negative, they were permitted to fix the set. If children were able to correctly generate only three of the four requested sets, they were given a second try on the failed trial. Scoring criteria: Children were classified as CP-knowers if they correctly generated sets for all four numbers.
Maruˇsiˇc et al, 2021	Adapted from Wynn (1992). Stimuli consisted of a plastic plate and a set of ten identical colorful buttons. To begin, the experimenter said, "Here are some buttons and here is a plate. I want you to put what I need on the plate. Are you ready?" Then, the experimenter asked the child to put a certain number of buttons onto the plate, starting from the number *one* (e.g., "Can you put one on the plate? Put one on the plate and tell me when you're all done."). When a child gave N buttons (e.g., 1) correctly, the answer was recorded; when they failed, the experimenter asked them to count and give them a chance to correct their response (e.g., "Is that one? Can you count and make sure?"). After the child confirmed their answer or made a correction, the experimenter recorded the final number of buttons the child put onto the plate. The experimenter proceeded and requested N + 1 buttons (e.g., 2). They tested comprehension of labels for 1, 2, 3, 4, 5, 6, 8, and 10 three times each. Scoring criteria: Per Wynn's (1992) criteria:

	1- A child was called an N-knower (e.g., a two-knower) if they successfully gave N buttons (e.g., two) on 2 out of 3 trials, but failed to give N + 1 buttons (e.g., three) on 2 out of 3 trials. 2- At least 2/3 of the trials on which children gave *N*, they did so in response to a request for *N* (and not for some other number).

2. Language questionnaire

Language Input Questionnaire

Child's name		Child's Date of Birth		Today's Date:

Name of the person completing the questionnaire:		Relationship to the child:

Mother's level of education:		Father's level of education:

At which age the child started school/nursery:

Thank you for taking the time to complete the questionnaire. This questionnaire focus on the input that your child receives at home.
Please answer by putting √ in the box that best describes the language environment in the house

	Never	Rarely	Sometimes	Always
1. Is English language spoken within the house?	☐	☐	☐	☐
2. Is Arabic language spoken within the house?	☐	☐	☐	☐
3. Is English language used in school?	☐	☐	☐	☐
4. Is Arabic language used in school?	☐	☐	☐	☐
8. Is English language used when reading/telling stories to/with your child?	☐	☐	☐	☐
9. Is Arabic language used when reading/telling stories to/with your child?	☐	☐	☐	☐
10. Does your child watch iPad/TV in English language?	☐	☐	☐	☐
- **How many hours the child spend on iPad/TV?**	1 hour> ☐	2-3 hours☐	3-4 hours ☐	> 4 hours☐
11. Does your child watch iPad/TV in Arabic language?	☐	☐	☐	☐
- **How many hours the child spend on iPad/TV?**	1 hour> ☐	2-3 hours☐	3-4 hours ☐	> 4 hours☐
12. Is there elderly people in the house? (if "Yes" answer the next Q)	Yes	☐	No	☐
- **Does the child use Arabic language when speaking to the elderly in house?**	☐	☐	☐	☐
13. Is there siblings/other children live in the house? (if "Yes" answer the next Qs)	Yes	☐	No	☐
- **Does the siblings use Arabic when speaking to the child?**	☐	☐	☐	☐
- **Does the siblings use English when speaking to the child?**	☐	☐	☐	☐
14. Is there nanny/baby sitter live in the house? (if "Yes" answer the next Qs)	Yes	☐	No	☐
- **Does the nanny use Arabic when speaking to the child?**	☐	☐	☐	☐
- **Does the nanny use English when speaking to the child?**	☐	☐	☐	☐
15. Which language your child prefer to use	Arabic	☐	English	☐

3.a Items used from the Comprehensive Arabic Language Test equivalent to CELF

Items selected from the Clinical Evaluation of Language Fundamental-Preschool, Second Version (CELF-P2; Wiig et al., 2004) and the Comprehensive Arabic Language Test (CALT; Altaib, 2014), to form the English and Arabic Language Tests.

CELF	CALT	Changes
Basic Concepts	**Commands and understanding of quantity**	
3- point to the one that is empty	1-point to the one that is empty	The type of foods was changed and 'few' was replaced with 'many'. However, all the changes were made systematically, respecting the original sentence.
8- point to the one that shows many	3-point to the one that shows few	
9- point to the one that is full	4-point to the one that is full	
10- point to the one that is alone	5-point to the one that is alone	
Basic concepts	**Commands and attributes**	
5-point to the one that is cold	2-point to the one that is hot	The type of the attributes and foods were changed; for example, hot and dirty was used instead of cold and wet. However, all the changes were made systematically, respecting the original sentence.
12-point to the one who is dry	6-point to the one who is dirty	
Basic concepts	**Commands and concept of "different"**	
17-point to the one that is different	7-point to the one that is different	The type of animal was changed
Basic concept	**Command and the concept of size 'longest'.**	
6-point to the one who is tall	8-point to the longest pencil	
Basic concept	**Command and the concept of equality 'same'.**	
14- point to the ones that are the same	9-point to the ones that are the same	No change was made
Linguistic concept	**Commands and concepts of temporality, location, and inclusion/exclusion.**	
8-point to the elephant next to the giraffe	10-point to the camel next to the monkey	The type of animals was changed
6-when I point to a tiger, you point to a giraffe	12-when I point to a horse, you point to a camel	
15-point to all animals except the bird	13-point to all animals except the cat	
	2 Level/commands and concepts of temporality and temporal + size	
	17-after you point to the dog, point to the cat	The type of animals and the arrangement of commands were changed
	2 Level/ commands and concepts of temporality, location, inclusion/exclusion, and sequence	
12- point to the tortoise before you point a fish	18-point to the horse before you point to the dogs	
19-before you point to the bear, point to the tiger	19-before you point to the cat, point to the chicken	
17- point to either one of the monkeys, and all the tigers	20-point to either one of the dogs, and all the chicken	
2-point to the elephant first, then point to the giraffe		

#	CALT	CELF
1	point to one of the camels	Point to one of the bears
2	point to the one that is empty	point to the one that is empty
3	point to the one that shows few	point to the one that shows many
4	point to the one that is full	point to the one that is full
5	point to the one that is alone	point to the one who is alone
6	point to the one that is hot	point to the one that is cold
7	point to the one who is dirty	point to the one who is dry
8	point to the one that is different	point to the one that is different
9	point to the longest pencil	point to the one who is tall
10	point to the ones that are the same	point to the ones that are the same
11	point to the camel next to the monkey	point to the elephant next to the giraffe
12	when I point to a horse, you point to a camel	when I point to a tiger, you point to a giraffe
13	point to all animals except the cat	point to all animals except the bird
14	after you point to the dog, point to the cat	point to the tortoise before you point to a fish
15	point to the horse before you point to the dogs	before you point to the bear, point to a tiger

16	before you point to the cat, point to the chicken	point to either of the monkeys, and all the tigers
17	point to either one of the dogs, and all the chicken	point to the elephant first, then point to the giraffe

3.b Items used from the Clinical Evaluation of Language Fundamental-Preschool, second version (CELF)

Item number	
Linguistic concepts	
1	Point to one of the bears
2	Point to the elephant first, and then point to the giraffe
6	When I point to a tiger, you point to a giraffe
8	point to the elephant next to the giraffe
12	Point to the tortoise before you point to a fish
15	Point to all the animals except the bird
17	Point to either of the monkeys and all the tigers
19	Before you point to the bear, point to a tiger
Basic concepts	
3	The one that is empty
5	The one that is cold
6	The one that is tall
8	The one that shows many
9	The one that is full
10	The one who is alone
12	The one who is dry
14	The ones that are the same
17	The ones that are different

3.c The scoring sheets of Arabic and English language tests

CALT Scoring Sheet (English version)

Child name: School name:

Date: DOB:

No.	Sentence	Score		
1	point to one of the camels	0	1	NR
2	point to the one that is empty	0	1	NR
3	point to the one that shows few	0	1	NR
4	point to the one that is full	0	1	NR
5	point to the one that is alone	0	1	NR
6	point to the one that is hot	0	1	NR
7	point to the one who is dirty	0	1	NR
8	point to the one that is different	0	1	NR
9	point to the longest pencil	0	1	NR
10	point to the ones that are the same	0	1	NR
11	point to the camel next to the monkey	0	1	NR
12	when I point to a horse, you point to a camel	0	1	NR
13	point to all animals except the cat	0	1	NR
14	after you point to the dog, point to the cat	0	1	NR
15	point to the horse before you point to the dogs	0	1	NR
16	before you point to the cat, point to the chicken	0	1	NR
17	point to either one of the dogs, and all the chicken	0	1	NR
Total raw score				

CALT Scoring Sheet (Arabic version)

Child name: School name:

Date: DOB:

Score			Sentence	No.
NR	1	0	أشر على جمل واحد	**1**
NR	1	0	أشر على الفاضي	**2**
NR	1	0	أشر على اللي فيه شوي \قليل	**3**
NR	1	0	أشر على المليان	**4**
NR	1	0	أشر على اللي لحاله\وحيد	**5**
NR	1	0	أشر على الحار	**6**
NR	1	0	أشر على الوصخ	**7**
NR	1	0	أشر على اللي غير\مختلف	**8**
NR	1	0	أشر على أطول قلم	**9**
NR	1	0	أشر على اللي زي بعض \ مثل بعض\ متشابهين	**10**
NR	1	0	أشر على الجمل اللي جنب القرد	**11**
NR	1	0	إذا أنا أشرت على الحصان, أشر إنت على الجمل	**12**
NR	1	0	أشر على كل الحيوانات ما عدا البسس\ القطو	**13**
NR	1	0	بعد ما تأشر على الكلب أشر على القطوه\البسه	**14**
NR	1	0	أشر على الحصان قبل ما تأشر على الكلاب	**15**
NR	1	0	قبل ما تأشر على القطوه\البسه أشر على الدجاجة	**16**
NR	1	0	أشر على واحد من الكلاب وعلى كل الدجاج	**17**
			Total raw score	

4.a The sets of the NNM task

	Set 1			Set 2		
Trial #	Picture number	English noun	Arabic noun	Picture number	English noun	Arabic noun
1	Car-1	Car-sing	/sajærah/	Tree-3	Tree-dual	/ʃadʒaraten/
2	Tree-3	Tree-plural	/ʔʃdʒar/	Chair-1	Chair- sing	/kursɪ/
3	Bag-1	Bag-sing	/ʃantˤah/	Pen-1	Pen-plural	/ʔqlæm/
4	Spoon-2	Spoon-plural	/malæʕɪq/	Bag-3	Bag-dual	/ʃantˤaten/
5	Pen-1	Pen-sing	/qalam/	Tree-2	Tree-sing	/ʃadʒara/
6	Bag-3	Bag-dual	/ʃantˤaten/	Pen-2	Pen-dual	/qalamen/
7	Chair-1	Chair-sin	/kursɪ/	Car-2	Car-sing	/sajærah/
8	Pen-2	Pen-dual	/qalamen/	Spoon-2	Spoon-plural	/malæʕɪq/
9	Spoon-3	Spoon-sing	/malʕaqa/	Pen-3	Pen-sing	/qalam/
10	Pen-3	Pen-plural	/ʔqlæm/	Chair-2	Chair-dual	/kursɪen/
11	Tree-2	Tree-dual	/ʃadʒaraten/	Bag-2	Bag-plural	/ʃunatˤ/
12	Chair-2	Chair-plural	/karæsɪ/	Spoon-1	Spoon-sing	/malʕaqa/
13	Car-3	Car-dual	/sajærten/	Chair-3	Chair-plural	/karæsɪ/
14	Bag-2	Bag-plural	/ʃunatˤ/	Car-3	Car-dual	/sajærten/
15	Tree-1	Tree-sing	/ʃadʒara/	Bag-1	Bag-sing	/ʃantˤah/
16	Spoon-1	Spoon-dual	/malʕaqten/	Car-2	Car-plural	/sajæræt/

17	Car-2	Car-plural	/sajæræt/	Spoon-3	Spoon- dual	/malʕaqten/
18	Chair-3	Chair-dual	/kursɪen/	Tree-1	Tree-plural	/ʔʃʤar/

4.b Nominal number marking comprehension test scoring sheet

Set 1

Child name: Child school:

Date: DOB:

Trials	Stimulus	Number/morpheme	Picture details	Response √-x	note
1	سيارة	Singular	Car-1		
2	أشجار	Plural	Tree-3		
3	شنطة	Singular	Bag-1		
4	ملاعق	Plural	Spoon-2		
5	قلم	Singular	Pen-1		
6	شنطتين	Dual	Bag-3		
7	كرسي	Singular	Chair-1		
8	قلمين	Dual	Pen-2		
9	ملعقة	Singular	Spoon-3		
10	أقلام	Plural	Pen-3		
11	شجرتين	Dual	Tree-2		
12	كراسي	Plural	Chair-2		
13	سيارتين	Dual	Car-3		
14	شنط	Plural	Bag-2		
15	شجرة	Singular	Tree-1		
16	ملعقتين	Dual	Spoon-1		
17	سيارات	Plural	Car-2		
18	كرسيين	Dual	Chair-3		

Total score:

Singular/6	Dual/6	Plural/6	Total/18

Set 2

Child name: Child school:

Date: DOB:

Trials	Stimulus	Number/morpheme	Picture details	Response √-x	note
1	شجرتين	Dual	Tree-3		
2	كرسي	Singular	Chair-1		
3	أقلام	Plural	Pen-1		
4	شنطتين	Dual	Bag-3		
5	شجرة	Singular	Tree-2		
6	قلمين	Dual	Pen-2		
7	سيارة	Singular	Car-2		
8	ملاعق	Plural	Spoon-2		
9	قلم	Singular	Pen-3		
10	كرسيين	Dual	Chair-2		
11	شنط	Plural	Bag-2		
12	ملعقة	Singular	Spoon-1		
13	كراسي	Plural	Chair-3		
14	سيارتين	Dual	Car-3		
15	شنطة	Singular	Bag-1		
16	سيارات	Plural	Car-1		
17	ملعقتين	Dual	Spoon-3		
18	أشجار	Plural	Tree-1		

Total score:

Singular/6	Dual/6	Plural/6	Total/18

5.a The sets for the Give-N task

	Set 1		Set 2	
Trial #	English number word	Arabic number word	English number word	Arabic number word
1	Five	/xamsah/	Two	/ʔεθnen/
2	Four	/ʔarbaʕah/	Five	/xamsah/
3	Two	/ʔεθnen/	Four	/ʔarbaʕah/
4	Three	/θalæθah/	Three	/θalæθah/
5	Four	/ʔarbaʕah/	Five	/xamsah/
6	Three	/θalæθah/	Two	/ʔεθnen/
7	Two	/ʔεθnen/	Three	/θalæθah/
8	Five	/xamsah/	Four	/ʔarbaʕah/
9	Three	/θalæθah/	Three	/θalæθah/
10	Four	/ʔarbaʕah/	Two	/ʔεθnen/
11	Five	/xamsah/	Four	/ʔarbaʕah/
12	Two	/ʔεθnen/	Five	/xamsah/

5.b Cardinality test and Knowledge of the number word sequence scoring sheets

Set 1 (English)

Child name: Child school:

Date: DOB:

#	Tested number	Response	Type of giving	Note
1	**5**			
2	**4**			
3	**2**			
4	**3**			
5	**4**			
6	**3**			
7	**2**			
8	**5**			
9	**3**			
10	**4**			
11	**5**			
12	**2**			

Total score:

numbers	2	3	4	5	**Total 12**
Results					

Count aloud scoring:

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30

Set 1 (Arabic)

Child name: Child school:

Date: DOB:

#	Tested number	Response	Type of giving	Note
1	**5**			
2	**4**			
3	**2**			
4	**3**			
5	**4**			
6	**3**			
7	**2**			
8	**5**			
9	**3**			
10	**4**			
11	**5**			
12	**2**			

Total score:

numbers	2	3	4	5	**Total 12**
Results					

Count aloud scoring:

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30

Set 2 (English)

Child name: Child school:

Date: DOB:

#	Tested number	Response	Type of giving	Note
1	**2**			
2	**5**			
3	**4**			
4	**3**			
5	**5**			
6	**2**			
7	**3**			
8	**4**			
9	**3**			
10	**2**			
11	**4**			
12	**5**			

Total score:

numbers	2	3	4	5	**Total 12**
Results					

Count aloud scoring:

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30

Set 2 (Arabic)

Child name: Child school:

Date: DOB:

#	Tested number	Response	Type of giving	Note
1	**2**			
2	**5**			
3	**4**			
4	**3**			
5	**5**			
6	**2**			
7	**3**			
8	**4**			
9	**3**			
10	**2**			
11	**4**			
12	**5**			

Total score:

numbers	2	3	4	5	**Total 12**
Results					

Count aloud scoring:

1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30

6.a Sets of number identification task

	Set 1		Set 2	
Trial #	Items	Number tested	Items	Number tested
1	201 vs. 21	201	36 vs. 306	306
2	15 vs. 5	15	7 vs. 3	3
3	4 vs. 6	6	64 vs. 604	604
4	8 vs. 2	2	11 vs. 24	11
5	12 vs 22	22	9 vs. 1	9
6	9 vs. 1	9	12 vs 22	22
7	11 vs. 24	11	8 vs.2	2
8	64 vs. 604	604	4 vs. 6	6
9	7 vs. 3	3	15 vs. 5	15
10	36 vs. 306	306	201 vs. 21	201

	Set 3 (tested on Eastern Arabic Numeral)	
Trial #	Items	Number tested
1	8 vs. 2 ٨ vs. ٢	2 ٢
2	64 vs. 604 ٦٤ vs.٦٠٤	604 ٦٠٤
3	11 vs. 24 ١١ vs. ٢٤	11 ١١
4	201 vs. 21 ٢٠١ vs. ٢١	201 ٢٠١
5	36 vs. 306 ٣٦ vs. ٣٠٦	306 ٣٠٦
6	7 vs. 3	3

	٧ vs. ٣	٣
7	4 vs. 6 ٤ vs. ٦	6 ٦
8	15 vs. 5 ١٥ vs. ٥	15 ١٥
9	9 vs. 1 ٩ vs. ١	9 ٩
10	12 vs 22 ١٢ vs٢٢	22 ٢٢

6.b Number identification task scoring sheets

Set 1 (Western English) Language presentation:

Child name: Child school:

Date: DOB:

Pairs	Response	Note
201 vs. 21		
15 vs. 5		
4 vs. 6		
8 vs. 2		
12 vs 22		
9 vs. 1		
11 vs. 24		
64 vs. 604		
7 vs. 3		
36 vs. 306		

Total score of correct responses:

Single digit (4)	**Double digit (4)**	**Triple digit (2)**	**Total 10**

Set 2 (Western English) Language presentation:

Child name: Child school:

Date: DOB:

Pairs	Response	Note
<u>36</u> vs. 306		
7 vs. <u>3</u>		
64 vs. <u>604</u>		
<u>11</u> vs. 24		
<u>9</u> vs. 1		
12 vs <u>22</u>		
8 vs. <u>2</u>		
4 vs. <u>6</u>		
<u>15</u> vs. 5		
<u>201</u> vs. 21		

Total score of correct responses:

Single digit (4)	**Double digit (4)**	**Triple digit (4)**	**Total 10**

Set 1 (Arabic)

Child name: Child school:

Date: DOB:

ملاحظات	الاجابة	الارقام
		٢١ / ٢٠١
		٥ / ١٥
		٦ / ٤
		٢ / ٨
		٢٢ / ١٢
		١ / ٩
		٢٤ / ١١
		٦٠٤ / ٦٤
		٣ / ٧
		٣٠٦ / ٣٦

Total score of correct responses:

Single digit (4)	**Double digit (4)**	**Triple digit (4)**	**Total 10**

Set 3 (Eastern Arabic numeral)

Child name: Child school:

Date: DOB:

ملاحظات	الاجابة	الارقام
		٢ / ٨
		٦٠٤ / ٦٤
		٢٤ / ١١
		٢١ / ٢٠١
		٣٠٦ / ٣٦
		٣ / ٧
		٦ / ٤
		٥ / ١٥
		١ / ٩
		٢٢ / ١٢

Total score of correct responses:

Single digit (4)	**Double digit (4)**	**Triple digit (4)**	**Total 10**

7. Item analysis of language test performance.

- English language test; Frequency of participants in each of three age groups responding correctly (1) and incorrectly (0) to each item. (17 items)

Quantity:

Item 2→ point to the one that is empty

Item 3→point to the one that shows many

Item 4→point to the one that is full

Item 5→point to the one who is alone

Item 13→point to all animals except the bird

Age range in months	Item 2		Item 3		Item 4		Item 5		Item 13	
	0	1	0	1	0	1	0	1	0	1
33-38	8	7	2	3	8	7	6	9	15	0
38-43	16	5	8	13	11	10	6	15	21	0
43-48	25	16	14	27	20	21	10	31	40	1

-

Temporal:

Item 12→when I point to a tiger, you point to a giraffe

Item 14→point to the tortoise before you point to a fish

Item 15→before you point to the bear, point to a tiger

Item 17→point to the elephant first, then point to the giraffe

Age range in months	Item 12		Item 14		Item 15		Item 17	
	0	1	0	1	0	1	0	1
33-38	8	7	10	5	12	3	13	2
38-43	16	5	16	5	20	1	19	2
43-48	23	18	32	9	37	4	28	13

Equality:

Item 8→point to the one that is different

Item 10→point to the ones that are the same

Age range in months	Item 8	Item 10

	0	1	0	1
33-38	12	3	10	5
38-43	11	10	14	7
43-48	29	12	15	26

Attribution:

Item 6→point to the one that is cold

Item 7→point to the one who is dry

Age range in months	Item 6		Item 7	
	0	1	0	1
33-38	6	9	14	1
38-43	7	14	16	5
43-48	5	36	28	13

-

Coordination:

Item 16→point to either of the monkeys, and all the tigers

Age range in months	Item 16	
	0	1
33-38	15	0
38-43	21	0
43-48	40	1

-

Spatial:

Item 11→point to the elephant next to the giraffe

Age range in months	Item 11	
	0	1
33-38	9	6
38-43	16	5
43-48	23	18

-

Inclusion/ exclusion:

Item 1→Point to one of the bears

Age range in months	Item 1	
	0	1

33-38	**0**	**15**
38-43	**0**	**21**
43-48	**0**	**41**

-

Size:

Item 9→point to the one who is tall

Age range in months	Item 9	
	0	**1**
33-38	**7**	**8**
38-43	**11**	**10**
43-48	**16**	**25**

- Arabic language test; Frequency of participants in each of three age groups responding correctly (1) and incorrectly (0) to each item. (16 items)

Quantity:

Item 2→ أشر على الفاضي

Literal translation (LL): point to the empty

English translation (ET): point to the one that is empty

Item 3→ أشر على اللي فيه شوي\قليل

LL: point to in it little/few

ET: point to the one that shows few

Item 4→ أشر على المليان

LL: point to the full

ET: point to the one that is full

Item 5→ أشر على اللي لحاله\وحيد

LE: point to the alone/lonely

ET: point to the one that is alone

Age range in months	Item 2		Item 3		Item 4		Item 5	
	0	1	0	1	0	1	0	1
33-38	12	3	4	11	3	12	8	7
38-43	10	11	5	16	4	17	9	12
43-48	18	23	10	31	5	36	17	24

Temporal:

Item 12→ إذا أنا أشرت على الحصان, أشر إنت على الجمل

LT: when I point to the horse, point you on the camel

ET: when I point to a horse, you point to a camel

Item 14→ بعد ما تأشر على الكلب أشر على القطوه\البسه

LT: after you point on the dog, point on the cat

ET: after you point to the dog, point to the cat

Item 16→ قبل ما تأشر على القطوه\البسه أشر على الدجاجة

LT: before you point on the cat, point on the chicken

ET: before you point to the cat, point to the chicken

Age range	Item 12		Item 14		Item 16	
	0	1	0	1	0	1
33-38	10	5	15	0	15	0
38-43	15	6	20	1	20	1
43-48	22	19	39	2	39	2

Inclusion & exclusion:

Item 1→ أشر على جمل واحد

LT: point on camel one

ET: point to one of the camels

Item 13→ أشر على كل الحيوانات ما عدا البسس\ القطو

LT: point on all animals except the cat

ET: point to all animals except the cat

Item 17→ أشر على واحد من الكلاب وعلى كل الدجاج

LT: point on one from dogs and on all chickens

ET: point to either one of the dogs, and all the chicken

Age range	Item 1		Item 13		Item 17	
	0	1	0	1	0	1
33-38	0	15	15	0	15	0
38-43	0	21	21	0	21	0
43-48	0	41	40	1	33	8

-

Attribution:

Item 6→ أشر على الحار

LT: point on the hot

ET: point to the one that is hot

Item 7→ أشر على الوصخ

LT: point on the dirty

ET: point to the one who is dirty

Age range	Item 6		Item 7	
	0	1	0	1
33-38	2	13	2	13
38-43	3	18	6	15
43-48	1	40	5	36

Location:

Item 11→ أشر على الجمل اللي جنب القرد

LT: point on the camel that next the monkey

ET: point to the camel next to the monkey

Item 15→ أشر على الحصان قبل ما تأشر على الكلاب

LT: point on the horse before you point on the dogs

ET: point to the horse before you point to the dogs

Age range	Item 11		Item 15	
	0	1	0	1
33-38	8	7	15	0
38-43	11	10	20	1

43-48	**17**	**24**	**36**	**5**

Same/different:

Item 8→ أشر على اللي غير\مختلف

LT: point on that different

ET: point to the one that is different

Item 10→ أشر على اللي زي بعض \ مثل بعض\ متشابهين

LT: point on that same other/ similar

ET: point to the ones that are the same

Age range	**Item 8**		**Item 10**	
	0	**1**	**0**	**1**
33-38	**8**	**7**	**13**	**2**
38-43	**9**	**12**	**21**	**0**
43-48	**15**	**26**	**32**	**9**

Size:

Item 9→ أشر على أطول قلم

LT: point on longest pen

ET: point to the longest pencil

Age range	**Item 9**	
	0	**1**
33-38	**9**	**6**
38-43	**4**	**17**
43-48	**8**	**33**

8. The patterns in the responses each individual gave to each trial of cardinality test

nom	ID	English knower level	Arabic knower level	Age
1	B1	All 2 exc 1	All 2 exc 1	35
2	B5		All 2 exc 2	36
3	B6	All 2 exc 2		39
4	B7	All 2 exc 1	All 2 exc 1	37
5	B8		All 1	40
6	B10	All 1	All 1 exc 1	36
7	B11		All 2 exc 1	38
8	B12	All 1	All 1	38
9	B13	<u>All 1</u>	All 2 exc 2	47
10	B14	All 1		42
11	B18		All 2 exc 1	37
12	B22	All 2 exc 2	All 2 exc 2	47
13	B23	All 2 exc 3	All 2 exc 1	40
	B26	All 2 exc 1		
14	B27	All 2 exc 1	<u>All 1</u>	46
15	B28	All 1 exc 3		44
16	B29	All 2 exc 1		43

17	B31		All 2 exc 1	45
18	B32		All 2 exc 2	39
19	B34		All 2 exc 2	48
20	B40	All 2 exc 3	All 2 exc 2	43
21	B41		All 1 exc 3	44
22	B42	All 2 exc 3		47
23	B43	All 2 exc 3	All 2 exc 2	34
24	B48	All 2 exc 2	All 2 exc 3	36
25	B49	All 1	All 1	36
26	B54		All 1 exc 1	41
27	B55	All 1	All 1	47
28	B56	All 1	All 1	34
29	B57		All 3 exc 3	47
30	B58	All 2 exc 1		45
31	B61	All 1	All 1	37
32	B63	All 1 exc 2	All 2 exc 1	45
33	B65		All 2 exc 2	41
34	B70		All 2	45
35	B71	All 2 exc 3	All 2 exc 2	41

All 1	10	10	
All 2	14	18	
All 2	0	1	

9.

Building up the English transcoding (Western numeral) models:

Model 1:

	Estimate	std.error	t-value	pr (<|t|)
(intercept)	1.53	2.22	0.68	0.49
Age	0.09	0.05	1.91	0.06

Standardised residuals:

Min	**Median**	**Mean**	**Max**
-2.04	-0.12	0.00	2.40
AIC	311.71		

Model 2:

	Estimate	std.error	t-value	pr (<|t|)
(intercept)	0.96	2.00	0.48	0.63
Age	0.09	0.04	1.39	0.16
English language	0.28	0.06	4.42	0.00

Standardised residuals:

Min	**Median**	**Mean**	**Max**
-2.04	-0.12	0.00	2.40
AIC	295.65		

Model 3:

	Estimate	std.error	t-value	pr (<|t|)
(intercept)	0.86	1.99	0.43	0.67
Age	0.07	0.04	1.58	0.11
English language	0.31	0.06	4.59	0.00
English Max count	-0.06	0.05	-1.20	0.23

Standardised residuals:

Min	Median	Mean	Max
-2.04	-0.12	0.00	2.40
AIC	296.14		

Model 4:

	Estimate	std.error	t-value	pr (<|t|)
(intercept)	2.36	1.93	1.22	0.22
Age	0.04	0.04	0.89	0.37
English language	0.23	0.06	3.44	0.00
English max count	-0.10	0.05	-2.00	0.05
English cardinality	0.19	0.06	3.23	0.00

Standardised residuals:

Min	Median	Mean	Max
-2.04	-0.12	0.00	2.40
AIC	287.72		

Model 5:

	Estimate	std.error	t-value	pr (<|t|)
(intercept)	3.36	2.04	1.64	0.10
Age	0.07	0.04	1.58	0.11
English Max count	-0.07	0.05	-1.20	0.20
English cardinality	0.27	0.06	4.41	0.00

Standardised residuals:

Min	Median	Mean	Max
-2.04	-0.12	0.00	2.40
AIC	297.44		

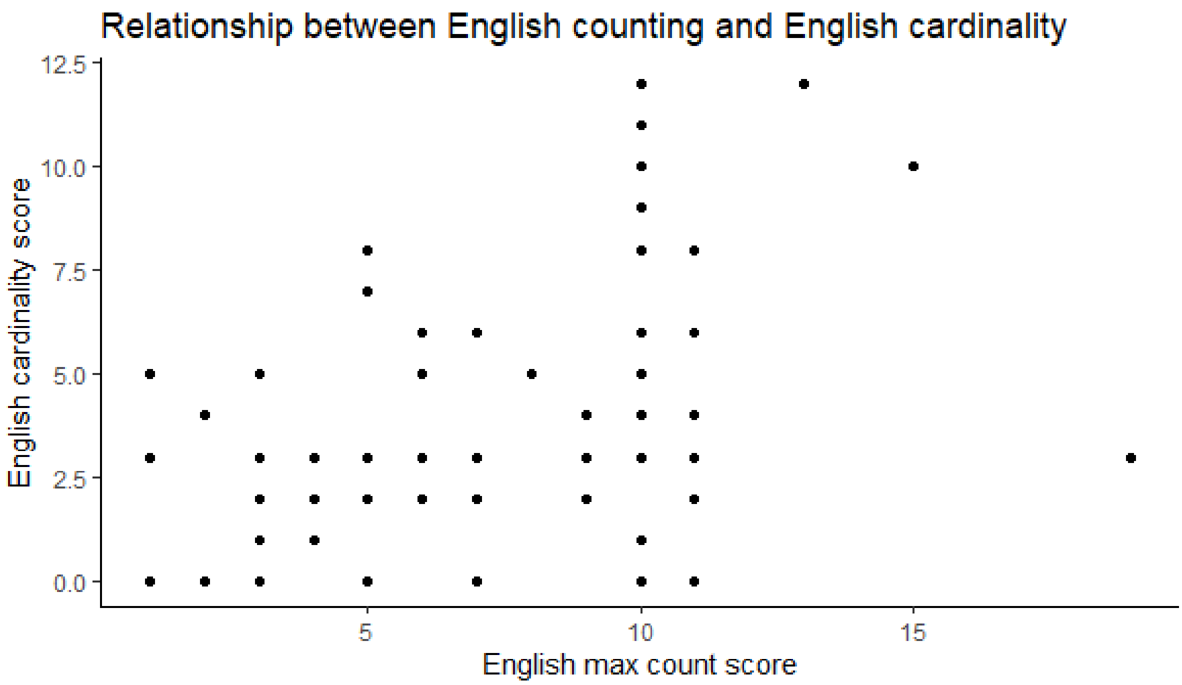
Model 6:

	Estimate	std.error	t-value	pr (<|t|)
(intercept)	2.30	1.97	1.16	0.24
Age	0.03	0.04	0.665	0.51
English language	0.20	0.06	3.05	0.00
English cardinality	0.16	0.06	2.78	0.01

Standardised residuals:

Min	Median	Mean	Max
-2.04	-0.12	0.00	2.40
AIC	289.89		

10. *scatter plot to investigate the presence of outliers*



11.

The scatterplot shows that there is an outlier in the sample. After going through the datasheet, it appears that one participant's max count was 19, and the English cardinality score was 3, which is considered an outlier.

The model after removing the outlier:

	Estimate	std.error	t-value	pr (<|t|)
(intercept)	2.34	1.95	1.19	0.23
Age	0.04	0.04	0.90	0.37
English language	0.23	0.07	3.39	0.00
English max count	-0.11	0.06	-1.84	0.06
English cardinality	0.19	0.06	3.20	0.00

Standardised residuals:

Min	**Median**	**Mean**	**Max**
-3.52	-0.19	0.00	3.83
AIC	285.10		