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# A kinematic study to assess graphomotor skills and their relationship to vocabulary, reading fluency, orthographic processing and spelling in bilingual Iranian-German children


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**Abstract**

The primary objective of this study was to investigate the contributions of reading, vocabulary, orthographic skills, and the kinematic processes of graphomotor skills to the spelling skills of bilingual Persian-German students. A sample of 10 bilingual students (mean age = 10.6, SD = 1.35) from Grades 3 and 4 in a German school participated in assessments of spelling, orthographic skills, reading, vocabulary and graphomotor skills. The findings revealed that, while spelling proficiency in these bilingual students was influenced by reading, vocabulary, and orthographic knowledge, graphomotor skills emerged as a significant predictor of spelling performance. Moreover, graphomotor skills were found to be a strong predictor of spelling, particularly in the native language, and also influenced the spelling of the second language based on the duration of exposure. Lastly, the effect size of orthographic and graphomotor skills on spelling was found to be greater for the second language than for the native language.

# 1 Chapter I: Introduction

## 1.1 Introduction

It is now widely recognized that cognitive skills are a prerequisite for language skills and conversely, so language is a significant factor influencing cognitive processes, particularly when considering the effect of foundational language skills (vocabulary and grammatical knowledge) on foundational cognitive skills (working memory and attention) (Blank, 1974; Carruthers, 2002a). Being proficient in everyday use of more than one language, which is referred to as bilingualism, is often considered to yield positive effects upon cognitive functioning (Bialystok & Craik, 2010; Hartanto et al., 2019; Valian, 2015). This is because the constant engagement with two language systems trains the brain, leading to superior performance in tasks requiring cognitive control, planning, attention, and task switching (Abutalebi & Green∗, 2008; Bialystok, 2011).

While some research has demonstrated that bilingualism positively impacts cognitive functions—such as improved cognitive control, attention, working memory, and motor coordination due to the cognitive demands of language switching—other studies report no significant effects. The advantages of bilingualism, particularly in relation to executive functions, appear to be task- and age-dependent. For instance, some scholars question the overall significance of these findings, suggesting potential issues with publication bias. As a result, the current literature remains inconclusive, presenting mixed evidence on the cognitive benefits of bilingualism (Abutalebi & Green∗, 2008; Bialystok & Craik, 2010; Paap et al., 2015).

Adding to this complexity, research has shown that bilinguals with different language systems, such as Welsh-English or Chinese-English, display distinct cognitive outcomes. For example, Welsh-English bilingual children were found to have poorer handwriting legibility compared to monolingual peers, highlighting the influence of spelling ability over handwriting experience. Similarly, Chinese-English bilinguals with lower proficiency in English rely more on sublexical processing when learning new words, suggesting that differences between language systems can impact cognitive processes like word recognition and writing (Caravolas et al., 2020a; Fu et al., 2024).

In a similar vein, Persian-German bilinguals experience unique cognitive and graphomotor challenges due to the interaction between distinct writing systems. Persian (Farsi) and German,

which belong to distinct language families, demonstrate unique orthographic and phonological characteristics. Persian, an Indo-Iranian language, utilizes an Abjad script derived from Arabic, written from right to left. This script primarily represents consonants, with vowels being implicit and sometimes indicated by diacritics. The need to infer vowel sounds from context requires significant phonological processing, which influences reading and spelling strategies (Baluch, 2013; Bakhtiar & Weekes, 2015; Windfuhr, 2009). In contrast, German uses the Latin alphabet and is written from left to right, with a relatively transparent phoneme-grapheme correspondence. This transparency facilitates a more straightforward decoding process, making German orthography easier to learn (Ziegler & Goswami, 2005) compared to Persian.

The structural differences between these languages suggest that bilingual children develop distinct reading and spelling strategies for each language (Bialystok, 2007; D'Angiulli et al., 2001a).

Consequently, these diverse writing systems challenge bilinguals to adapt to varying orthographic rules, which enhance cognitive flexibility, phonological awareness, and orthographic processing Additionally, working with different scripts improves eye-hand coordination and fine motor skills. (Buchweitz & Prat, 2013; Ferris & Hedgcock, 2023). Thus, bilingual children must manage the complexities of both scripts, which can lead to enhanced phonological awareness, improved orthographic processing, and greater movement skills. Additionally, this can also improve executive functions and better cognitive control (Xie et al., 2022). However, it is important to note that they may also face challenges in harmonizing their cognitive and motor skills across these languages.

For young writers, the cognitive load associated with spelling retrieval can impact writing fluidity (Schwanenflugel et al., 2006a). Danna et al., (2022) suggest that children who manage orthographic systems may face additional cognitive challenges that affect their graphomotor skills and handwriting fluency. Similarly, research has confirmed that bilingual children, who navigate two orthographic systems, may experience heightened cognitive demands that influence their handwriting fluency (Bialystok et al., 2005; Caravolas et al., 2020b). This line of inquiry helps researchers understand how bilingualism impacts literacy development and cognitive functioning, particularly in contexts involving diverse writing systems (Bialystok, 2011; Bialystok & Craik, 2010).

In this context, spelling—an essential aspect of writing—reflects the complex interplay between cognitive, motor, and linguistic skills, including phonological awareness, orthographic processing, reading, and vocabulary knowledge (Caravolas, 2004; Dębska et al., 2019). Specifically, it involves translating spoken language into written form, requiring a precise understanding of the sounds, letters, and patterns that constitute words. Moreover, it requires the combination of motor skills with cognitive skills. Poor spelling can hinder effective communication and may reflect underlying issues in language processing, vocabulary, or cognitive skills (Ehri, 2014).

Research indicates that proficient spelling is not only a reflection of orthographic knowledge but also of the ability to retrieve and manipulate phonological information, emphasizing the interconnectedness of these cognitive processes (Graham et al., 2021). Furthermore, spelling development follows a predictable trajectory, influenced by factors such as language exposure, phonological awareness, and orthographic knowledge. As children develop literacy skills, they gradually move from phonetic spellings to more conventional forms (Georgiou et al., 2020; Treiman et al., 1993).

In bilingual contexts, these challenges can be more complex. The challenges of spelling may be compounded by the interaction of multiple orthographic systems. Bilingual children often face unique challenges in spelling due to the differing rules and conventions of their languages, which can lead to transfer effects and interference between languages. For instance, they may apply spelling rules from one language to another, resulting in errors or inconsistencies in their writing (Bialystok & Hakuta, 1999; Olsen, 1999). Thus, understanding these challenges is crucial for developing effective literacy interventions that support bilingual learners in their spelling development and overall language proficiency.

Central to this process is orthographic processing, which refers to the cognitive ability to recognize and process written words and their components, such as letters, letter patterns, and whole words. It plays a critical role in fluent reading and writing by enabling individuals to perceive, store, and recall spelling patterns and letter sequences (Arab-Moghaddam & Senechal, 2001; Cunningham et al., 2002; Rahbari et al., 2007; Rothe et al., 2015; Rothe et al., 2024). Efficient orthographic processing enhances word recognition and decoding abilities, which are crucial for reading fluency, comprehension, and accurate spelling (Rothe et al., 2024).

In languages with high grapheme-phoneme consistency, such as Persian, decoding words via the nonlexical route often leads to correct pronunciation (Gholamain & Geva, 1999). However, repeated decoding strengthens word-specific representations, essential for fluent reading and accurate spelling. Orthographic processing is therefore recognized as a key predictor of literacy outcomes (Cunningham et al., 2002).

Researchers generally agree that orthographic processing consists of two components: general orthographic knowledge (sensitivity to permissible letter patterns) and word-specific knowledge (correct spelling of individual words) (Hagiliassis et al., 2006; Rothe et al., 2015; Rothe et al., 2024). General orthographic knowledge is often assessed through nonword forced-choice tasks, while word-specific knowledge is measured using tasks like the Orthographic Choice Task (Rothe et al., 2024). Both contribute to literacy development, though word-specific knowledge is more strongly linked to spelling (Arab-Moghaddam & Senechal, 2001; Rothe et al., 2015, 2024; Zarić et al., 2021), particularly in languages with complex orthographies like Persian and English (Arab-Moghaddam & Senechal, 2001; Rahbari et al., 2007). This distinction is particularly relevant for bilingual children navigating distinct writing systems with unique orthographic rules.

Reading fluency, in turn, encompasses the ability to read connected text accurately and at a conversational rate, linking the skills of handwriting and orthographic processing to overall literacy development. Reading fluency is the ability to read connected text accurately, at a conversational rate, with appropriate expression and prosody (Álvarez-Cañizo et al., 2015; Hudson et al., 2005a; Kuhn et al., 2010; T. Rasinski et al., 2011). It involves several cognitive processes and develops progressively, often starting with slow, effortful accuracy. Gradually, word and text reading become quicker and more automatic, occurring without conscious effort (Schwanenflugel et al., 2006a). A fluent reader demonstrates this capability consistently over time, retains the skill even without regular practice, and applies it across various texts (Kuhn et al., 2010; Schwanenflugel et al., 2006b). Fluent reading acts as a crucial bridge between basic decoding skills and advanced comprehension, allowing readers to focus cognitive resources on understanding the text rather than focusing solely on decoding words (Álvarez-Cañizo et al., 2015). Hudson et al., (2005b) highlight that fluency encompasses accuracy, rate, and prosody, facilitating a smoother reading experience and reducing cognitive load. By integrating these elements, fluency supports deeper comprehension and efficient reading, illustrating its integral role in literacy development

and its importance in achieving proficient and expressive reading (Miller & Schwanenflugel, 2008; T. V. Rasinski et al., 2005).

Vocabulary knowledge is another fundamental component of language processing that significantly impacts word recognition, reading comprehension, and spelling. Vocabulary refers to the knowledge of words, their meanings, and their applications. This knowledge is essential for reading and writing because it enables the transfer of oral language skills to written language proficiency. Vocabulary is not just about knowing a large number of words, but also understanding the various meanings and uses of those words (Biemiller & Boote, 2006; Reed et al., 2016a). It encompasses an individual's understanding of lexical meanings and the conceptual connections associated with words. Research highlights that a robust vocabulary facilitates more effective word recognition and enhances reading comprehension (Aarnoutse et al., 2001). In the context of spelling, vocabulary knowledge plays a crucial role as it aids in converting spoken language into written symbols, which is essential for accurate orthographic processing (Ehri, 2014). Cunningham et al., (2002) note that orthographic processing skills, which are influenced by vocabulary, account for substantial variance in reading ability. Thus, a well-developed vocabulary not only supports the ability to decode and understand written text but also contributes to the fluency and accuracy of spelling, making it a vital area of focus in evaluating language skills in bilingual children.

While cognitive-linguistic processes like spelling, reading fluency, orthographic processing, and vocabulary play critical roles in language acquisition, the motor aspect of writing, particularly graphomotor skills, also significantly contributes to a child's overall writing proficiency.

Graphomotor skills, essential for tasks like writing, involve the coordination of hand movements with cognitive processes (Christensen, 2005; Deane et al., 2008). These fine motor abilities are critical for handwriting fluency, which is necessary for effective written communication and the integration of orthographic and linguistic processes (Barghandan et al., 2023; Danna et al., 2022). In bilingual children, mastering graphomotor skills for two distinct writing systems further complicates this development, as both linguistic and motor demands must be managed simultaneously. Proficiency in graphomotor abilities is crucial for tasks like writing and drawing and is linked to broader cognitive and academic achievements (Sinvani & Gilboa, 2023; Vasileva, 2023). Before handwriting becomes automatic, children are particularly sensitive to the demands of orthographic retrieval, which can interfere with their motor execution of writing. This

interaction between orthographic processing and motor constraints plays a significant role in the development of writing skills (Barghandan et al., 2023; Danna et al., 2022, p. 202; Ghanamah et al., 2023). A key component of graphomotor function is the number of velocity inversions (NIV) per stroke, a measure of writing fluidity (Taverna, Tremolada, Tosetto, et al., 2020). Efficient handwriting is linked to accurate spelling, as it allows children to focus more on language retrieval and less on motor execution (Berninger et al., 2002).

Studies have shown that children with poor graphomotor skills often struggle with spelling and writing fluency (Medwell & Wray, 2008; Suggate et al., 2016a; Suggate et al., 2019; Wicki et al., 2014). In bilingual children, who must navigate distinct orthographic rules for each language, mastering graphomotor skills becomes even more critical for reducing cognitive load and improving spelling accuracy. These fine motor skills are important not only for legibility but also for enabling children to focus on retrieving correct spelling patterns (Maldarelli et al., 2015; Suggate et al., 2016a).

Given these complexities, it is essential to explore how bilingualism enhances cognitive functions and shapes unique developmental trajectories. Bilingualism requires executive skills and cognitive flexibility due to the constant engagement of managing two languages (Bialystok & Craik, 2010; Hartanto et al., 2019; Kroll & Bialystok, 2013; Mechelli et al., 2004; Valian, 2015). For bilinguals navigating writing systems like Persian and German, the impact on cognitive and motor abilities is even more pronounced. Persian, with its Abjad script and implicit vowels (Daniels, 2013), and German, with its transparent Latin alphabet (Schüppert et al., 2017), present different learning challenges that refine cognitive and graphomotor skills. Examining the interplay between these diverse writing systems and bilingualism offers valuable insights into how language and script complexity shape cognitive and motor development.

Despite extensive research on the cognitive and linguistic factors that influence spelling and literacy development, few studies have examined the role of graphomotor skills in language contexts (Maldarelli et al., 2015; Tucha et al., 2008). While it is well-established that cognitive functions like orthographic processing and vocabulary knowledge contribute to literacy outcomes, there is a notable gap in understanding how fine motor skills—specifically graphomotor abilities—affect spelling performance in bilingual children navigating distinct writing systems. For instance, Persian's right-to-left script with implicit vowel representation presents unique challenges

compared to the left-to-right Latin alphabet used in German. These differences may require children to develop distinct graphomotor strategies for each language, which could uniquely impact their spelling performance.

This study aims to address this gap by investigating whether graphomotor skills, particularly the number of velocity inversions (NIV) per stroke, can predict spelling performance in bilingual children beyond cognitive factors such as reading fluency, vocabulary, and orthographic knowledge. By focusing on the motor aspects of writing, this research offers a novel perspective in the study of literacy development, especially in bilingual populations who must navigate the complexities of multiple writing systems. Understanding how motor control interacts with cognitive processes in spelling performance will provide new insights that could inform educational strategies tailored to the needs of bilingual learners.

Furthermore, the findings of this study could have broader implications for designing targeted interventions to support children with neurodevelopmental disorders such as developmental coordination disorders, dysgraphia, and dyslexia. Exploring the role of graphomotor skills in these contexts may lead to improved instructional strategies that address both the cognitive and motor challenges faced by bilingual learners, ultimately enhancing their academic outcomes and overall literacy development.

### 1.2 Hypothesis:

Prediction of spelling performance:

1. Linear model with Persian spelling performance as dependent variable and Persian Language Variables as predictors

    i. Persian vocabulary, Persian reading fluency, Persian orthographic processing will be significant predictor of Persian spelling performance

    ii. NIV of Persian sentence and letter writing will significantly predict Persian spelling performance above and beyond the predictors like Persian vocabulary, Persian reading, Persian orthographic processing

2. Linear model with German spelling performance as dependent variable and German Language Variables as predictors

i. German vocabulary, German reading fluency, German orthographic processing will be significant predictor of German spelling performance

ii. NIV of German sentence and letter writing will significantly predict German spelling performance above and beyond the predictors like German vocabulary, German reading, German orthographic processing

iii. NIV of German sentence and letter writing will significantly predict German spelling performance, particularly in the context of the interaction with immigration

3. Effect sizes of NIV and orthographic processing will be larger for Persian spelling performance than for German spelling performance

# 2 Chapter II: Literature review

## 2.1 Language

Language is a complex structured system of communication and the basis of human interaction. The communication is required encoding and decoding the messages. Language is the communication of thoughts and ideas in an optional system of symbols that are used according to certain rules to convey a meaning. Language serves a dual function, while it can be considered as a cognition, allowing for thought and understanding, it is a medium of communication, facilitating social interaction (Carruthers, 2002b; Vygotsky, 2012). As Noam Chomsky's theory of generative grammar suggests, humans have an innate ability to acquire language due to a "universal grammar" that underlies all human languages, providing a framework that allows for the infinite combination of words and sentences (Chomsky, 2002).

From a biological standpoint, language is also considered a unique human capacity that has evolved to support advanced cognitive and social functions. The biolinguistic approach, often associated with Chomsky and his followers, argues that language is rooted in a specialized, innate component of the human mind, which distinguishes it from other forms of animal communication. Research in evolutionary linguistics explores how the human capacity for language has developed through natural selection and cultural evolution, emphasizing both the universality and diversity of linguistic forms across human societies. This scientific perspective positions language as a cornerstone of human evolution, critical for complex thought, social coordination, and cultural transmission (Chomsky, 2002).

From a cognitive perspective, language is seen as a complex mental faculty involving various cognitive processes such as perception, memory, attention, and reasoning. Cognitive scientists view language as a system of mental representations that enables individuals to encode, store, and manipulate information. Steven Pinker’s theory of "The Language Instinct" posits that language is an innate cognitive ability, shaped by evolutionary pressures to enhance communication and social cooperation (Pinker, 1994). It functions as a "cognitive tool," allowing humans to conceptualize abstract ideas, categorize experiences, and engage in higher-order thinking. Similarly, Vygotsky’s sociocultural theory emphasizes that language not only facilitates communication but also shapes cognitive development by providing a medium for internal dialogue, reflection, and the

construction of meaning (Vygotsky, 1987). Neurolinguistics supports these views by showing how specific brain regions, such as Broca's and Wernicke's areas, specialize in language production and comprehension. Thus, language is both a cognitive faculty and a social construct, evolving over time and influenced by cultural, social, and biological factors (Wong et al., 2016).

Cognitive linguistics, a branch of cognitive science, argues that language is not an autonomous module of the mind, as Chomsky's generative grammar suggests, but rather is deeply interconnected with general cognitive processes (Evans, 2012; Jackendoff, 2007). From a neuroscience perspective, language is understood as a function of the brain that involves a network of specialized regions that work together to process and produce linguistic information. Research in neurolinguistics has identified key brain areas involved in language, such as Broca's area, which is associated with language production and syntactic processing, and Wernicke's area, which is crucial for language comprehension and semantic processing. These regions are connected by the arcuate fasciculus, a bundle of nerve fibers that enables coordination between language production and comprehension areas (Friederici, 2015; Wong et al., 2016).

Moreover, modern neuroscience research using brain imaging techniques like fMRI (functional magnetic resonance imaging) and ERP (event-related potentials) has expanded our understanding of how language is processed in the brain. It has been discovered that language functions are not localized to just a few regions; instead, they are distributed across a broader network, including areas involved in memory, attention, and motor planning. The dual-stream model of language processing, proposed by researchers like Hickok and Poeppel, suggests that there are two pathways in the brain: a dorsal stream for mapping sounds to motor actions (speech production) and a ventral stream for mapping sounds to meaning (comprehension). This model illustrates that language is an integrative function that relies on the dynamic interaction of multiple brain systems, further highlighting its complexity and the importance of both the left and right hemispheres in processing different aspects of language, such as prosody, emotion, and syntax (Hickok & Poeppel, 2007).

Both perspectives, cognitive and neuroscience, provide a comprehensive understanding of language as an intricate system shaped by both mental processes and neural structures, underscoring its critical role in human cognition and social behavior.

## 2.2 Bilingualism

Bilingualism can be defined as the ability to communicate effectively in two languages, either by learning both languages simultaneously from birth or sequentially through exposure to one language first and then another (Bialystok, 2001; De Houwer, 2009). Simultaneous bilinguals acquire two languages concurrently, typically before the age of three, whereas sequential bilinguals learn their second language later in life (Genesee, 2003). The level of proficiency and fluency in both languages can vary among bilingual individuals, and the degree of exposure and usage of each language plays a significant role in developing linguistic competence (Grosjean, 2010). Furthermore, balanced bilinguals possess equal proficiency in both languages, whereas dominant bilinguals have a more robust command of one language over the other (Lambert, 1955). Bilingualism is a complex linguistic phenomenon that encompasses cognitive, social, and cultural dimensions, ultimately shaping an individual's language development and overall cognitive processes (Bialystok, 2001; Wei, 2020).

Early bilingualism has been found to impact the development of the language network in the brain positively, shaping its maturation process (Bialystok et al., 2012). During the first few years of life, the brain is highly sensitive to sensory experiences, which activate parvalbumin cells in the cortex and promote functional and structural changes under the influence of various triggers and brakes (Cisneros-Franco et al., 2020; Takesian & Hensch, 2013; Werker & Hensch, 2015). As neuronal maturation occurs rapidly during these early stages, simultaneous exposure to multiple languages enhances the complexity of sociolinguistic and sensorimotor processing, extending or delaying the closing of sensitive periods for language development, particularly in phonology (Berken et al., 2017). Consequently, multilingual exposure takes advantage of developmental neuroplasticity by optimizing the mapping between the sound structures of languages. Although macroscopic differences in brain structures appear subtle among adults with comparable proficiency levels in both languages, there are distinct neural network efficiency differences due to developmental variations between simultaneous and sequential bilinguals (Berken et al., 2016, 2017; Peñaloza et al., 2019). Therefore, exposure to multiple languages from birth may serve as a promising approach to enhance cognitive and language processes, ultimately facilitating overall brain development.

Bilingualism encompasses a wide variety of experiences, where individuals actively use more than one language, but the ways in which they acquire and utilize these languages differ. Some are exposed to two languages from birth, while others acquire a second language later in life, once their native language has been firmly established. Despite these differences, research demonstrates that both languages remain active when bilinguals listen, speak, read, or even plan speech in either language (Kroll et al., 2014). This simultaneous activation leads to cross-linguistic influences, even when speakers are unaware of them, as both languages compete for cognitive resources. Bilinguals develop mechanisms to control this competition, minimizing errors in language use (Dijkstra, & Kroll, 2005; Kroll et al., 2015; Marian & Spivey, 2003). Moreover, while it was once thought that the second language (L2) does not influence the native language (L1), recent findings suggest otherwise. As proficiency in L2 increases, it begins to affect L1, indicating a bidirectional influence between the two languages (Bergmann et al., 2015; Bernolet et al., 2013; Kartushina & Martin, 2019). This interaction also highlights the shared neural resources for processing both languages, with differences in brain activation being more related to the need for language control than to separate representations of L1 and L2 (Abutalebi & Green, 2007; Wattendorf et al., 2014).

### 2.3 Spelling

Writing is one of the highest forms of communication, which is learned after other forms in the hierarchy of language abilities. Writing is an intentional act, that is, one of the most complex acts that a child must achieve. This acquisition requires The development of the basic motor capacities is sufficient, the ability to hold the writing tool in a way that is firm and flexible at the same time, and guiding it in very specific directions, providing the support necessary for the hand and arm, and besides, this action also requires the creation of movement coordination (Deane et al., 2008b).

In fact, the writing with some very specific skills, including the ability to maintain the topic in the mind, organizing the subject in the form of words, drawing the shape of each letter and word, the correct use of writing tools, sufficient visual and motor memory is involved. Children's writing reflects the ability to organize, store and recall words, that they can read (Lunenburg & Lunenburg, 2014).

Spelling is an essential aspect of literacy, involving the correct writing of words, and mastering it requires the use of various cognitive processes. These processes, collectively referred to as spelling processing, include recognizing spelling patterns, understanding spelling rules, and using verbal

memory effectively. Together, these skills help individuals improve their spelling accuracy and reduce mistakes (Henderson & Templeton, 1986).

Spelling processing is defined as the set of mental stages and abilities that enable people to write words correctly. The key components of spelling processing are identifying spelling patterns and understanding spelling rules. Identifying spelling patterns refers to recognizing common letter combinations and structures in words, while understanding spelling rules involves knowing the principles that govern correct spelling, such as the use of prefixes, suffixes, or phonetic changes (Henderson & Templeton, 1986; Reed, 2012)

Identifying and using spelling patterns is a crucial part of spelling processing. Through pattern recognition, individuals can identify familiar combinations of letters, like "tion" or "ing," that often appear in English words. Recognizing these patterns makes it easier to spell words correctly by reducing uncertainty or confusion when writing. Additionally, people can apply these recognized patterns to new or unfamiliar words, which enhances their spelling accuracy (Ehri, 1997; Graham et al., 2000).

Understanding and applying spelling rules is another vital aspect. Spelling rules guide how words are constructed, including when to change phonetic elements or how to use specific prefixes and suffixes. For example, rules like changing “y” to “i” before adding a suffix (e.g., "happy" becomes "happiness") or knowing how certain letter combinations work (e.g., "ie" versus "ei") are critical to spelling words correctly. Spelling rules are especially important for language learners or when writing complex texts, as they provide a framework for accurate word formation (Joshi et al., 2008; Treiman & Kessler, 2014).

Verbal memory plays an important role in spelling processing by helping individuals recall the correct spelling of words. This involves both short-term and long-term memory. Short-term memory helps with immediate recall of recently encountered words, while long-term memory allows for retention and retrieval of words learned over time. Strengthening verbal memory through practice and repetition improves a person’s ability to remember and apply correct spelling, thereby reducing errors (Bourassa & Treiman, 2001; Jongejan et al., 2007; Pickering, 2005). spelling is not just about memorizing how words look, but about engaging in a set of cognitive processes that include identifying patterns, understanding rules, and using memory. These

processes work together to enhance spelling skills and help individuals write accurately. By strengthening spelling processing, individuals can improve their spelling performance and reduce errors, making spelling an integral part of effective written communication (O'Sullivan, 2000).

In conclusion, Spelling is the ability to form words by correctly arranging letters according to the conventions of a language's writing system. This process requires an understanding of both phonological (sound) and morphological (meaning) features of the language (Verhoeven & Carlisle, 2006). Proficient spelling involves recognizing and applying the rules and patterns that govern the combination and arrangement of letters, which can include graphemic (letter-related) and graphotactic (letter arrangement) principles (Pacton et al., 2005). Effective spelling is influenced by various factors, including language development disorders, phonological awareness, and co-occurring literacy difficulties. Mastery of spelling not only aids in the writing process but also enhances reading fluency, as a solid grasp of word spelling helps to reinforce mental representations of words. As such, spelling is a critical skill for successful communication and literacy in modern societies (Dich & Cohn, 2013; Bourassa & Treiman, 2001; Verhoeven & Carlisle, 2006).

### 2.3.1 Spelling Theory

The study of spelling encompasses various theoretical frameworks that highlight the interplay between different cognitive processes. The dual-route model, developed by researchers such as (Barry, 1994) and (Rapp, 2015), posits that individuals spell words through two distinct pathways: the lexical route, which retrieves word spellings from memory for familiar words, and the nonlexical route, which generates spellings based on phoneme-to-spelling rules for unfamiliar words. This model distinguishes between regular words, which align predictably with phoneme mappings (e.g., "hat"), and irregular words that require lexical retrieval due to their unpredictable nature (e.g., "have"). As children develop, they initially rely more on the nonlexical route and gradually transition to the lexical route as they accumulate memorized spellings. However, critics argue that this framework oversimplifies the complexities of writing systems, particularly when dealing with exceptions that could be explained through graphotactic and morphological principles. In contrast, the Integration of Multiple Patterns (IMP) framework proposed by Treiman and Kessler (2014b) emphasizes that spelling involves a variety of interrelated, probabilistic

patterns rather than strict rules. This model suggests that spellers draw upon context-free links, context-sensitive phonological patterns, graphotactic principles, and morphological knowledge, highlighting the importance of exposure and adaptation in learning spellings. In line with this perspective, graphotactics examines the arrangements of letters within a language, revealing that even prephonological spellers demonstrate an awareness of basic graphotactic principles, such as the horizontal organization of text and preferences for varied letter arrangements. Graphotactic knowledge not only influences young children but also persists into adulthood, impacting spelling choices based on structural patterns rather than solely phonological rules. Furthermore, while phonological awareness is crucial in alphabetic writing systems, it presents challenges, particularly as mappings between phonemes and letters can vary contextually. Children often make early spelling errors by omitting letters in consonant clusters or producing unconventional spellings influenced by phonetic pronunciation. As they mature, children begin to show sensitivity to phonological context, reinforcing the statistical learning aspect of spelling development. Lastly, understanding the morphological structure of words aids spelling accuracy, particularly in languages like English and French, where morphemes govern consistent letter patterns. This morphological awareness develops over time, with children beginning to apply morphological rules around ages 7 to 9, and even adults can struggle to apply these rules consistently. Collectively, these theoretical perspectives on spelling elucidate a multifaceted understanding of how spelling abilities develop, considering not only phonological and memory-based processes but also the influence of visual structure, context, and morpheme understanding in various languages (Treiman, 2017).

### 2.3.2 Linguistic predictors of spelling performance

1. Phonological Awareness: phonological awareness refers to a person's ability to identify and analyze sounds and linguistic structures. This skill includes recognizing and combining sounds, syllables, and words. A strong linguistic awareness helps a person to better understand and apply spelling rules (Gillon, 2005).

2. Phonemic Awareness: Phonemic awareness refers to the ability to identify and process specific sounds (vocabulary) in words. This ability is especially important for learning the correct spelling

of complex words. Research shows that phonological awareness is associated with better spelling performance (Norris & Hoffman, 2002).

3. Vocabulary Knowledge: Vocabulary knowledge refers to the amount of words known and usable by a person. A larger vocabulary can help a person write more words correctly and be more successful in spelling (Reed et al., 2016b; Schmitt, 2014).

4. Structural writing ability (Orthographic Knowledge): Structural writing ability is related to understanding spelling rules and patterns in the language. This skill includes identifying how to write words correctly and following spelling rules. A strong structured writing ability helps a person to write words correctly and avoid spelling mistakes (Ehri, 2014).

### 2.4 Kinematic processes

Kinematic processes are integral to understanding the motor control involved in writing and spelling, particularly in children. These processes encompass the movement mechanics and the neural pathways that govern the fine motor skills necessary for handwriting. In the context of writing, kinematics refers to the study of motion without considering the forces that cause it, focusing on parameters such as velocity, acceleration, and the trajectory of hand movements (Palmis et al., 2019).

Children's writing development can be analyzed through kinematic studies, which often employ tools like digitizing tablets or motion capture systems to record and analyze handwriting movements. These analyses provide insights into the coordination and smoothness of hand movements, revealing crucial aspects of motor learning and control. For instance, during the early stages of writing, children display slower, more irregular movements as they learn to coordinate their muscles. Over time, with practice and maturation, their movements become more fluid and consistent, reflecting improved motor control and memory integration (Gerth & Festman, 2023; Rueckriegel et al., 2008a; Palmis et al., 2019). Writing involves complex motor sequences that are planned and executed by the brain. The prefrontal cortex is responsible for planning the writing movement, while the motor cortex executes it. Sensory feedback from the eyes and hands is continuously integrated to adjust the motion in real-time, ensuring accuracy. Disruptions in these processes can lead to difficulties in writing, commonly observed in conditions such as dysgraphia,

where children struggle with the physical act of writing despite normal intellectual abilities (Biotteau et al., 2019; Danna & Velay, 2015; Megumi et al., 2023).

Spelling, while primarily a cognitive task, also involves kinematic processes during handwriting. Accurate spelling requires the retrieval of orthographic information from memory and the precise execution of letter forms. Studies have shown that children with good spelling skills tend to produce more consistent and faster writing movements compared to those with spelling difficulties. This suggests a strong interconnection between cognitive processes and motor execution in spelling tasks (Palmis et al., 2019).

Kinematic studies highlight several key developmental stages in children's writing and spelling. Early writing is characterized by large, imprecise movements as children rely heavily on visual guidance. With practice, they transition to more efficient motor strategies, utilizing proprioceptive feedback and developing a more refined motor schema. By examining the velocity and acceleration profiles of writing strokes, researchers can identify developmental milestones and potential areas of intervention for children with writing difficulties (Biotteau et al., 2019; Palmis et al., 2019).

In summary, the kinematic processes involved in writing and spelling in children are crucial for understanding how these skills develop and are executed. These processes reflect the intricate coordination between cognitive planning and motor execution, highlighting the importance of both neural and muscular components in effective handwriting. Further research in this area can lead to better diagnostic tools and interventions for children with writing and spelling difficulties.

### 2.4.1 Motor skills

Motor skills are defined as complex abilities that involve physical activities and movements of the individual. These skills are generally divided into two main categories:

Gross Motor Skills: These involve larger movements that engage major muscle groups. Examples include walking, running, jumping, and climbing stairs (Rimmer & Kelly, 1989).

Fine Motor Skills: These involve more precise and controlled movements that require greater coordination between the eyes and hands. Examples include writing, drawing, and using small tools (WILLIAMS, 2010).

Research indicates that the development of motor skills during childhood has a significant impact on cognitive, social, and emotional growth, helping individuals function more effectively in daily activities and social interactions (Barnett et al., 2016; Logan et al., 2018)

**Definitions and dimensions of graphomotor skills**

Graphomotor skills refer to a set of motor abilities and activities that are necessary for writing and other similar activities. These skills include the fine motor skills and eye-hand coordination necessary to perform tasks such as writing, drawing, and performing artistic activities (WILLIAMS, 2010).

These skills generally include two main dimensions:

Fine motor skills: These skills include the ability of the hands and fingers to control precisely and coordinate (Rule & Smith, 2018; Willliams,2010). For example, taking a pen and drawing smooth lines or writing letters in an orderly manner.

Eye-hand coordination is defined as a perceptual-motor skill involving the integration and processing in the central nervous system of visual and tactile input so that a purposeful motor movement can be made (Nayak, 2015). For example, while writing, one must be able to control the movement of the pen according to the shape of letters and words.

### 2.4.2 Importance of Graphomotor Skills

**Foundation for Learning to Write**

Graphomotor skills are essential prerequisites for learning to read and write. Children need precise hand control and hand-eye coordination to write letters and words effectively (Nazaruk et al., 2018; Willliams, 2010). These skills enable them to utilize writing instruments properly, ensuring that their written work is legible. As children practice these foundational skills, they develop muscle memory and dexterity, which are critical for achieving fluency in writing. This early stage of writing instruction, which includes activities like tracing letters and engaging in creative scribbling, lays the groundwork for more complex writing tasks in later educational stages (Graham et al., 2000; Marr & Cermak, 2002).

Moreover, as children progress from writing letters to forming words and sentences, their graphomotor skills continue to be refined. The ability to manipulate a pencil or pen, maintain appropriate pressure, and control movement on paper contributes not only to the quality of their handwriting but also to their overall confidence in written expression. As they see their skills improve, children are more likely to engage in writing activities, which fosters a positive attitude toward literacy. Thus, strong graphomotor skills serve as a vital link between early literacy experiences and future academic success (Wann & Nimmo-Smith, 1991).

**Cognitive Development**

Graphomotor skills have a direct impact on cognitive growth and analytical abilities. Engaging in tasks that require fine motor coordination and visual-motor integration—such as drawing, coloring, and writing—stimulates various cognitive functions, including concentration, memory, and problem-solving skills. For instance, when children participate in activities that require them to draw shapes or letters, they are not only practicing their motor skills but also enhancing their ability to focus and remember information (Baker et al, 2015; Piek et al., 2008; Taverna et al., 2020).

The connection between graphomotor activities and cognitive development is particularly significant in the context of early childhood education (Taverna, Tremolada, Tosetto, et al., 2020). Research suggests that children who regularly engage in graphomotor tasks tend to perform better in tasks that require higher-order thinking. This is because these activities encourage the brain to create and strengthen neural pathways associated with fine motor skills, ultimately contributing to improved academic performance in areas like mathematics and language. Thus, fostering graphomotor skills is not just about improving handwriting; it's about enhancing the cognitive abilities that are crucial for overall learning and development (Maurer et al., 2023; Taverna, Tremolada, Tosetto, et al., 2020).

**Communication and Social Interaction**

Graphomotor skills enable individuals to effectively participate in various social activities, such as writing letters, completing forms, or collaborating on group projects (Piek, Bradbury, et al., 2008; Taverna, Tremolada, Tosetto, et al., 2020). These skills are essential for effective communication, allowing individuals to express themselves clearly in writing, which is vital in

both academic and social contexts. When children possess strong graphomotor abilities, they are more likely to feel confident when engaging in writing, spelling, whether it's in a classroom setting or during social interactions with peers (Piek, Bradbury, et al., 2008; Taverna, Tremolada, Dozza, et al., 2020).

Furthermore, the development of these skills contributes to self-esteem and a sense of self-efficacy. When children can successfully write and communicate their ideas, they experience a boost in confidence, which can encourage them to take on more complex writing tasks and engage in collaborative efforts with their peers. This sense of competence fosters positive social interactions, helping children build relationships and navigate social settings more effectively. Thus, graphomotor skills are not only about personal expression but also about facilitating meaningful connections with others (Sinvani et al., 2023).

**Personal Independence**

Graphomotor skills play a crucial role in promoting personal independence in daily activities. The ability to write and complete tasks associated with writing—such as filling out forms, taking notes, or writing down important information—enables individuals to act more autonomously. As children develop these skills, they become less reliant on others for assistance, fostering a sense of self-sufficiency that is vital for their overall development. Therefore, the development of graphomotor skills is fundamental to fostering a sense of autonomy and independence in children (Sinvani et al., 2023; Taverna, Tremolada, Tosetto, et al., 2020).

**Educational Success**

In the educational context, graphomotor skills are regarded as foundational for success across various academic domains. Teachers recognize that proficiency in writing and related motor skills significantly affects students' performance in subjects like language arts, mathematics, and even science. By assessing and enhancing these skills, educators can help improve students' overall academic outcomes (Contreras Jordán & Infantes-Paniagua, 2021; Taverna, Tremolada, Dozza, et al., 2020; Taverna, Tremolada, Tosetto, et al., 2020).

Moreover, integrating graphomotor skill development into the curriculum can lead to more effective teaching strategies. For example, teachers can implement activities that promote fine motor skills alongside writing instruction, which not only supports writing but also encourages

critical thinking and creativity. By prioritizing the development of graphomotor skills, educators can ensure that students are well-equipped for the demands of their educational journeys, ultimately setting the stage for lifelong learning and success (Contreras Jordán & Infantes-Paniagua, 2021; Zachopoulou et al., 2006).

### 2.4.3 Key movement parameters in graphomotor skills

Graphomotor skills relate to motor and cognitive abilities related to writing and drawing. To analyze and improve these skills, several key movement parameters are considered:

1. Automaticity in graphomotor movements (NIV): This parameter refers to the speed changes during each stroke or writing movement. In writing, the speed of movement of the pen or writing instrument may change during each stroke. The ability to control and coordinate these speed changes is essential to produce accurate and smooth lines and shapes. Excessive variation or lack of consistency in speed can lead to illegible or inconsistent writing (Rueckriegel et al., 2008b).

2. Motor Precision: Motor precision refers to a person's ability to accurately control hand and finger movements. This parameter includes the ability to maintain uniform pressure and make small and precise movements, which are necessary for writing clearly and regularly. Movement accuracy plays an important role in producing smooth lines and legible letters (Feder & Majnemer, 2007; Rosenblum et al., 2003).

3. Hand-Eye Coordination: This parameter refers to a person's ability to coordinate hand movements with visual information. Proper hand-eye coordination is very important for following writing patterns and creating accurate designs. Problems in this coordination can lead to writing errors and difficulty in following correct patterns (Moldovan, 2016; Sonar (Limgaokar) et al., 2022).

4. Motor Stability: Motor stability refers to a person's ability to maintain control and stability during writing movements. This parameter includes the prevention of vibration or uncontrollable movements that can affect the quality of writing. Movement stability is important for long-term writing and drawing (Rosenblum et al., 2003).

### 2.4.4 The Role of Graphomotor Skills in Writing and Spelling

**Effect on Writing Quality**

### Accuracy and Readability

Graphomotor skills are recognized as a key component in producing accurate and legible writing. The ability to control hand movements allows children to write letters and words in an organized and clear manner. In fact, precision in writing movements is essential not only for readability but also for the effective communication of ideas. Research indicates that strengthening graphomotor skills can lead to a reduction in writing errors and an increase in writing quality. Additionally, illegible writing can create comprehension issues and diminish students' self-confidence. Therefore, teaching graphomotor skills in the early stages of education helps children establish a strong foundation for writing. (Ratzon et al., 2007).

### Motor Coordination

Motor coordination between hand movements and visual tracking is another vital factor in writing quality. This coordination enables individuals to accurately draw lines and letters, resulting in writing that has correct spacing and word arrangement. research emphasizes the importance of this coordination, demonstrating that difficulties in motor coordination can lead to the production of disorganized and illegible writing. This issue can particularly affect children in the early stages of learning to write, potentially leading to feelings of frustration and decreased motivation. Therefore, enhancing motor coordination through targeted exercises can improve writing quality and boost confidence in writing. Given that graphomotor skills are directly related to success in writing, paying attention to these skills in the educational process is crucial. (Feder & Majnemer, 2007).

## Effect on spelling learning

### Retention of Writing Patterns

Graphomotor skills significantly contribute to the learning and retention of writing patterns, which are crucial for spelling proficiency. Children with strong graphomotor skills can easily recognize and replicate letter and word patterns, aiding them in accurately learning spellings (Graham et al., 2000). The ability to control fine motor movements allows these individuals to engage more deeply with the act of writing, which is vital for memory retention. Research has shown that the act of writing can reinforce memory through a multi-sensory approach, where visual, tactile, and motor experiences converge. This multi-faceted engagement aids children in creating mental

representations of words, which subsequently enhances their spelling abilities (Schlesinger & Gray, 2017)

Furthermore, effective graphomotor skills facilitate the connection between auditory and visual aspects of language. As children hear words and then write them down, their ability to translate sounds into written forms is strengthened. This connection is essential in spelling, as it helps children internalize phonetic patterns alongside visual patterns. Studies indicate that children who practice writing regularly demonstrate better spelling outcomes, as they develop a more profound understanding of how letters form words and the patterns associated with them. Thus, fostering graphomotor skills in early education can provide a substantial advantage in learning to spell accurately (Suggate et al., 2016b).

**Ability to Identify and Correct Errors**

Graphomotor skills also play a critical role in the ability to identify and correct writing errors, which is particularly important for spelling. Children who can recognize when a word doesn't look right or match the sounds they hear are more likely to make corrections. This self-monitoring ability is essential for developing independent writing skills and improving spelling accuracy. Furthermore, the ability to correct errors is linked to persistence and motivation. When children successfully identify and rectify mistakes, they experience a sense of accomplishment that fosters confidence and encourages continued practice. This self-corrective ability, critical for learning, promotes a growth mindset, where mistakes are seen as opportunities for improvement rather than failures. Cultivating graphomotor skills not only enhances spelling accuracy but also empowers children to take an active role in their learning process, fostering a positive attitude toward spelling and writing tasks (Mohamed & O'Brien, 2022)

**The influence of graphomotor skills on spelling performance**

The relationship between graphomotor skills and spelling in bilingual children, particularly those with differing writing and spelling systems, remains underexplored. This gap leaves questions about whether the same relationships identified in monolingual populations apply across languages with distinct orthographic structures. However, evidence from studies on monolingual children underscores the crucial role of graphomotor skills in spelling performance. Fine motor abilities, especially grapho-motor functions, have been found to significantly influence both spelling

accuracy and fluency. For example, a longitudinal study conducted in Singapore monolingual children demonstrated that graphomotor skills accounted for a significant portion of the variance in spelling and reading performance, even after adjusting for various cognitive and educational factors (Mohamed & O'Brien, 2022).

Research also on monolingual children shows that handwriting, a complex skill encompassing legibility and fluency, is closely linked to both graphomotor and spelling abilities. Studies have indicated that graphomotor skills more strongly affect handwriting legibility, whereas spelling ability has a greater impact on fluency. A study involving children in Year 3, Year 4, and Year 5 revealed that these skills together explained a moderate amount of variance in handwriting legibility ($R^2$ = .37–.42) and fluency ($R^2$ = .41–.58). Furthermore, selective attention was found to predict handwriting fluency and partially mediate the influence of graphomotor skills, demonstrating the interplay between cognitive and motor functions in literacy development (Downing & Caravolas, 2023).

While the specific relationship between graphomotor skills and spelling in bilingual populations has not been definitively studied, the findings from monolingual research suggest that early interventions targeting graphomotor skills could enhance literacy outcomes, including spelling.

### 2.5 Orthographic knowledge

Orthographic processing refers to the cognitive ability to recognize written words and their components, including letters, letter patterns, and whole words (Rothe et al., 2024). Orthographic knowledge refers to the understanding of a language's spelling system, rules, and conventions. It involves recognizing common letter patterns, word structures, and positional constraints of letters within words. For example, in English, certain combinations like "ck" usually appear at the end of a word or syllable (e.g., "duck"). This type of knowledge helps individuals identify how letters can be arranged to form valid words in a given language. This skill facilitates fluent reading and writing by enabling the visual identification and memory of specific letter arrangements that constitute words. According to (Bourassa & Treiman, 2001), orthographic processing is essential for decoding words quickly and accurately, allowing readers to recognize words automatically without sounding out each letter or syllable.

Orthographic processing develops through exposure to written language and becomes more sophisticated with practice and instruction. As noted by (Ehri, 2014), this skill is acquired through systematic teaching and repeated exposure to print. It requires an understanding of the rules governing letter combinations and word structures, including common prefixes, suffixes, and root words, as well as the ability to distinguish frequently confused letter patterns. So it plays a fundamental role in reading fluency and writing development, as it allows readers to decode words quickly by understanding the spelling patterns and rules they follow. This knowledge grows through exposure to language, practice, and systematic instruction. As readers encounter new words, their orthographic knowledge helps them apply spelling conventions and identify whether a word "looks right." Additionally, recognizing prefixes, suffixes, and root words aids in reading and spelling unfamiliar words. Research shows that explicit instruction in orthographic rules and patterns improves reading proficiency, especially in younger learners (Bourassa & Treiman, 2001; Treiman et al., 1993).

Research indicates that proficient readers typically have more efficient orthographic processing skills, which enhance their ability to recognize words quickly and accurately (Cunningham et al., 2002). Conversely, individuals with reading difficulties, such as dyslexia, often struggle with orthographic processing, making word recognition more challenging. Targeted educational practices, including explicit instruction in phonics and orthographic patterns, as well as interventions like multisensory teaching methods, can help improve orthographic processing and support the development of effective reading strategies.

The study by (Rothe et al., 2015) confirms the relationship between orthographic processing and spelling, particularly in children with reading and spelling disorders. It demonstrates that orthographic processing encompasses the recognition and application of letter patterns and conventions in a writing system, which is vital for effective spelling.

The findings indicate that dyslexic children have reduced word-specific orthographic knowledge and show difficulties in identifying illegal letter patterns. These challenges negatively impact their spelling abilities, as successful spelling relies on recognizing and applying correct orthographic representations. Thus, the study underscores that strong orthographic processing skills are essential for proficient spelling, highlighting the need for targeted interventions to support children struggling with these skills.

The study by (Squires & Wolter, 2016) emphasizes the critical role of orthographic processing in spelling development, particularly for students with reading disabilities. It synthesizes evidence from five high-quality studies demonstrating that spelling interventions focused on orthographic patterns significantly improve spelling skills in students from kindergarten to ninth grade. These interventions showed moderate to large effect sizes on standardized spelling measures, indicating that enhancing orthographic pattern knowledge can lead to substantial gains in spelling performance. This finding that underscore the importance of orthographic processing in spelling, reinforcing the connection between these skills.

The study by (Rahbari et al., 2007) aimed to explore how phonological and orthographic skills contribute to reading and spelling in Persian. Persian has a consistent relationship between graphemes (letters) and phonemes (sounds), but the reverse can be inconsistent.

In the study, 109 second-grade Persian students (average age 8 years) were tested on their reading, spelling, and phonological and orthographic skills. The findings revealed that while the children used both phonological and orthographic skills, phonological skills were a stronger predictor of their reading and spelling abilities.

Additionally, the study compared spelling accuracy for words with consistent versus inconsistent phoneme-to-grapheme correspondences. As expected, the children spelled words with consistent correspondences more accurately. They also relied more on orthographic skills when spelling inconsistent words. The results highlight the different impacts of orthographic consistency on reading and spelling in monolingual Persian children.

The study by (Rothe et al., 2024) examined the relationship between two types of orthographic knowledge—General Orthographic Knowledge (GOK) and Word-Specific Orthographic Knowledge (WOK)—and literacy skills in German elementary school children. In a sample of 2,636 third and fourth graders, the researchers used mediation models to investigate whether GOK predicts reading fluency and spelling, with WOK acting as a mediator.

The findings confirmed that WOK facilitates the relationship between GOK and literacy skills, suggesting that a strong understanding of permissible letter combinations enhances word-specific learning. Additionally, correlations varied by item type, showing stronger connections with pseudohomophones and illegal letter patterns. The study concludes that GOK plays a vital role in

orthographic learning and encourages future research to differentiate between correct targets and incorrect options in orthographic tasks.

## 2.6 Vocabulary

Vocabulary refers to the knowledge of the meanings of words and the concepts associated with those meanings. It plays a critical role in language acquisition, impacting both reading comprehension and spelling abilities (Aarnoutse et al., 2001; Biemiller & Boote, 2006). Vocabulary development involves the acquisition, understanding, and effective use of words, which is facilitated by various instructional methods and experiences (Aarnoutse et al., 2001). Research indicates that a rich vocabulary enhances cognitive and communicative skills, making it essential for academic success and overall linguistic proficiency. Notably, vocabulary size can predict reading comprehension, with larger vocabularies correlating with better comprehension skills (Biemiller & Boote, 2006). According to (Beck et al., 1982), the size of one's vocabulary significantly impacts their word recognition abilities and reading comprehension. This means that students with larger vocabularies can more easily recognize words and understand what they read.

In the realm of spelling, vocabulary plays a crucial role. Spelling involves converting spoken words into written symbols, which requires a good grasp of vocabulary and orthographic processing skills. Cunningham et al., (2002) found that these orthographic skills are a significant factor in reading ability. Students who can recognize and process the spelling patterns of words tend to be better readers.

Moreover, in the early grades, there is a strong connection between decoding and spelling. Decoding involves sounding out words, which is closely related to spelling. As students learn to decode words, they also improve their spelling skills. Karakoç & Durmuşoğlu Köse, (2017) emphasized that a solid vocabulary foundation helps students become proficient in both reading and spelling, highlighting the interdependence of these skills in early education.

Vocabulary growth begins with oral language and expands as children transition to written language. Exposure to spoken words shapes early vocabulary, while reading and writing further enhance it. By Grade 2, students with strong vocabularies know significantly more words than their peers, which can affect their reading comprehension and spelling abilities for years (Biemiller & Boote, 2006).

In essence, vocabulary is not only about knowing words but also about understanding and applying them effectively in communication. Strong vocabulary instruction, especially in early education, is critical for academic achievement, reading comprehension, and overall language development.

**Vocabulary and Spelling Performance**

The relationship between vocabulary range and spelling ability is a critical area of study in literacy development. Research indicates that a broader vocabulary enhances spelling performance, as individuals with extensive word knowledge are better equipped to recall and accurately reproduce the orthographic forms of words (Bialystok et al., 2005). When children have a larger repertoire of words, they can recognize and internalize spelling patterns more effectively, which is crucial for spelling proficiency.

Furthermore, vocabulary knowledge contributes to phonological awareness, a skill essential for spelling. Studies have shown that children who are proficient in recognizing sounds within words tend to have better spelling outcomes. As they learn new words, they not only acquire their meanings but also their corresponding spellings, reinforcing their understanding of language structure. This interplay suggests that enriching vocabulary through reading and direct instruction can lead to improved spelling skills, underscoring the importance of a well-rounded language education (Reed et al., 2016c).

Vocabulary plays a crucial role in spelling comprehension and processing, as it directly influences how individuals understand and reproduce written language. A robust vocabulary not only provides learners with a diverse array of words but also enhances their ability to recognize spelling patterns and rules. Research indicates that children with a richer vocabulary are often better at spelling because they can draw on their knowledge of word meanings and structures, which aids in the recall of correct spellings (Bialystok et al., 2005). This relationship suggests that vocabulary acquisition and spelling development are interdependent processes.

Moreover, the connection between vocabulary and spelling is particularly evident in the context of phonological awareness, which refers to the ability to recognize and manipulate sounds within words. Studies have shown that students who exhibit strong vocabulary skills also tend to have heightened phonological awareness, facilitating their ability to decode and spell words accurately.

As children learn new words, they not only expand their vocabulary but also become more adept at identifying sound-letter correspondences, thereby improving their spelling comprehension.

Additionally, the processing of spelling involves both cognitive and linguistic components, which are influenced by vocabulary knowledge. When learners encounter unfamiliar words, their existing vocabulary helps them infer possible spellings based on similar words they know. This strategy underscores the importance of teaching vocabulary in conjunction with spelling instruction. By fostering a strong vocabulary foundation, educators can significantly enhance students' spelling abilities, ultimately leading to better literacy outcomes (Norris & Hoffman, 2002; Reed et al., 2016c)

**Vocabulary and Its Impact on Spelling**

Study by (Karakoç & Durmuşoğlu Köse, 2017) explored the incremental and multidimensional nature of vocabulary development and its influence on reading and writing performance, as well as general proficiency in English as a foreign language (EFL) learners. Their study, involving 175 students in an intensive language program, revealed significant findings regarding the interaction between vocabulary knowledge and language skills. The study found that receptive vocabulary knowledge—the ability to recognize and understand words—was generally larger than productive vocabulary knowledge, which refers to the ability to use words in writing and speaking. Moreover, vocabulary knowledge was significantly related to the students' reading and writing performances, indicating that an expanded vocabulary enhances overall language proficiency.

Karakoç and Köse also noted the relationship between the lexical sophistication of students' essays and their productive vocabulary knowledge. This suggests that learners with a stronger command of productive vocabulary can use a wider range of words more effectively in writing, which can directly improve their spelling accuracy and the overall quality of their written output.

In another significant study, (Zhong, 2018) investigated the progression from receptive to productive vocabulary knowledge within a multi-aspect framework. Zhong's study examined various dimensions of vocabulary knowledge, including meaning, form, word class, collocation, and association, and their relationship to controlled productive word use in sentence writing. Using a sample of 620 Year 8 EFL learners, the research provided empirical evidence of the complex nature of vocabulary knowledge, revealing that each aspect contributes uniquely to productive

word use in context. This multi-faceted understanding of vocabulary knowledge is crucial for spelling accuracy, as it suggests that students with a strong grasp of word forms and collocations are more likely to spell words correctly in writing.

Both studies emphasize that vocabulary knowledge, particularly productive vocabulary, has a profound impact on spelling and overall writing proficiency. In particular, Zhong's (2018) research underscores the importance of teaching not only word meanings but also their forms and uses in different contexts, which directly relates to spelling competence. Moreover, the multi-task approach used in the study demonstrates how different aspects of vocabulary can be assessed and developed to enhance both spelling and broader language skills.

## 2.7 Reading

Reading fluency is the ability to read text accurately, quickly, and with appropriate expression, integrating automaticity and prosody. Automaticity refers to the effortless recognition of words, enabling readers to process text with minimal cognitive effort, thereby facilitating smoother reading. Prosody involves the rhythm, intonation, and expression used in reading, which helps convey the text's meaning through natural vocalization (Taguchi et al., 2004).

Reading fluency is a critical component of reading development, acting as a bridge between basic decoding skills and higher-level reading comprehension. It allows readers to allocate more cognitive resources to understanding the text rather than focusing on decoding individual words. Effective assessment and instruction of reading fluency should consider accuracy, speed, and expression to provide a holistic understanding of a reader's fluency and its impact on comprehension.

Overall, reading fluency encompasses several core components:

Accuracy: Correct recognition and pronunciation of words.

Rate: The speed at which text is read, facilitating comprehension.

Prosody: The rhythm, intonation, and expression used during reading, reflecting the reader's understanding of the text (Kocaarslan, 2019).

This construct integrates decoding skills with comprehension, making it particularly important for struggling readers, as it bridges basic decoding abilities and higher-level comprehension (Kuhn et al., 2010).

Previous research has shown that fluency in reading and spelling accuracy are directly related. Fluency refers to the ability to read text smoothly, quickly, and without frequent pauses, and this skill can have a significant impact on spelling accuracy and quality. Below are some key studies in this area:

Research by (Park & Uno, 2015) on Korean Hangul learners highlights the dynamic relationship between reading and spelling, emphasizing the shared cognitive abilities underlying both skills. The study found that receptive vocabulary is a key predictor of both reading accuracy and spelling performance. A strong vocabulary base enables learners to recognize and comprehend words in reading, while also supporting accurate spelling.

In the early stages of literacy development (Grades 1-3), phonological awareness—the ability to recognize and manipulate sounds—was crucial for both reading fluency and spelling. This suggests that understanding sound patterns in spoken language directly aids in the ability to spell words correctly. As students gain more reading experience, their reading ability further contributes to spelling accuracy, indicating a transfer of skills from reading to spelling.

Overall, the study suggests that as learners become more proficient readers, the cognitive abilities required for reading and spelling evolve, but vocabulary knowledge and reading competence remain critical factors in developing accurate spelling.

The study by (Rossi et al., 2019) investigated the relationship between orthographic quality and reading speed through the Lexical Quality Hypothesis (LQH), which posits that words with better cognitive representations are accessed more efficiently. In their study with 90 teenagers, participants read 30 words, and their reading times were recorded. After a two-week period, they spelled the same words three times to measure orthographic quality. The results indicated that words with higher spelling accuracy and stability were associated with faster reading speeds, providing empirical support for the idea that orthographic quality exists on a continuum.

## 2.8 Research finding in bilingualism

Study by (Chung et al., 2018) explored the relationship between orthographic processing and spelling among grade 1 French immersion children learning to read in both English and French. The study involved 152 children and assessed their lexical orthographic processing and spelling in both languages. The findings revealed a significant within-language relationship between orthographic processing and spelling for both English and French. Additionally, cross-language transfer was observed, with French orthographic processing positively impacting English spelling, but not vice versa. These results underscore the importance of orthographic processing in spelling development for bilingual children learning languages that share the same Roman script.

According to (Chung et al., 2023), the relationship between orthographic knowledge and word reading and spelling in bilingual children in a French immersion program. The study followed 73 children from Grades 1 to 3 and employed cross-lagged panel models to analyze the temporal order of these skills. The results indicated that word reading at grade 1 and word spelling at grade 2 predicted gains in both English and French orthographic knowledge. However, early orthographic knowledge did not predict improvements in word reading or spelling. Additionally, there was a consistent cross-linguistic transfer, with English word reading and spelling influencing later French orthographic knowledge, while French skills affected English orthographic knowledge only from grade 2. These findings highlight the complex and dynamic relationships between orthographic knowledge and literacy skills in bilingual contexts.

O'Brien et al., (2020) conducted a longitudinal study examining the relationship between reading and spelling skills in bilingual children learning English alongside an Asian script (Chinese, Malay, or Tamil). The study involved 620 participants over three years, utilizing cross-lag analysis to explore the dynamic interrelations of literacy skills. The results revealed that the patterns of reading and writing development varied among the bilingual groups. Chinese and Tamil speakers exhibited relational patterns similar to monolingual learners, showing mutual influences between skills. In contrast, Malay speakers demonstrated a later influence of reading on spelling, reflecting the characteristics of its transparent orthography. Additionally, the study found distinct cross-language influences, with consistent mutual influence for Malay-English reading and variable

patterns for Chinese and Tamil. These findings highlight the complexity of literacy development across different languages and scripts, suggesting the need for updated cross-linguistic models.

The study by (Arab-Moghaddam & Senechal, 2001) examined how phonological and orthographic processing skills influence reading and spelling in bilingual Persian-English children. It involved 55 Iranian children in grades 2 and 3 who had lived in English-speaking Canada for about four years. The research found that phonological and orthographic processing skills were important predictors of reading performance in both languages. However, the predictors for spelling were different:

In English, both phonological and orthographic skills contributed to spelling success.

In Persian, only orthographic processing skills were significant.

This suggests that the structure of Persian orthography encourages children to use different strategies for reading and spelling. Specifically, spelling Persian words may lead children to adopt an analytic approach, enhancing their reliance on orthographic skills.

The study by (Abu-Rabia & Siegel, 2002) examined the reading, language, and memory skills of 56 bilingual Arabic-English speaking Canadian children aged 9-14. The children's primary instructional language was English, while Arabic was spoken at home. The study aimed to understand the relationship between reading, syntactic awareness, orthographic processing, and working memory in both languages and how bilingualism impacts language development.

The researchers administered word and pseudo-word reading, language, and working memory tests in both English and Arabic. Findings showed that most children had at least adequate proficiency in both languages. There was a significant correlation between word and pseudo-word reading, working memory, and syntactic awareness skills in both languages. Children who had difficulties reading Arabic scored lower on all linguistic tasks, except the visual task.

The study revealed no significant differences between bilingual Arabic-English children and monolingual English-speaking children on reading, language, and memory tasks. Interestingly, bilingual Arabic-English children with reading difficulties in English performed better on English pseudo-word reading and spelling tasks compared to monolingual English-speaking children with reading disabilities. This suggests a positive transfer of skills from the regular nature of Arabic

orthography, indicating that bilingualism does not necessarily have negative consequences for language and reading skills development in both languages, despite their differing orthographic characteristics.

Aaron & Joshi (2013) investigates the spelling performance of Tamil-speaking children, focusing on the influence of their native language's orthography and the impact of learning English first as a written language. Tamil, a Dravidian agglutinative language, has a shallow orthography with a nearly one-to-one correspondence between letters and sounds. As expected, Tamil-speaking children in Grades 6 through 12 made very few spelling errors on a dictation test due to the straightforward nature of Tamil orthography. The few errors that did occur could be attributed to unique features of Tamil phonology and morphology.

The research examines whether learning English initially through textbooks, rather than through speech, would result in fewer spelling errors. The spelling performance of Tamil-speaking children who learned English first as a written language was compared to that of American children who learned English first as a spoken language. Findings indicated that learning English first as a written language helped children avoid dialect-related spelling errors. However, the influence of Tamil phonology led children to make different kinds of spelling errors.

The study also revealed that Indian children exposed to textbook English throughout the entire school day demonstrated better English spelling skills than those exposed to written English for only about an hour per day. This highlights the importance of both speech and print in the development of spelling abilities, suggesting that exposure to written language plays a significant role in learning to spell accurately.

In the study, (D'Angiulli et al., 2001b) examined the relationship between English and Italian reading skills in bilingual Canadian children. Researchers administered various language tasks in both languages to children aged 9-13. They found a strong connection between phonological skills in both languages, while the connection was weaker for syntax and absent for working memory. Skilled readers outperformed less skilled readers across all tasks, with older children performing better than younger ones. Although bilingual children performed worse in Italian compared to their monolingual peers, they showed enhanced English skills compared to monolingual English-Canadian children with similar reading abilities. The findings suggest that English-Italian

bilingualism may influence various linguistic modules and that exposure to Italian could improve phonological skills in English.

Dixon and colleagues (Dixon et al., 2010) conducted a study examining the influence of first language (L1) orthography on bilingual children's spelling performance in their second language (L2), English. The researchers administered subtests of spelling and letter-word identification from the Woodcock Proficiency Battery to 285 six-year-olds in Singapore. All participants received English literacy instruction through the "look-say" method.

The study aimed to determine whether L1 orthography affected conventional spelling, controlling for reading proficiency. The results showed a significant effect of L1 on conventional spelling, but not phonological spelling. Children with a Chinese (morphosyllabic) L1 outperformed those with a Malay (alphabetic) or Tamil (syllabic) L1, not only in overall scores but also in making more real-word substitution and transposition errors.

The findings suggest that L1 orthographic depth significantly influences L2 spelling skills. This information can be valuable for learning disability specialists when assessing the spelling and literacy abilities of English L2 learners, highlighting the importance of considering learners' L1 background in literacy instruction and evaluation.

In this chapter we confirmed an overview of existing research exploring the connection between graphomotor skills and various linguistic abilities, particularly in bilingual children. Several studies have examined the influence of first language (L1) orthography on second language (L2) literacy development, demonstrating that L1 orthographic depth can significantly impact L2 spelling skills. Research has also demonstrated a strong correlation between phonological processing abilities across languages, while the relationship is less evident for syntax.

Overall, these studies emphasize the importance of understanding the impact of bilingualism and L1 orthographic depth on L2 literacy development. Findings suggest that exposure to a language with more predictable grapheme-phoneme correspondences, such as Italian, may enhance phonological skills in English, but the result was different for different language with grapheme-phoneme. These insights can be valuable for educators and specialists when assessing and supporting the literacy development of bilingual children

# 3 Chapter III: Research Methodology

In this chapter, the target population, the sample, and the sampling method will be described, along with the psychometric characteristics of the tools and the process for conducting the sessions. Finally, the research design, the method of research execution, and the methods of statistical data analysis will be discussed

## 3.1 Research Design and Sampling Method

The present study is a proof-of-concept study for later investigation of the research question in a larger sample. The kinematic study in bilingual students is recognized as the first comprehensive and innovative research initiative aimed at advancing understanding of the effect of kinematic processes, particularly in graphomotor skills, on cognitive linguistics in bilingual students. The study employs a descriptive correlational and predictive research design, focusing on a cohort of bilingual Persian-German children aged 9 to 13 years. This design allows for the exploration of relationships between multiple independent variables—namely, kinematic processes, orthographic skills, vocabulary, and reading fluency—and the dependent variable of spelling performance.

The sample for this study consisted of ten bilingual Persian-German children aged 9 to 13 years. All participants were enrolled in third and fourth grades of schools located in Dresden, Germany, and possessed a strong command of both languages, with Persian (Farsi) as their first language and German as their second.

The sampling method employed in this study was purposive sampling, which allowed for the selection of participants based on specific inclusion criteria. This method ensured that the sample was homogenous and aligned with the research objectives.

**Inclusion criteria included:**

Enrollment in third or fourth grade in German school in 2024.

Bilingual status, with Persian as the first language and German as the second language.

Participation in Persian and German educational settings.

By utilizing purposive sampling, the study aimed to recruit participants who could provide valuable insights into the interplay between linguistic proficiency and cognitive processes related to spelling performance in a bilingual context.

### 3.2 Participants

This study involved ten Persian–German bilingual speakers, aged between 9 and 13 years. All participants identified Persian as their first language and demonstrated proficiency in speaking, reading, and writing Persian. They had resided in Dresden, Germany, for periods ranging from 6 months to more years and were enrolled in local German schools at the time of the research. In addition to their first language, the participants communicated in German as their second language and were capable of reading and writing in German.

All participants were born and raised in the same geographical region of Iran and Afghanistan, utilizing the same urban Farsi dialect. Consequently, Farsi served as the primary language of communication among the participants. Prior to relocating to Germany, they had lived in Iran or Afghanistan for 3–9 years. Notably, both parents of each participant were native Farsi speakers, which contributed to the linguistic environment at home.

Participant selection was based on several criteria: both parents' language background, previous attendance at Persian language schools, and current enrollment in German schools. Among the ten bilingual speakers, three had attended Persian schools for their first three years of education, while the other five began their formal education in Persian schools and transitioned to German schools thereafter, also two children learn Farsi from the private Farsi class in Germany. This division allowed for a comparison between early exposure to the German language (from primary school level) and late exposure (at the fourth grade).

At the time of this study, all participants were active members of a Persian community in Dresden, regularly using Persian in their daily lives. Importantly, all participants reported no history of speech, language, reading, or neurological issues.

The sample consisted of 7 right-handed, 2 left-handed and 1 ambidextrous child, including 4 third graders and 6 fourth graders. They were pupils from various schools within the Dresden area, and the assessments were conducted in September at the year 2024.

Participants were tested twice, with each session lasting approximately 1.5 hours. The order of testing was designed to minimize potential language interference, beginning with the German assessment followed by the Persian assessment.

Ethical considerations were upheld throughout the research process, with informed consent obtained from the parents of all participants as well as from the participants themselves prior to their involvement in the study. Additionally, the research adhered to guidelines set forth by Technische Universität Dresden, ensuring the well-being and confidentiality of the participants. To express gratitude for their involvement, each participant received a €15 gift at the conclusion of the study.

### 3.3 Procedure

Initially, the children and their parents were provided with thorough explanations regarding the testing process in both German and Persian. This was conducted by the experimenter to ensure comprehension. Following this, a brief interview was conducted to gather information about the children's developmental history and any neurological disorders. After obtaining parental consent, the parent of participants completed an immigration questionnaire, DCDQ and DISYPS-III: FBB-SCREEN., after which they were directed to a waiting room to complete these forms.

The testing with the children commenced after obtaining signed consent. First, the children read the consent information and had the opportunity to ask any questions before signing. Once consent was confirmed, the procedure began with the children filling out the Edinburgh Handedness Inventory (EHI) questionnaire. If any child encountered difficulties understanding the questions due to limited proficiency in German, the examiner provided explanations in Persian.

Next, the graphomotor assessment was conducted. The children used a digital writing desk with a paper on it equipped with a digital pen without ink fill. The assessment consisted of eight tasks, which were administered one at a time. The children were instructed to write sentences or shapes as requested, with the important detail that they could not see their writing on the desk, as it was recorded on a laptop. A total of eight tasks were saved from the graphomotor test, which included: two tests in German (one sentence and one repeated letter), two fine and gross motor tests, two movement tests (one with eyes open and one with eyes closed), and finally, two Persian tests (one Persian sentence and one repeated Persian letter). We checked that Persian and German letters are

similar in terms of motor complexity, and length, and do not contain any difficult graphemes or rare words.

Subsequently, the reading fluency was assessed using German words. This test consisted of two stages. In the first stage, children were shown examples and received explanations from the examiner. They were presented with real German words and instructed to read as many as they could within one minute, column by column. Their reading was recorded, and they were prompted to stop reading after one minute by the examiner. In the second stage, the children were presented with German pseudowords, following the same structure as the first stage. Again, their reading was recorded for one minute.

The third test involved assessing German orthographic knowledge, conducted on a laptop. Children were given explanations and a practical example of the test format. Each word was presented in lowercase on the center of the laptop screen (Times New Roman font, size 18). Children had to determine whether each word was correct by touching the green tick on the left side of the screen for correct words and the red tick on the right side of the screen for incorrect words. Although instructions were given to use their left hand for the green tick and their right hand for the red tick, most children used their dominant hand for both. Moreover, after the German orthographic knowledge test children complete the same test for Persian.

In the fourth step, the children completed the PPVT test in German. Based on their age, they began with a series of 12 picture-word associations. Each series contained four pictures, and the examiner articulated one German word corresponding to one of the images. Children were instructed to select the picture that matched the spoken word. If the child answered correctly for all or only one wrong answer in the first 12 series, they progressed to the next, more challenging level. If they made more than one error, the examiner moved to a lower level. The test concluded when the child answered eight or more items incorrectly.

Following the PPVT test in German, a spelling test was administered according to the children's current grade level. Each child received a writing exercise with blank spaces, where they listened to a story and filled in the blanks with the words they heard. There were 55 blanks for third graders and 60 for fourth graders.

To minimize fatigue and negative effects on performance, all German tests and some Persian tests were conducted during the first session. The second session began with the Persian version of the PPVT test, following the same structure as in German. The spelling test was then administered, which included 60 Persian words for third graders and 80 for fourth graders. The examiner read each word aloud, allowing children to write without a time limit.

Lastly, the reading test involved real Persian words, which the children were required to read within two minutes. After an explanation and practice example, their readings were recorded. They also read a set of fantasy Persian words following the same structure.

At the conclusion of the testing sessions, each child was rewarded with a €15 gift as a token of appreciation for their participation in the study, followed by expressions of gratitude and farewells from the experimenter.

### 3.4 Participant Inclusion Criteria

The criteria for inclusion in the present study were carefully defined to ensure a homogenous sample of participants that aligned with the research objectives. Specifically, participants were required to be the developmental stage of third and fourth grade students, corresponding to age between 9 to 13 years. This age range was selected to capture critical periods of language acquisition and literacy development. Additionally, participants were required to be Persian-German bilingual students, with Persian (Farsi) identified as their native language and as their first language, while German served as their second language. Participants must be able to speak, read and write in both Persian and German language. This bilingual background was essential for the study, as it allowed for the examination of spelling performance in a context where both languages are utilized, thereby facilitating an understanding of the interplay between linguistic proficiency and cognitive processes in bilingual children.

**Research measurement tools:**

### 3.5 Questionnaires for Parents

#### 3.5.1 Immigration Questioner

In the study an Immigration Questionnaire was employed to collect comprehensive information regarding the immigration experiences of both the child and their parents. This questionnaire consisted of eight thoughtfully crafted questions aimed at exploring various aspects of their

migration journey, including the reasons for immigration, duration of stay in the new country, and any challenges faced during the transition. By capturing these experiences, we aimed to gain deeper insights into the contextual factors that may influence the children's language development and educational outcomes in a bilingual setting.

### 3.5.2 The Developmental Coordination Disorder Questionnaire (DCDQ)

The Developmental Coordination Disorder Questionnaire (DCDQ) is a screening tool used to identify and evaluate motor coordination disorder in children aged 5-15 years. It assesses both gross motor skills, such as throwing, catching, and hitting, and fine motor skills, like writing quickly and legibly with appropriate effort. Typically, parents or caregivers complete the DCDQ, rating their child's motor performance on a five-point Likert scale in comparison to other children at the same age. Each question is scored from 1 to 5, with the total score ranging from 15 to 75. The test includes 15 items that evaluate gross motor skills (6 items, Cronbach's alpha = .83), fine motor skills (4 items, Cronbach's alpha = .94), and general coordination (5 items, Cronbach's alpha = .65). The original English version has demonstrated good reliability, with an overall internal consistency (Cronbach's alpha = .88), and its validity is supported by a significant correlation with the Movement Assessment Battery ($r = .55$, $p < .001$) and with the test of Visual-Motor Integration (r =. 42) (Wilson et al., 2009). The questionnaire includes questions about various motor activities relevant to the child's age, such as writing, cutting with scissors, catching a ball, and other tasks requiring coordination and dexterity. Scores are used to assess whether the child's motor skills are within the typical range or if they indicate significant coordination difficulties (Wilson et al., 2009).

### 3.5.3 DISYPS-III: FBB-SCREEN

The parent-rated FBB-SCREEN assess several symptom areas with 51 items rated from not true at all (0) to very true or often true (3). There are seven first-order scales for symptoms of ADHD, conduct disorders, anxiety, depression, nonorganic enuresis and encopresis, autism, obsessive–compulsive disorder, and tic disorders. In addition, four superordinate scales (internalizing, externalizing, contact problems, and overall symptoms) are formed, which have shown acceptable to good internal consistencies (Cronbach's $\alpha \geq 0.76$) in community samples (Meininger et al., 2022). Each component of DISYPS-III can be used independently or in combination, with clinical

judgment guiding diagnoses based on diagnostic checklists and assessment results. For most scales of the questionnaire, at least satisfactory internal consistencies with values ranging from α equal to .70 to α equal to .90 were determined. The construct validity of the most important procedures was checked using factor analyses.

## 3.6 Questionnaires for Children

### 3.6.1 The Edinburgh Handedness Inventory

The Edinburgh Handedness Inventory (Oldfield, 1971) is a measurement scale which is employed to establish hand dominance. The Edinburgh Handedness Inventory (EHI) includes 20 tasks, but a shorter 10-item version that was developed by Oldfield is more commonly used for its practicality. In this research we have used of the second version (10-item). It evaluates an individual's preferred hand for various everyday tasks to determine their dominant hand. The laterality quotient was calculated according to the following formula: (R-L)/(R+L) * 100. The laterality of the participants was classified as follows: less than -40 points are left-handed, between -40 and +40 points are ambidextrous and more than +40 points are right-handed. The inventory can be administered through direct observation of hand use or via self-report by the individual regarding their hand preference in daily activities. While useful for assessing hand preference, the EHI alone is not sufficient for a comprehensive evaluation of cerebral lateralization. It is best used as part of a broader assessment framework (Robinson, 2021).

## 3.7 Spelling in German and Persian Test

### 3.7.1 WRT 3+, WRT 4+: (German Spelling Test)

**Assessment Tools: Weingartener Grundwortschatz Rechtschreibtest**

The Weingartener Grundwortschatz Rechtschreibtest is a well-known tool for assessing primary students' spelling skills using a core vocabulary list essential to early education. The Weingartener Grundwortschatz Rechtschreibtest is typically administered as a dictation exercise, where students write down words as they are dictated by the test administrator. This format directly evaluates the student's spelling abilities by focusing on commonly used words that are expected to be mastered at this stage of education. This test helps identify students struggling with spelling, providing valuable insights for tailored instruction.

The test is reliable, with high internal consistency (r = .94) and strong test-retest reliability (3rd grade: r = .93; 4th grade: r = .94). (Birkel, 2007a; Birkel, 2007b).

In this study, we used the WRT 3+ (Vocabulary and Spelling Test for Third Grade) to assess third graders' vocabulary and spelling. Developed by Werner Birkel in 2007, the WRT 3+ follows a cloze format, where students fill in blanks in a text based on a dictation. The test consists of 55 items and typically takes about 45 minutes. Also, we used the WRT 4+ is a similar test for fourth graders, with 60 items. (Birkel, 2007a; Birkel, 2007b).

### 3.7.2 Falah Chai Spelling Test (Persian Spelling Test)

The Falah Chai Spelling Test is an assessment tool used to evaluate students' spelling skills, particularly in Persian-speaking countries. This test is designed to measure students' ability to spell words accurately and identify any spelling difficulties they may have. The validity and reliability of this test were evaluated by Falah Chai (1995) at Tarbiat Modares University. The validity of the test was confirmed by experts and experienced teachers, and its reliability was estimated at 95% and 91% using the inter-rater reliability method (Falah Chai, 1995).

The primary goal of the Falah Chai Spelling Test is to assess spelling abilities. It helps identify spelling problems and difficulties in writing, which can be useful in diagnosing specific learning disabilities and spelling weaknesses. The test typically includes a series of words and sentences that students are required to spell correctly, with third graders spelling 60 words and fourth graders spelling 80 words. These words and sentences are selected to assess spelling skills at different levels. The test consists of spelling dictations, where students either listen to or read texts and must write them accurately and with precision.

## 3.8 Reading in German and Persian Test

### 3.8.1 Salzburger one-minute Reading Fluency Test (SLT) (German Reading Test)

The SLT and SRT are both components of the Salzburger Reading and Spelling Test (SLRT-II; Moll et al., 2014). The SLT is appropriate for students starting from grade 1, where children are asked to read aloud as many words and pseudowords as possible within one minute. This test provides separate scores for the number of words and pseudowords read. The SLT evaluates both decoding skills and reading fluency. In this study, children read from a paper, and their verbal

responses were recorded by a test administrator using a paper-pencil method. To enhance the reliability of repeated testing, the SLRT-II includes two equivalent versions, Form A and Form B. Both forms are similar in structure but contain different sets of tasks. This design allows for multiple assessments over time without the risk of practice effects, where familiarity with test content could influence a student's performance. Form A was used in this study. The SLRT-II (Moll et al., 2014) demonstrates strong parallel test reliability, with coefficients ranging from rtt = .90 to .98.

### 3.8.2 Name test (Persian Reading Test)

This test was standardized by Karami Nouri & Moradi (2004) for monolingual (Persian) and bilingual (Tabrizi) male and female students from first to fifth grade. The overall alpha coefficient of the test is 0.82. The primary goal of this test is to diagnose dyslexia or other reading-related issues. Dyslexia is a type of learning disability that affects an individual's ability to read but does not impact general intelligence or other cognitive abilities. This test helps identify students who need special support. The test battery includes 10 subtests:

Word Reading Test: Includes a list of 40 words.

Word Comprehension.

Text Comprehension: Includes two subtests, general and specific, for each educational level.

Phoneme Deletion**.**

Word Chain Test**.**

Naming Pictures 1 and 2**.**

Rhyme Test**.**

Letter Markers**.**

Category Markers**.**

Pseudoword Reading**.**

In this research, we utilized the Word Reading and Pseudoword Reading subtests, each with a time limit of 2 minutes.

**Word Reading**: This subtest consists of three lists (high, medium, and low frequency) of 40 words each. The examinee is required to read these words from left to right and top to bottom as quickly and accurately as possible within two minutes.

**Pseudoword Reading**: In this subtest, the examinee reads 40 meaningless words, focusing on accuracy and speed while pointing to each word. They are instructed to ignore any meaning and read each pseudoword as it appears. Practice examples are provided beforehand, and the test lasts two minutes.

## 3.9 Graphomotor (German and Persian Test)

### 3.9.1 Automaticity in graphomotor movements (NIV)

Automaticity in graphomotor movements was assessed using a digitizing tablet (WACOM INTUOS4, Wacom, Neuss, Germany) with an inkless pen. The tablet accurately tracked the pen tip's location within 0.25 mm in both x and y directions at a frequency of 200 Hz, continuously recording velocity, acceleration, and axial pen pressure during the tasks. Data analysis was performed using commercial software (CSWin) (Mai & Marquardt, 1992). The writing environment was designed to feel natural, resembling a regular desk pad, and participants were not instructed to focus on neatness, accuracy, or legibility. The fluency of graphomotor movements was evaluated through the Number of Inversions in Velocity per stroke (NIV), a measure reflecting the degree of automaticity. Automated movements are characterized by smooth, single-peaked velocity curves, with an ideal NIV value of 1. Higher NIV values indicate less automatic movements (Marquardt, Gentz, Mai, 1999). For healthy adolescents aged 14 to 18, the average NIV ranges from 0.05 to 0.06 for drawing circles and from 0.30 to 0.13 for writing sentences (Rueckriegel et al., 2008c).

## 3.10 Vocabulary in German and Persian

### 3.10.1 The Peabody Picture Vocabulary

The Peabody Picture Vocabulary Test, Fourth Edition (PPVT-4), is a widely recognized assessment tool designed to measure receptive vocabulary, which refers to the words a person can understand when heard. This test is often used in educational and clinical settings to assess

language development and is suitable for individuals from 2.5 years old to 90 years old (L. M. Dunn & Dunn, 1965).

During the test, the examiner says a word aloud, and the participant is shown four pictures on a page. The task is to select the picture that best represents the meaning of the spoken word. The test items increase in difficulty as the participant progresses. Testing continues until the participant makes eight or more errors within a set of 12 items or until all items are completed. The test terminates when the participant reaches the ceiling, defined as making eight or more errors in a single set of 12 items. The raw score is calculated based on the number of correct responses. This raw score is then converted into a standard score using normative data.

The PPVT-4 demonstrates strong test-retest reliability, (r) of 0.92 (M. Dunn & Dunn, 2007), indicating that it consistently produces stable results across multiple administrations. Additionally, the test is highly regarded for its validity, meaning it accurately measures receptive vocabulary as intended.

In this study, we utilized the PPVT-4 not only for assessing vocabulary in German but also for evaluating Persian vocabulary.

## 3.11 Orthographic Knowledge in German and Persian

### 3.11.1 Word specific orthographic knowledge (WOK) in German

Orthographic processing at the lexical level was assessed using a word-specific orthographic knowledge (WOK) task. In this task, children were shown single words and asked to decide whether each word was spelled correctly by pressing a green tick or a red cross. The stimuli consisted of two types: correctly spelled words and pseudohomophones, which sound like real words but are misspelled. Some pseudohomophones used less common spellings (e.g., "ai" for /aɪ̯/ instead of the more common "ei" in German), while others used more common spellings than their base words (e.g., "eu" for /ɔʏ/ instead of "äu").

To ensure fairness, the words and pseudohomophones were matched in length and bigram/trigram frequencies. The words were selected from the 5% most frequent words in the childLex corpus, which contains about 9.9 million words. Pseudohomophones were created by altering a single grapheme in these high-frequency words. Each type consisted of 30 stimuli, resulting in a total of 60 stimuli presented in a single block to optimize time and maintain the children's attention. The

stimuli were shown in a pseudorandom order, ensuring no more than four consecutive items of the same type. Children practiced before the test, and the primary outcome measured was the number of correct responses. The task showed good internal consistency (Cronbach's α = .83) (Rothe et al., 2024).

### 3.11.2 Word specific orthographic knowledge (WOK) in Persian

To assess specific orthographic knowledge of Persian words, we utilized the construction of these words based on German word formation rules, adapted to Persian grammar. The task for the children was to indicate whether a visually presented word was spelled correctly by pressing a green tick or a red cross. There were two types of test stimuli: words and pseudohomophones, both of which appeared like real words. The words were spelled correctly, while the pseudohomophones contained spelling errors. Some pseudohomophones used different letters with similar sounds, but writing them with other letters is unacceptable in Persian orthography. For example, the letter "س" (S) could be replaced with "ص" (S) in the word "دست" (Hand in English), resulting in "دصت." Although this gives the same sound, its written form is unacceptable in Persian. Additionally, for some other words, a letter was omitted, which does not change the pronunciation in Persian but makes the spelling incorrect. For instance, the letter "و" (OW) in "بیسکویت" (Biscuit in English) was changed to "بیسکیت," where "و" is pronounced as OW and not U, but plays the role of a consonant that, even if omitted in writing, is still pronounced.

Therefore, on average, orthographic typicality was matched between words and pseudohomophones: all words were high-frequency words according to the research by Shirin Nemat Zadeh and colleagues (Nemat Zadeh et al, 2016). It is expected that participants have a strong representation of the spoken forms of these words. Nemat Zadeh's research includes around 17 million words distributed in the Persian language, which children up to the age of 11 use. This research categorizes 5,000 high-frequency words. The pseudohomophones were derived from these high-frequency words by substituting one grapheme with a similar-sounding one. First, for both words and pseudohomophones, the study identified the number of letters and the frequency of bigrams and trigrams through a Python code. Bigram and trigram frequencies in language refer to the occurrence rates of two-letter (bigram, e.g., "th," "er") and three-letter (trigram, e.g., "the," "ing") combinations, respectively, within a given language corpus (Gao et al., 2022; Massaro et al., 1981). These frequencies help quantify the likelihood of specific letter sequences appearing in

written language, offering insights into orthographic patterns, reading fluency, and language processing. The selection of these items was made to assess word-specific orthographic knowledge, rather than general orthographic knowledge related to positional constraints and the legality of letter combinations. Then, based on high frequencies, we extracted the words and pseudohomophones. There were 30 stimuli in each category (words and pseudohomophones), totaling 60 stimuli presented in a single block, with 30 words and 30 pseudohomophones included. Each stimulus was presented individually on a display screen. The stimuli were presented in a pseudo-random order to ensure that no more than four consecutive stimuli of the same type were presented. Children received practice items before starting the test. The outcome variable was the number of correct responses.

### 3.11.3 General orthographic knowledge (GOK) in German

Sublexical orthographic processing was assessed by measuring general orthographic knowledge (GOK) through a pseudoword decision task. Children were shown single pseudowords and asked to press a green tick or red cross to indicate whether the stimulus could be a real German word. They saw one item at a time and made yes-or-no decisions about its word-likeness, meaning whether the item could resemble a real word or not. For legal words, they selected a green check mark, and for illegal words, they chose a red cross. This task is suitable for this age group to prevent ceiling effects and allows for separate analysis of responses to legal and illegal pseudowords.

The stimuli included two types: legal pseudowords, which followed German orthographic rules, and illegal pseudowords, which contained one grapheme that violated these rules (e.g., "fruhl" as a legal pseudoword vs. "fruul" as an illegal one). Most illegal pseudowords had double consonants or vowels that are not allowed in German, such as “üü,” “ää,” or “zz.” Legal and illegal pseudowords were matched by letter count but not by bigram or trigram frequency, since illegal sequences have a frequency of zero. There were 24 stimuli for each type, presented in a single block. Stimuli were presented in a pseudorandom order to ensure no more than four consecutive items of the same type. The children completed practice items before the test, and the main outcome measures were the number of correct responses and response times. The task demonstrated good internal consistency (Cronbach’s $\alpha = .84$) (Rothe et al., 2024).

### 3.11.4 General orthographic knowledge (GOK) in Persian

Sublexical orthographic processing was assessed by measuring general orthographic knowledge through a pseudoword decision task for Persian words, following the structure of a similar task in German. Children were told that they would see individual pseudowords. Their task was to press a green tick or a red cross to indicate whether the visually presented stimulus could be a real word in Persian. They saw one item at a time on the screen and made "yes" or "no" decisions based on the similarity to real words.

There were two types of experimental stimuli: legal and illegal pseudowords. Both were unfamiliar in terms of spelling and sound. Legal pseudowords consisted of letter sequences that followed Persian orthographic rules, while illegal pseudowords contained a grapheme that violated these rules. For example, the legal pseudoword "شوار" is acceptable because the "وا" grapheme appears in the middle of the word "دیوار" (Wall). In contrast, the illegal pseudoword "شاار" is not acceptable because the double-vowel grapheme "اا" is not permitted in Persian (as two consonants cannot be placed together in this way). This rule was used to construct several illegal pseudowords. We also used the bigram and trigram frequencies from the previous table to construct these legal and illegal pseudowords, aiming to match the frequencies of the legal and illegal pseudowords as closely as possible.

Legal and illegal pseudowords were matched only by the number of letters, as illegal letter sequences have a frequency of 0, making it impossible to match them by bigram and trigram frequency. There were 24 stimuli for each type, resulting in a total of 48 stimuli presented in a single block. Each item was presented as a single stimulus in the center of the screen. The stimuli were presented in a pseudorandom order, ensuring no more than four consecutive items of the same type. Children received practice items before the test. The outcome variables were the number of correct responses and response times.

## 3.12 Development of Bigram and Trigram Frequency to Measure Orthographic knowledge

The WOK and GOK tests are employed to assess the orthographic skills and knowledge of children. However, a corresponding version of these tests did not exist in Persian. Therefore, the Persian version was developed, following the structural components of the German childLex corpus, meticulously following its structural components.

To initiate this process, the need for a comprehensive corpus of Persian words familiar to and utilized by Persian-speaking children was recognized. Unfortunately, no digital or application-based corpus was readily available in Persian. Nevertheless, a substantial research initiative titled "Persian Vocabulary," overseen by Professor Shahin Nemat-Zadeh and her colleagues, had compiled a written corpus of Persian words from 2001 to 2011 over a span of ten years.

Accessing this vocabulary database required extensive outreach. Emails were sent to numerous educators and researchers, but due to internet limitations in Iran, responses were slow and sporadic. This process was extended over a month, during which assistance was persistently sought. Ultimately, a reply was received from Professor Nemat-Zadeh, the lead researcher and compiler of the vocabulary corpus. We were informed that the printing of the book had concluded and that it would take approximately six months for a new print run.

In the end, access was gained to 305,000 repeated words of Persian children, and from these, 5,000 high-frequency words were selected from a total of 17 million words collected during the study. The 5,000 words represented the most frequently used words across the first to fifth elementary school books of Persian children. From two sets of word, the frequencies for both sets of 13,000 words and 5,000 high-frequency words were calculated, and since the frequencies were close to each other, it was decided to use the frequently used vocabulary from elementary school books

At first, access was only gained to the printed edition of the book in Iran, which was subsequently scanned. Using Optical Character Recognition (OCR) technology, the words were transcribed into a digital format to facilitate the analysis.

Following this, the calculation of bigram (two-letter combinations) and trigram (three-letter combinations) frequencies for these vocabulary words was required. To accomplish this, Python programming was utilized, and specific code was implemented to extract and compute these frequencies. The generated data provided the necessary vocabulary for the tests, ensuring that the assessments were grounded in a reliable linguistic framework.

After the bigrams and trigrams were extracted, access was gained to a comprehensive collection of these bigrams and trigrams in Persian, similar to the German childLex corpus. Utilizing this data, a variety of real and pseudoword Persian words were meticulously constructed. This process involved ensuring that the frequency distributions of these words were consistent and closely

aligned with those found in the original corpus. By adhering to these frequency patterns, a linguistically rich and contextually appropriate set of words was aimed to be created that could effectively assess children's language skills in both real and pseudoword contexts.

# 4 Chapter IV: Results

Data were analyzed using the R and JASP software. To analyze the data, Linear Regression Models were used in R, and a Bayesian Linear Regression Model was used in JASP, since the experiment was a pilot study with a small sample (10 data). Through the analysis of bilingual data, it was researched how graphomotor skills, vocabulary, reading, and orthographic knowledge (WOK and GOK) of the German and Persian languages predict the spelling of German and Persian. Six hypotheses were analyzed first in R. In R, the linear regression model was found to be significant, but it could not be determined which predictor variable (reading, vocabulary, orthographic knowledge, graphomotor) was the most significant in predicting the dependent variable (spelling) due to the small sample size. Therefore, the hypotheses were also checked with a Bayesian linear regression model, as this method is better equipped for data analysis of small samples and could identify which variable is a better predictor of spelling in the model.

Cognitive linguistic Variable: spelling.P, spelling.G, NIV1,NIV2 (graphmotor variable of German), NIV7,NIV8 (graphmotor variable of Persian), vocabulary.P, vocabulary.G, reading.P, reading.G, WOK.P and KOG.P, WOK.G and KOG.G (orthographic knowledge)

**Abbreviations of Variables**

P=Persian

G=German

Spelling.P= the spelling score of Persian

Spelling.G= the spelling score of German

Reading.P= the reading score of Persian

Reading.G= the reading score of German

Vocabulary.P= the vocabulary score of Persian

Vocabulary.G= the vocabulary score of German

WOK.P= the word specific orthographic knowledge score of Persian

WOK.G= the word specific orthographic knowledge score of German

GOK.P= the General orthographic knowledge score of Persian

GOK.G= the General orthographic knowledge score of German

NIV1, NIV2= the Graphmotor score of German, NIV1 (German sentence), NIV2 (German letter)

NIV7, NIV8= the Graphmotor score of Persian, NIV7 (Persian sentence), NIV8 (Persian letter)

Other variable: Immigration (the duration of student immigration, the duration of Parent immigratin), age, grade, nathionality, handedness, movement skills, mental disorders

Before starting the analyses, the dataset was inspected for normality and homoscedasticity of the residual distribution, including checking for outliers. Following the normality assumptions testing methods of (Larson-Hall, 2015), histograms and q–q plots were charted for each variable. Acceptable values of skewness (between − 1 and + 1) and kurtosis (ranging from − 1 to + 1) (Blanca et al., 2013) were found for all variables. All variables formed histograms with a normal distribution. The variance inflation factor (VIF) was checked by R and for all variable in each model was not higher than 5 (Akinwande et al., 2015), so it suggests that the predictors might not be highly correlated with others, the reliability of the model confirmed.

**Descriptive analysis of bilingual student can be find below:**

Table 1: Participant Demographics Distribution by Sex, Grade, Nationality, and Handedness

| Sex | | Grade | | Nationality | | Handedness | | |
|---|---|---|---|---|---|---|---|---|
| Boy | Girl | Third grade | Fourth grade | Iran | Afghanistan | Right hand | Left hand | Both hand |
| 6 | 4 | 4 | 6 | 6 | 4 | 8 | 1 | 1 |

This chapter presents the results of the study, focusing on the demographic characteristics of the participants. The sample consisted of 10 children, whose characteristics are detailed below.

## 4.1 Demographics Distribution

### 4.1.1 Gender Distribution

The gender distribution of the participants is as follows:

- Boys: 6 (60%)
- Girls: 4 (40%)

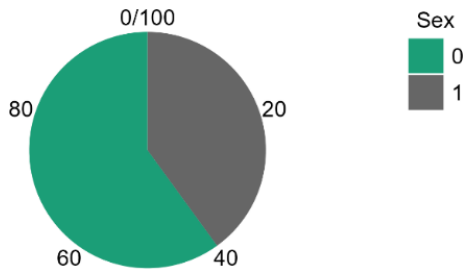


Figure 1: Gender Distribution

### 4.1.2 Grade Level

Participants were divided by grade level:

- Fourth Grade: 6 children (60%)
- Third Grade: 4 children (40%)

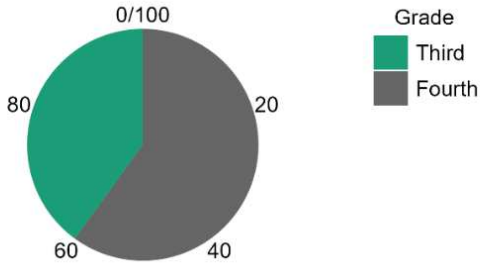


Figure 2: Grade Level

### 4.1.3 Nationality

The nationality of the participants was recorded:

- Iranian: 6 children (60%)
- Afghan: 4 children (40%)

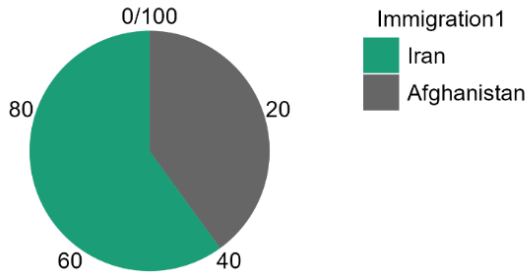


Figure 3: Nationality

### 4.1.4 Handedness

Handedness among the participants was assessed, resulting in the following distribution:

- Right-Handed: 8 children (80%)
- Left-Handed: 1 child (10%)
- Ambidextrous: 1 child (10%)

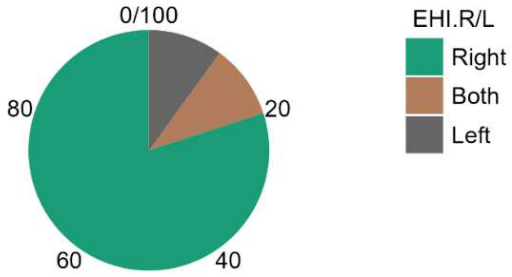


Figure 4: Handedness

Table 2: : Descriptive Statistic Of Age and Immigration of Students and Family

| | Age | Immigration1.a | Immigration3.a | Immigration4.a |
|---|---|---|---|---|
| Valid | 10 | 10 | 10 | 10 |
| Missing | 0 | 0 | 0 | 0 |
| Mean | 10.6 | 26.3 | 31.4 | 30.6 |
| Std. Deviation | 1.35 | 21.64 | 25.97 | 26.27 |

Immigration1.a= the duration of immigration of student in month

Immigration3.a= the duration of immigration of mother in month

Immigration4.a= the duration of immigration of father in month

## 4.2 Age

The age of participants ranged from 9 to 13 years, with a mean age of 10.60 years (SD = 1.35).

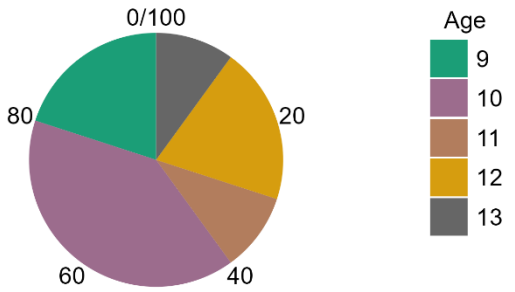


Figure 5: Age

## 4.3 Immigration Variables

The immigration-related variables were measured as follows:

- Immigration1.a had a mean score of 26.30 (SD = 21.64)
- Immigration3.a exhibited a mean of 31.40 (SD = 25.97)
- Immigration4.a demonstrated a mean of 30.60 (SD = 26.28)

All variables had complete data with no missing values. These descriptive statistics provide essential insights into the duration of immigration for the children, their mothers, and their fathers, and will inform subsequent analyses related to the study's hypotheses regarding the impact of immigration duration on developmental and cognitive outcomes.

### 4.4 Descriptive Statistics of Developmental Coordination Disorder Questionnaire (DCDQ)

The following table summarizes the descriptive statistics for the scores obtained from the Developmental Coordination Disorder Questionnaire (DCDQ), which includes the subscales for motor movement, fine motor skills, general coordination, and the total score.

Table 3: Descriptive Statistic of DCDQ

| | Motor Movement | Fine Motor | General Coordination | Total Score. |
|---|---|---|---|---|
| Valid | 10 | 10 | 10 | 10 |
| Missing | 0 | 0 | 0 | 0 |
| Mean | 28.70 | 17.50 | 18.50 | 66.50 |
| Std. Deviation | 2.21 | 5.58 | 3.89 | 5.91 |

The mean score for the Motor Movement DCDQ subscale was 28.70 (SD = 2.21). For the Fine Motor DCDQ, participants achieved a mean score of 17.50 (SD = 5.58). The mean score for General Coordination DCDQ was 18.50 (SD = 3.89), while the Total Score DCDQ exhibited a mean of 66.50 (SD = 5.91).)

All variables showed complete data with no missing values. These descriptive statistics provide critical insights into the motor skills and coordination abilities of the participants, which will be useful in understanding their performance in the context of developmental coordination disorder. Additionally, it was confirmed that none of the participants had any diagnosed movement disorders, ensuring that the data reflect typical motor development within the sample.

### 4.5 Descriptive Statistics of Mental Disorders from Screening Measures

The following table presents the descriptive statistics for the various screening measures utilized in the study, including Attention deficit hyperactivity disorder (ADHD), social behavior disorders (SSV), Anxiety, Depression, Autism, Obsessive-compulsive spectrum disorders (OCD) and Tic disorders, and the overall FBB score. A score above the critical value indicates clinically relevant symptoms.

Table 4: Descriptive Statistic of Mental Disorder from FBB SCREEN

| | ADHD.Screen | SSV.Screen | Anxiety.Screen | Depression.Screen | Autism.scren | OCD&Tic.Screen | Overall.Screen.FBB |
|---|---|---|---|---|---|---|---|
| Valid | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Missing | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean | 3.90 | 4.20 | 5.30 | 3.40 | 3.80 | 1.40 | 3.70 |
| Std. Deviation | 3.41 | 2.89 | 2.54 | 3.74 | 3.52 | 3.10 | 3.13 |

The mean score for the ADHD Screen was 3.90 (SD = 3.41), participants scored an average of 4.20 (SD = 2.89) on the SSV Screen, while the Anxiety Screen yielded a mean score of 5.30 (SD = 2.54). For the Depression Screen, the mean was 3.40 (SD = 3.74), and the Autism Screen showed a mean score of 3.80 (SD = 3.52). Participants had a mean score of 1.40 (SD = 3.10) on the OCD & Tic Screen, while the Overall Screen FBB had a mean score of 3.70 (SD = 3.13).

All screening measures were complete, with no missing values. These descriptive statistics provide important insights into the mental health was confirmed that none of the participants had diagnosed mental disorders above the score critical value, ensuring that the data reflect typical mental health and developmental characteristics within the sample.

## 4.6 Descriptive statistic of variables in Persian

Table 5: Descriptive Statistic of vocabulary, spelling, reading, WOK, GOK, NIV1, NIV2 in Persian language

| | Vocabulary | Spelling | Reading | Reading Pseudo | WOK | GOK | NIV7 | NIV8 |
|---|---|---|---|---|---|---|---|---|
| Valid | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Missing | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean | 55.60 | 33.80 | 49.70 | 49.10 | 45.90 | 42.90 | 1.35 | 1.96 |
| Std. Deviation | 13.08 | 23.46 | 10.00 | 10.00 | 7.95 | 3.38 | 0.44 | 0.76 |

For the Persian language data, the mean score for vocabulary was significantly higher at 55.60 (SD = 13.08), while the mean for spelling was lower at 33.80 (SD = 23.46). The mean for

reading was 49.70 (SD = 10.00), and for the Persian pseudo-word reading task, the mean was 49.10 (SD = 10.00). The Persian word Orthographic Knowledge (WOK) had a mean score of 45.90 (SD = 7.95), while Persian General Orthographic Knowledge (GOK) mirrored the German GOK, with a mean of 42.90 (SD = 3.38). In terms of kinematic measures, the NIV for the (NIV7) had a mean of 1.35 (SD = 0.44), and the (NIV8) matched the German NIV2 score, with a mean of 1.96 (SD = 0.76).

## 4.7 Descriptive statistic of variables in German

Table 6: Descriptive Statistic of vocabulary, spelling, reading, WOK, GOK, NIV7, NIV8 in German language

| | Vocabulary | Spelling | Reading | Reading Pseudo | WOK | GOK | NIV1 | NIV2 |
|---|---|---|---|---|---|---|---|---|
| Valid | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Missing | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mean | 30.1 | 44.40 | 22.4 | 33.1 | 45.4 | 42.9 | 1.12 | 1.96 |
| Std. Deviation | 4.55 | 11.40 | 31.18 | 12.27 | 9.72 | 4.28 | 0.62 | 0.76 |

For the German language data, the mean score for vocabulary was 30.1 (SD = 4.55), while the mean for spelling was higher at 44.40 (SD = 11.40). The mean for reading was notably lower at 22.4 (SD = 31.18). For the German pseudo-word Reading task, participants had a mean score of 33.1 (SD = 12.27). The German word Orthographic Knowledge (WOK) and German General Orthographic Knowledge (GOK) scores were close, with means of 45.4 (SD = 9.72) and 42.9 (SD = 4.28), respectively. Regarding the kinematic measures, the number of velocity inversions (NIV) for the first stroke (NIV1) had a mean of 1.12 (SD = 0.62), while the second stroke (NIV2) had a mean of 1.96 (SD = 0.76).

## 4.8 Analysis

The data were first analyzed using R and then with JASP.

JASP provides robust options for Bayesian analysis, which can be especially useful when dealing with smaller samples, as it allows for more informative conclusions where traditional frequentist methods might struggle with low power (Van De Schoot et al., 2014).

## 4.9 Hypothesis

**Persian vocabulary, Persian reading fluency, Persian orthographic processing will be significant predictor of Persian spelling performance**

For this hypothesis we first analysis of the model in linear regression in R, and the result in Table A- 1 and Table A- 2 showed that Residual Standard Error (RSE): 10.49 indicates that, on average, observed spelling scores deviate from predicted scores by about 10.49 points, suggesting reasonable prediction accuracy.

Multiple R-squared: 0.88 indicates that approximately 88% of the variance in spelling performance is explained by the model, indicating a strong fit.

Adjusted R-squared: 0.80 suggests that about 80% of the variance is explained after adjusting for the number of predictors, still indicating a robust model.

F-statistic: 10.2 suggests that the model provides a significantly better fit than a null model, indicating meaningful relationships among predictors.

p-value: 0.01 is below 0.05, indicating that the model is statistically significant, confirming that at least one predictor significantly affects spelling performance.

Overall, the regression analysis shows a strong model fit and significant predictors, highlighting meaningful relationships in explaining spelling performance among participants.

Since the sample is small and in R the analysis showed that overall model is statistically significant and found reading, WOK and GOK is also statistically significant but vocabulary is not significant. The model was analyzed in JASP via Bayesian linear regression to found is there the effect of independent variable to each other.

In below there is some table to show the analysis in JASP:

Table 7: Model 1 Comparison - Spelling Persian

| Models | P(M) | P(M\|data) | $BF_M$ | $BF_{10}$ | $R^2$ |
|---|---|---|---|---|---|
| Vocabulary.P + Reading.P + P.WOK + P.GOK | 0.200 | 0.392 | 2.583 | 1.000 | 0.889 |
| Reading.P | 0.050 | 0.098 | 2.070 | 1.002 | 0.608 |
| Reading.P + P. WOK + P.GOK | 0.050 | 0.088 | 1.834 | 0.898 | 0.810 |

| Models | P(M) | P(M\|data) | $BF_M$ | $BF_{10}$ | $R^2$ |
|---|---|---|---|---|---|
| Null model | 0.200 | 0.063 | 0.271 | 0.162 | 0.000 |
| Reading.P + P. WOK | 0.033 | 0.057 | 1.740 | 0.865 | 0.713 |
| Reading.P + P. WOK | 0.033 | 0.055 | 1.679 | 0.837 | 0.709 |
| Vocabulary.P + Reading.P + P. WOK | 0.050 | 0.046 | 0.917 | 0.470 | 0.739 |
| P. WOK | 0.050 | 0.045 | 0.903 | 0.463 | 0.486 |
| Vocabulary.P + Reading.P + P.GOK | 0.050 | 0.042 | 0.823 | 0.423 | 0.725 |
| Vocabulary.P + Reading.P | 0.033 | 0.027 | 0.804 | 0.412 | 0.609 |

Table 8: Posterior Summaries of Coefficient of Model1. Spelling Persian s

| Coefficient | P(incl) | P(excl) | P(incl\|data) | P(excl\|data) | BFinclusion | Mean | SD |
|---|---|---|---|---|---|---|---|
| Intercept | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 33.800 | 4.612 |
| Vocabulary.P | 0.500 | 0.500 | 0.562 | 0.438 | 1.285 | -0.212 | 0.319 |
| Reading.P | 0.500 | 0.500 | 0.805 | 0.195 | 4.117 | 0.914 | 0.603 |
| P. WOK | 0.500 | 0.500 | 0.693 | 0.307 | 2.260 | 0.811 | 0.732 |
| P.GOK | 0.500 | 0.500 | 0.638 | 0.362 | 1.765 | 1.267 | 1.317 |

The probabilities of each model being the best given the data vary. The highest probability is for the model with reading, vocabulary, orthographic knowledge (0.39), suggesting it is the most plausible model. This model should be a focus because it incorporates all variables.

The Bayes factor for the model with all variables (2.58) suggests strong evidence in favor of this model compared to the null model. This indicates that the relationship between reading, vocabulary, orthographic knowledge and spelling is likely meaningful.

The $BF_{10}$ for the model with vocabulary, reading and orthographic knowledge is 1 and compeer to null model $BF_{10}$ = 0.16, indicating the plausibility of the hypothesis that vocabulary, reading fluency, and orthographic processing are indeed significant predictors of spelling performance.

$R^2$ Value: The $R^2$ indicates how well the model explains the variance in spelling performance. The model with reading, vocabulary and orthographic knowledge has an $R^2$ of 0.88, which means it explains a significant proportion of the variance in spelling.

P(incl) and P(excl): Focus on the inclusion probabilities. For reading, vocabulary and orthographic, all have P(incl) = 0.500, indicating uncertainty, but their P(incl|data), the posterior inclusion probability is strong (0.8 for reading, 0.56 for vocabulary and 2.2, 0.88 for orthographic knowledge), suggesting they contribute meaningfully to the model. It means that each predictor has a chance of being a necessary predictor in the model for spelling performance based on the data.

For reading and WOK&GOK orthographic the mean coefficient is 0.91, 0.81, 1.26 respectively, indicating a positive relationship with spelling performance.

From Bayes Factor for Inclusion (BFinclusion), for all variables showed moderate evidence that the predictors were important in explaining spelling performance, suggesting their inclusion improved model fit, especially for reading (4.11) and orthographic knowledge WOK (2.26).

Model performance emphasize the strong performance of the model incorporating all variables in explaining spelling variance.

**NIV of Persian writing will significantly predict Persian spelling performance above and beyond the predictors like Persian vocabulary, Persian reading, Persian orthographic processing**

For this hypothesis we first analysis of our model in linear regression in R, and the result in Table A- 3 and Table A- 4 confirmed that Residual Standard Error (RSE): 9.33 (on 2 degrees of freedom) indicates an average deviation of the observed values from the predicted values, suggesting high prediction accuracy.

Multiple R-squared: 0.94 indicates that approximately 94% of the variance in spelling performance is explained by the model, indicating a strong fit.

Adjusted R-squared: 0.84 suggests that about 84% of the variance is explained after adjusting for the number of predictors, still indicating a robust model.

F-statistic: 8.97 suggests that the model provides a significantly better fit than a null model, indicating meaningful relationships among predictors.

p-value: 0.04 is below 0.05, indicating that the model is statistically significant, confirming that at least one predictor significantly affects spelling performance.

Overall, the regression analysis shows a strong model fit and significant predictors, highlighting meaningful relationships in explaining spelling performance among participants.

Since the small sample was analyzed and in R, it just showed overall model is statistically significant and not found the effect of each variable. We analysis our model in JASP via Bayesian linear regression.

Table 9: Model 2 Comparison - Spelling Persian

| Models | P(M) | P(M\|data) | $BF_M$ | $BF_{10}$ | $R^2$ |
|---|---|---|---|---|---|
| Vocabulary.P + Reading.P + P.WOK + P.GOK + NIV7+ NIV8 | 0.143 | 0.152 | 1.074 | 1.000 | 0.947 |
| Reading.P | 0.024 | 0.055 | 2.391 | 2.177 | 0.608 |
| Null model | 0.143 | 0.053 | 0.339 | 0.352 | 0.000 |
| Reading.P + NIV7 | 0.010 | 0.041 | 4.464 | 4.065 | 0.789 |
| Reading.P + P.WOK + P.GOK + NIV7 + NIV8 | 0.024 | 0.034 | 1.454 | 1.353 | 0.916 |
| Vocabulary.P + Reading.P + P.WOK + P.GOK + NIV8 | 0.024 | 0.033 | 1.421 | 1.323 | 0.914 |
| Vocabulary.P + Reading.P + P.WOK + P.GOK + NIV7 | 0.024 | 0.028 | 1.189 | 1.113 | 0.902 |
| P.WOK | 0.024 | 0.025 | 1.071 | 1.005 | 0.486 |
| Reading.P + NIV7+ NIV8 | 0.007 | 0.025 | 3.498 | 3.232 | 0.851 |
| Reading.P + P.WOK+ P.GOK + NIV7 | 0.010 | 0.024 | 2.535 | 2.350 | 0.894 |

Table 10: Posterior Summaries of Coefficients of Model2. Spelling Persian

| Coefficient | P(incl) | P(excl) | P(incl\|data) | P(excl\|data) | BFinclusion | Mean | SD |
|---|---|---|---|---|---|---|---|
| Intercept | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 33.800 | 4.457 |
| Vocabulary.P | 0.500 | 0.500 | 0.461 | 0.539 | 0.854 | -0.123 | 0.388 |
| Reading.P | 0.500 | 0.500 | 0.721 | 0.279 | 2.586 | 0.696 | 0.597 |
| P.WOK | 0.500 | 0.500 | 0.571 | 0.429 | 1.331 | 0.537 | 0.683 |
| P.GOK | 0.500 | 0.500 | 0.515 | 0.485 | 1.063 | 0.791 | 1.199 |
| NIV7 | 0.500 | 0.500 | 0.632 | 0.368 | 1.719 | -12.415 | 14.185 |
| NIV8 | 0.500 | 0.500 | 0.504 | 0.496 | 1.017 | 3.795 | 6.864 |

The probabilities of each model being the best given the data vary. The highest probability is for the model with Reading, Vocabulary, orthographic knowledge, NIV7 and NIV8 (0.15), suggesting it is the most plausible model. This model should be a focus because it incorporates all variables.

The Bayes factor for the model with all variables (1.07) suggests strong evidence in favor of this model compared to the null model. This indicates that the relationship between reading, vocabulary, orthographic knowledge, NIVs and spelling is likely meaningful.

$R^2$ Value: The $R^2$ indicates how well the model explains the variance in spelling performance. The model with reading, vocabulary, orthographic knowledge and NIVs has an $R^2$ of 0.94, which means it explains a significant proportion of the variance in spelling.

P(incl) and P(excl): Focus on the inclusion probabilities. For reading, vocabulary and orthographic, all have P(incl) = 0.500, indicating uncertainty, but their BFinclusion values are strong 2.58 for reading, 1.33 for WOK, 1.06 for GOK and 1.71 for NIV7, 1.01 for NIV8, suggesting they contribute meaningfully to the model. It means that each predictor has a chance of being a necessary predictor in the model for spelling performance based on the data.

For reading, WOK, GOK and NIV8 the mean coefficient is 0.69, 0.53, 0.79 and 3.79 respectively, indicating a positive relationship with spelling performance.

For vocabulary the mean coefficient is -0.12, and NIV7 is -12.41 indicating a negative relationship with spelling performance.

From Bayes Factor for Inclusion (BFinclusion), for all variables showed moderate evidence that the predictors were important in explaining spelling performance, suggesting their inclusion improved model fit, especially for reading (2.58) and NIV sentence (1.71).

Model Performance emphasize the strong performance of the model incorporating all variables in explaining spelling variance.

**German vocabulary, German reading fluency, German orthographic processing will be significant predictor of German spelling performance**

For this hypothesis we first analysis of our model in linear regression in R, and the result in

Table A- 5 and

Table A- 6 confirmed that Residual Standard Error (RSE): 4.38 (on 2 degrees of freedom) indicates a low average deviation of the observed values from the predicted values, suggesting high prediction accuracy.

Multiple R-squared: 0.91 indicates that approximately 91% of the variance in spelling performance is explained by the model, indicating a strong fit.

Adjusted R-squared: 0.85 suggests that about 85% of the variance is explained after adjusting for the number of predictors, still indicating a robust model.

F-statistic: 13.97 suggests that the model provides a significantly better fit than a null model, indicating meaningful relationships among predictors.

p-value: 0.006 is below 0.05, indicating that the model is statistically significant, confirming that at least one predictor significantly affects spelling performance.

Overall, the regression analysis shows a strong model fit and significant predictors, highlighting meaningful relationships in explaining spelling performance among participants.

Since our sample is small and in R we just understand overall model is statistically significant and not found which model is the best. We analysis our model in JASP via Bayesian linear regression.

Table 11: Model 1 Comparison- Spelling German

| Models | P(M) | P(M\|data) | $BF_M$ | $BF_{10}$ | $R^2$ |
|---|---|---|---|---|---|
| Reading.G | 0.050 | 0.338 | 9.690 | 1.000 | 0.878 |
| Vocabulary.G | 0.050 | 0.118 | 2.548 | 0.350 | 0.832 |
| Vocabulary.G + G.WOK | 0.033 | 0.096 | 3.089 | 0.428 | 0.907 |
| Reading.G + G.WOK | 0.033 | 0.073 | 2.291 | 0.325 | 0.897 |
| Vocabulary.G + Reading.G + G.WOK+ G.GOK | 0.200 | 0.058 | 0.248 | 0.043 | 0.918 |
| Reading.G + G.GOK | 0.033 | 0.056 | 1.724 | 0.249 | 0.886 |
| Vocabulary.G + Reading.G | 0.033 | 0.050 | 1.524 | 0.222 | 0.881 |
| Vocabulary.G + G.GOK | 0.033 | 0.047 | 1.429 | 0.209 | 0.879 |
| Vocabulary.G + G.WOK + G.GOK | 0.050 | 0.044 | 0.866 | 0.129 | 0.914 |
| Vocabulary.G + Reading.G + G.WOK | 0.050 | 0.041 | 0.805 | 0.120 | 0.912 |

Table 12: Posterior Summaries of Coefficients of Model1. Spelling German

| Coefficient | P(incl) | P(excl) | P(incl\|data) | P(excl\|data) | $BF_{inclusion}$ | Mean | SD |
|---|---|---|---|---|---|---|---|
| Intercept | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 44.400 | 1.414 |
| Vocabulary.G | 0.500 | 0.500 | 0.485 | 0.515 | 0.941 | 0.738 | 0.993 |

| Coefficient | P(incl) | P(excl) | P(incl\|data) | P(excl\|data) | $BF_{inclusion}$ | Mean | SD |
|---|---|---|---|---|---|---|---|
| Reading.G | 0.500 | 0.500 | 0.676 | 0.324 | 2.087 | 0.179 | 0.163 |
| G.WOK | 0.500 | 0.500 | 0.354 | 0.646 | 0.548 | 0.104 | 0.196 |
| G.GOK | 0.500 | 0.500 | 0.269 | 0.731 | 0.369 | -0.074 | 0.243 |

The probabilities of each model being the best given the data vary. The probability for the model with Reading, Vocabulary, orthographic knowledge is (0.05), suggesting it is plausible model. This model should be a focus because it incorporates all variables.

The Bayes factor for the model with all variables (0.24) suggests the evidence in favor of this model compared to the null model. This indicates that the relationship between reading, vocabulary, orthographic knowledge, and spelling is likely meaningful.

$R^2$ Value: The $R^2$ indicates how well the model explains the variance in spelling performance. The model with reading, vocabulary, orthographic knowledge and NIVs has an $R^2$ of 0.91, which means it explains a significant proportion of the variance in spelling.

P(incl) and P(excl): Focus on the inclusion probabilities. For reading, vocabulary and orthographic, all have P(incl) = 0.500, indicating uncertainty, but their BF inclusion values are strong 2.08 for reading, 0.94 for vocabulary and 0.54, for WOK, 0.36 for GOK suggesting they contribute meaningfully to the model.

The model comparison reveals that reading fluency alone explains a substantial portion of spelling variance ($R^2$ = 0.878, BF10 = 1.000). While vocabulary and orthographic knowledge add value, particularly when combined with reading, the highest explanatory power comes from including all predictors together ($R^2$ = 0.918), although with weaker evidence (BF10 = 0.043). The data suggest that reading fluency is the strongest individual predictor, supported by vocabulary and specific orthographic skills, providing valuable insights into factors influencing spelling performance.

For reading, vocabulary, WOK the mean coefficient is 0.17, 0.73, 0.10 respectively, indicating a positive relationship with spelling performance.

For GOK the mean coefficient is -0.07, indicating a negative relationship with spelling performance.

Model Performance emphasize the strong performance of the model incorporating all variables in explaining spelling variance.

**German vocabulary, German reading fluency, German orthographic processing and NIVs will be significant predictor of German spelling performance**

For this hypothesis we first analysis of our model in linear regression in R, and the result in

Table A- 7 and Table A- 8 showed that Residual Standard Error (RSE): 4.46 (on 2 degrees of freedom) indicates an average deviation of the observed values from the predicted values, suggesting high prediction accuracy.

Multiple R-squared: 0.94 indicates that approximately 94% of the variance in spelling performance is explained by the model, indicating a strong fit.

Adjusted R-squared: 0.84 suggests that about 84% of the variance is explained after adjusting for the number of predictors, still indicating a robust model.

F-statistic: 9.03 suggests that the model provides a significantly better fit than a null model, indicating meaningful relationships among predictors.

p-value: 0.04 is below 0.05, indicating that the model is statistically significant, confirming that at least one predictor significantly affects spelling performance.

Overall, the regression analysis shows a strong model fit and significant predictors, highlighting meaningful relationships in explaining spelling performance among participants.

Since our sample is small and in R we just understand overall model is statistically significant and not found which model is the best. We analysis our model in JASP via Bayesian linear regression.

Table 13: Model 2 Comparison - Spelling German

| Models | P(M) | P(M\|data) | $BF_M$ | $BF_{10}$ | $R^2$ |
|---|---|---|---|---|---|
| Reading.G | 0.024 | 0.240 | 12.926 | 1.000 | 0.878 |
| Reading.G + NIV2 | 0.010 | 0.136 | 16.421 | 1.422 | 0.939 |
| Vocabulary.G | 0.024 | 0.084 | 3.756 | 0.350 | 0.832 |
| Reading.G + NIV1 | 0.010 | 0.050 | 5.457 | 0.520 | 0.913 |

| Models | P(M) | P(M\|data) | $BF_M$ | $BF_{10}$ | $R^2$ |
|---|---|---|---|---|---|
| Vocabulary.G + G.WOK | 0.010 | 0.041 | 4.445 | 0.428 | 0.907 |
| Reading.G + G.WOK | 0.010 | 0.031 | 3.346 | 0.325 | 0.897 |
| Reading.G + G.GOK | 0.010 | 0.024 | 2.546 | 0.249 | 0.886 |
| Reading.G + NIV2 + G.GOK | 0.007 | 0.023 | 3.247 | 0.317 | 0.942 |
| Vocabulary.G + Reading.G | 0.010 | 0.021 | 2.259 | 0.222 | 0.881 |
| Reading.G + G.WOK+ NIV2 | 0.007 | 0.021 | 2.950 | 0.289 | 0.940 |

Table 14: Posterior Summaries of Coefficients of Model2. Spelling German

| Coefficient | P(incl) | P(excl) | P(incl\|data) | P(excl\|data) | $BF_{inclusion}$ | Mean | SD |
|---|---|---|---|---|---|---|---|
| Intercept | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 44.400 | 1.350 |
| Vocabulary.G | 0.500 | 0.500 | 0.372 | 0.628 | 0.593 | 0.465 | 0.950 |
| Reading.G | 0.500 | 0.500 | 0.749 | 0.251 | 2.978 | 0.232 | 0.166 |
| G.WOK | 0.500 | 0.500 | 0.250 | 0.750 | 0.334 | 0.038 | 0.189 |
| NIV1 | 0.500 | 0.500 | 0.221 | 0.779 | 0.283 | -0.309 | 1.678 |
| NIV2 | 0.500 | 0.500 | 0.366 | 0.634 | 0.578 | -1.171 | 1.986 |
| G.GOK | 0.500 | 0.500 | 0.211 | 0.789 | 0.268 | -0.052 | 0.201 |

The probabilities of the model dose not being the best given the data vary. And the model with reading, vocabulary, orthographic with NIVS are not significant.

The highest probability for the model with Reading+NIV2 is (0.13), and for reading+NIV1 is (0.05), suggesting the NIVs with reading is the plausible model. This model should be a focus because it incorporates some variables related to our hypothesis.

The Bayes factor for the model with reading + NIV2 variables (1.42) and for the model with reading + NIV1 variable (0.52) suggests strong evidence in favor of this model compared to the null model. This indicates that the relationship between reading, and, NIVs and spelling is likely meaningful.

$R^2$ Value: The $R^2$ for each model of NIVs indicates how well the model explains the variance in spelling performance. The model with reading, and NIVs has an $R^2$ of 0.91-0.93, which means it explains a significant proportion of the variance in spelling.

P(incl) and P(excl): Focus on the inclusion probabilities. For reading, vocabulary and orthographic, all have P(incl) = 0.500, indicating uncertainty, but their BFinclusion values are strong 2.97 for reading, 0.46 for vocabulary and 0.33 for WOK, 026 for GOK and 0.28 for NIV1, 0.57 for NIV2 suggesting they contribute meaningfully to the model.

For reading, vocabulary, WOK the mean coefficient is 0.23, 0.46, 0.03 respectively, indicating a positive relationship with spelling performance.

For GOK the mean coefficient is -0.05, and NIV1 is -0.3 and NIV2 is 1.17 indicating a negative relationship with spelling performance.

Model Performance does not emphasize the strong performance of the model incorporating all variables in explaining spelling variance.

**The NIV can be a predictor variable of spelling in German language**

For this hypothesis we first analysis of our model in linear regression in R, and the result in Table A- 9 and Table A- 10 showed that the regression analysis yielded an intercept estimate of 51.66, indicating the predicted value of the dependent variable when all independent variables are zero. For NIV1, the result is not statistically significant (p = 0.1), suggesting that it does not have a meaningful impact on the dependent variable. Similarly, for NIV2, the result also lacks statistical significance (p = 0.1), indicating that any potential association between NIV2 and the dependent variable is not definitive.

The overall model's fit is reflected in the multiple R-squared value of 0.31, meaning that approximately 31% of the variance in the dependent variable can be explained by the model, which is considered a moderate effect size. However, the adjusted R-squared value of 0.11 indicates that after adjusting for the number of predictors, only 11% of the variance is explained, suggesting that the model may not be capturing the data's complexities effectively. The F-statistic of 1.57 and corresponding p-value of 0.27 indicate that the overall model does not significantly predict the dependent variable, implying that the combination of NIV1 and NIV2 does not provide a strong basis for understanding the outcome in this context. Overall, the results indicate that while there may be trends present, neither NIV1 nor NIV2 demonstrates a statistically significant effect on the dependent variable in this analysis. It may be beneficial to consider other variables that could

influence the dependent variable, as their inclusion might reveal more meaningful relationships within the data.

Since our sample is small and in R we just understand there is small effect of NIV on spelling but not statistically significant. We analyses our model in JASP via Bayesian linear regression.

Table 15: Model 3 Comparison - Spelling German

| Models | P(M) | P(M\|data) | $BF_M$ | $BF_{10}$ | $R^2$ |
|---|---|---|---|---|---|
| Null model | 0.333 | 0.441 | 1.576 | 1.000 | 0.000 |
| NIV1 + NIV2 | 0.333 | 0.309 | 0.896 | 0.702 | 0.310 |
| NIV2 | 0.167 | 0.131 | 0.755 | 0.595 | 0.072 |
| NIV1 | 0.167 | 0.119 | 0.673 | 0.539 | 0.035 |

Table 16: Posterior Summaries of Coefficients of Model3. Spelling German

| Coefficient | P(incl) | P(excl) | P(incl\|data) | P(excl\|data) | $BF_{inclusion}$ | Mean | SD |
|---|---|---|---|---|---|---|---|
| Intercept | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 44.400 | 3.571 |
| NIV1 | 0.500 | 0.500 | 0.428 | 0.572 | 0.748 | 2.297 | 4.665 |
| NIV2 | 0.500 | 0.500 | 0.441 | 0.559 | 0.787 | -2.138 | 3.976 |

The null model has the highest probability of being the true model based on the data (P(M|data) = 0.44). This suggests that NIV alone (NIV1, NIV2) doesn't add significant predictive power for spelling performance over the null model.

However, the model including both NIV1.Trans + NIV2.Trans has an $R^2$ of 0.31, meaning it explains 31% of the variance in spelling performance. The adjusted $R^2$ is 0.11, which indicates that once you adjust for the number of predictors, the explained variance drops, suggesting some overfitting.

The p-value for the model is 0.27, which is not statistically significant. This means there's no strong evidence to suggest that NIV alone is a strong predictor of spelling performance.

Posterior Summaries of Coefficients

Neither NIV1.Trans nor NIV2.Trans is strongly included in the model (P(incl|data) for NIV1 = 0.42 and NIV2 = 0.44), suggesting weak evidence that these variables are important predictors.

The mean coefficient for NIV1.Trans is 2.29 with a standard deviation of 4.665, indicating high uncertainty in its effect size.

The mean coefficient for NIV2.Trans is -2.138, also with substantial uncertainty (SD = 3.97).

**The NIV with duration of immigration can be a predictor variable of spelling**

For this hypothesis we first analysis of our model in linear regression in R, and the result in Table A- 11 and Table A- 12 showed that with the duration of immigration effect the NIV1 with P=0.03 and NIV2 with P=0.01 statistically significant with 91% of prediction model.

Since our sample is small and in R we just understand overall model is statistically significant and not found which model is the best. We analysis our model in JASP via Bayesian linear regression.

Table 17: Model 4 Comparison - Spelling German

| Models | P(M) | P(M\|data) | $BF_M$ | $BF_{10}$ | $R^2$ |
|---|---|---|---|---|---|
| Immigration | 0.083 | 0.293 | 4.564 | 1.000 | 0.763 |
| NIV1 + immigration | 0.083 | 0.261 | 3.892 | 0.891 | 0.843 |
| NIV1+ NIV2+ Immigration | 0.250 | 0.260 | 1.053 | 0.295 | 0.843 |
| NIV2 + Immigration | 0.083 | 0.135 | 1.718 | 0.461 | 0.798 |
| Null model | 0.250 | 0.031 | 0.097 | 0.036 | 0.000 |
| NIV1.+ NIV2 | 0.083 | 0.007 | 0.081 | 0.025 | 0.310 |
| NIV2 | 0.083 | 0.006 | 0.069 | 0.021 | 0.072 |
| NIV1 | 0.083 | 0.006 | 0.062 | 0.019 | 0.035 |

Table 18: Posterior Summaries of Coefficients of Model4. Spelling German

| Coefficient | P(incl) | P(excl) | P(incl\|data) | P(excl\|data) | $BF_{inclusion}$ | Mean | SD |
|---|---|---|---|---|---|---|---|
| Intercept | 1.000 | 0.000 | 1.000 | 0.000 | 1.000 | 44.400 | 1.901 |
| NIV1 | 0.500 | 0.500 | 0.534 | 0.466 | 1.146 | 2.351 | 3.239 |
| NIV2 | 0.500 | 0.500 | 0.408 | 0.592 | 0.690 | 0.216 | 2.363 |
| Immigration | 0.500 | 0.500 | 0.949 | 0.051 | 18.775 | 0.380 | 0.122 |

| Coefficient | P(incl) | P(excl) | P(incl\|data) | P(excl\|data) | $BF_{inclusion}$ | Mean | SD |
|---|---|---|---|---|---|---|---|

When duration of immigration is included, the model's predictive power improves dramatically.

When NIV1. NIV2 and Immigration are included together, the $R^2$ increases to 0.84, indicating strong statistical significance. This model is highly likely to predict spelling performance correctly.

Posterior Summaries of Coefficients - With Immigration:

The inclusion probability for Immigration is 0.94, meaning it is almost certainly an important variable in predicting spelling.

The mean effect of Immigration is 0.38 with a small standard deviation of 0.12, showing a relatively stable effect size.

NIV1 and NIV2 has a lower inclusion probability (P(incl|data) = 0.53, 0.4), but it still contributes to the model.

Duration of Immigration plays a substantial role in predicting spelling performance, explaining much more variance than NIV alone. It seems to be a critical variable.

While NIV shows some relationship to spelling, its contribution is not as strong or consistent, especially without duration of immigration included. When duration of immigration is factored in, NIV1 still plays a role, but its effect is secondary to duration of immigration.

NIV alone may not be a robust predictor of spelling performance, but when combined with duration of immigration, the model significantly improves.

**The effect size of orthographic knowledge and NIV to predict spelling in Persian performance will be larger than for German performance**

The hypothesis posits that Persian spelling performance, as the dependent variable, will be more significantly predicted by orthographic knowledge and the number of velocity inversions (NIV) from Persian in writing than German spelling performance, as the dependent variable, will be more significantly predicted by orthographic knowledge and the number of velocity inversions (NIV) from Persian in writing. In this context, orthographic knowledge and NIV in each language serve as the independent variables. This suggests that the effect size of these predictors on Persian

spelling will be larger than on German spelling compared to their effect on spelling performance in German.

Table 19: The Compression of Orthographic and NIV of Spelling in German and Persian

| Model | Cohen's f2 Value | Effect size |
|---|---|---|
| German | 2.56 | Cohen's f2≥0.15 |
| Persian | 2.27 | Cohen's f2≥0.15 |

Both models exhibit a large effect size, indicating that the independent variables significantly impact the dependent variable. While both models show a strong relationship, the German model has a slightly higher effect size than the Persian model, suggesting that the predictors may be more effective or influential in the German context.

# 5 Chapter V: Discussion and conclusion

## 5.1 Discussion

The bilingual cognitive-motor study using Linear Regression Models offers a comprehensive view of the factors influencing cognitive performance in bilingual students. This chapter will explore how spelling scores, immigration duration, and cognitive and graphomotor skills interact to shape cognitive functioning in bilingual individuals.

Initially, this study aimed to examine the impact of cognitive and motor variables on the spelling performance of bilingual students. Specifically, it sought to determine whether spelling performance in bilingual students is influenced by vocabulary, reading, and orthographic knowledge, and whether the inclusion of graphomotor skills serves as an additional predictor of spelling performance. In the second phase, these variables were examined in the students' second language to investigate whether spelling performance in a language with a different writing system is similarly influenced by vocabulary, reading, orthographic knowledge, and graphomotor skills. Lastly, the study compared the effect sizes of these models to determine if the combined effect of motor skills, vocabulary, reading, and orthographic knowledge is larger for the first language than for the second language.

The first model aimed to investigate the predictors of Persian spelling performance, specifically focusing on the roles of vocabulary, reading fluency, and orthographic processing in bilingual students. The findings provide substantial support for the hypothesis that these cognitive factors are significant predictors of spelling skills in Persian bilingual students.

The results reveal that the model incorporating reading, vocabulary, and orthographic knowledge accounts for a considerable amount of variance in spelling performance ($R^2 = 0.88$). This highlights the importance of these cognitive domains in literacy development. The strong Bayes factor (2.58) further reinforces the validity of the proposed model, suggesting that interventions aimed at improving reading fluency, vocabulary, and orthographic skills could effectively enhance spelling abilities in bilingual students.

This finding is consistent with existing literature that underscores the interconnectedness of these cognitive processes on bilingual students. For instance, studies have shown that strong reading skills facilitate better orthographic processing and, consequently, improved spelling outcomes

(Arab-Moghaddam & Senechal, 2001; Chung et al., 2018, 2023; D'Angiulli et al., 2001b; Dixon et al., 2010; O'Brien et al., 2020). Therefore, educational strategies that integrate reading and orthographic training may be particularly beneficial for enhancing spelling proficiency in bilingual students.

Although vocabulary knowledge has been widely recognized as a critical factor in spelling, the current study's model did not strongly confirm its significance. Vocabulary plays a crucial role in spelling, as it involves not only word recognition but also semantic understanding, which supports the encoding and recall of spelling patterns. This finding aligns with past research indicating that vocabulary size predicts spelling ability across various languages (Aaron & Joshi, 2005; Abu-Rabia & Siegel, 2002; Bialystok et al., 2005). Therefore, enhancing vocabulary development could still be a key component in spelling interventions, even if the current model did not strongly find it predictive. In the Persian language, the presence of homophonic letters—where multiple letters represent the same sound—may contribute to spelling difficulties, particularly among bilingual students. For these students, although they may be proficient in spoken Persian and possess a basic vocabulary, accurately spelling Persian words can be challenging due to this orthographic complexity. This characteristic of Persian may obscure the relationship between vocabulary knowledge, reading and spelling ability, as even familiar words may present challenges in their written forms (Rahbari et al., 2007).

The current model provides robust evidence that reading fluency, and orthographic processing from first language serve as significant predictors of first spelling performance in bilingual students. This underscores the critical role these cognitive skills play in the literacy development of individuals navigating multiple languages. By implementing targeted educational interventions that focus on these areas, educators can foster a more effective learning environment that addresses the unique challenges and strengths of bilingual students. Such an approach can yield substantial benefits for spelling proficiency and contribute to their overall literacy success (Rahbari, 2019).

The findings of this study also underscore the critical role of the Number of Velocity Inversions (NIV) in predicting Persian spelling performance, highlighting the intersection of cognitive and motor skills in literacy development. The inclusion of NIV alongside traditional predictors, such as vocabulary, reading fluency, and orthographic processing, suggests that spelling is not solely a cognitive task but also involves intricate motor processes.

For first study in bilingual students, the positive relationship observed between NIV and spelling performance from first language indicates that the mechanics of writing—specifically how students execute their writing motions—can significantly influence their spelling abilities. This finding emphasizes the importance of kinematic aspects of writing, which have often been overlooked in traditional literacy models.

In conclusion, while the model confirms that reading, orthographic processing, and motor skills can be reliable predictors of spelling performance in bilingual students for their native language, it also reveals complexities among the cognitive predictors. Notably, monolingual studies have shown a clear relationship between motor skills and spelling, supporting the idea that motor proficiency contributes to literacy development by reinforcing cognitive and orthographic skills. This alignment between bilingual and monolingual findings underscores the potential benefit of including motor skills development in literacy programs, as it may enhance spelling performance across diverse linguistic backgrounds (Khoury-Metanis & Khateb, 2024). Although vocabulary and reading fluency typically support spelling abilities, the presence of negative coefficients for certain predictors suggests that aspects of vocabulary knowledge may not always translate into improved spelling. This may stem from the Persian language's orthographic structure, where a single sound can correspond to multiple letters, complicating spelling for children who primarily speak Persian at home but lack formal instruction in the language. These findings underscore the need for a nuanced understanding of how different dimensions of vocabulary knowledge influence spelling performance (Rahbari et al., 2007).

These insights carry important implications for educational practice. For bilingual students, especially those learning Persian, instructional approaches that integrate motor skill development with cognitive training could be particularly beneficial. Incorporating writing exercises that focus on fluency and efficiency may help strengthen students' spelling abilities.

Overall, this study contributes to a broader understanding of literacy development in bilingual contexts. It suggests that a more universal approach—one that encompasses cognitive, linguistic, and motor skills—could lead to better outcomes in spelling and, by extension, in overall literacy for bilingual students. Future research should further explore these relationships, considering additional variables and broader contexts to refine educational interventions that support bilingual literacy development.

The findings of the German model in parallel to previous study confirmed that German vocabulary, reading fluency, and orthographic processing significantly predict spelling performance in German among bilingual Persian-German students. This suggests that these cognitive skills operate together, enhancing spelling abilities and highlighting the interplay between linguistic proficiency and cognitive development in bilingual contexts (Arab-Moghaddam & Senechal, 2001; Chung et al., 2018, 2023; D'Angiulli et al., 2001b; Dixon et al., 2010; O'Brien et al., 2020).

The model that includes reading, vocabulary, and orthographic knowledge from second language presents a plausible explanation for second spelling performance. It underscores the interconnectedness of these cognitive skills, indicating that proficiency in vocabulary and reading fluency may facilitate more effective spelling, particularly in a bilingual context where students navigate different writing systems.

The substantial $R^2$ value indicates that this model captures a significant proportion of the variance in spelling performance, further supporting the idea that these cognitive skills are crucial in the bilingual experience. The findings suggest that as bilingual students improve their German vocabulary and reading fluency, their spelling performance also improves, emphasizing the role of cognitive processes in literacy.

However, the inclusion probabilities reflect some uncertainty regarding the individual contributions of reading, vocabulary, and orthographic processing, despite their overall significance in the model. The weaker relationship observed between German orthographic knowledge (GOK) and spelling suggests that different aspects of orthographic knowledge may interact with spelling performance in varied ways. For example, the negative relationship observed with one orthographic measure (WOG) indicates that not all components of orthographic processing contribute equally to spelling. This highlights the complexities of managing multiple linguistic systems, where certain elements of orthographic knowledge may even hinder rather than support spelling accuracy (Rothe et al, 2024).

Furthermore, the study reinforces the importance of reading and vocabulary in enhancing spelling performance, aligning with prior research that indicates students with robust vocabulary in one language tend to demonstrate greater spelling proficiency in that language (San Francisco et al., 2006). This highlights the necessity of developing vocabulary and reading in German to support

overall spelling abilities. Additionally, the relationship between vocabulary and orthographic processing confirms the critical interaction between these two cognitive skills. As demonstrated in this study, proficiency in the orthographic rules of German positively influences spelling performance among bilingual students, suggesting that instruction should not only focus on vocabulary acquisition but also on the specific orthographic features of both languages. Overall, the results provide compelling evidence for the intricate relationship between vocabulary, orthographic knowledge, and spelling performance in bilingual students, underscoring the importance of comprehensive literacy instruction that addresses the unique challenges faced by bilingual learners, particularly in developing their spelling abilities in the context of German.

The results indicate that German vocabulary, reading fluency, orthographic processing, and the number of velocity inversions (NIVs) serve as predictors of German spelling performance, though their predictive strength is not highly significant, and the overall significance of models incorporating these variables varies. Notably, the model combining reading fluency with NIV2 demonstrates the highest probability of being the best fit, suggesting a meaningful relationship between reading proficiency, graphmotor skills and spelling ability.

These findings emphasize the modest yet critical role of reading fluency, particularly in conjunction with kinematic measures (NIVs), in predicting spelling performance. The positive relationship observed between reading fluency and spelling suggests that as reading skills improve, so does the ability to spell accurately. However, the negative association observed with the number of velocity inversions (NIV1) indicates an inverse relationship, whereby lower NIV1 values correspond to improved spelling performance. This finding confirmed the complexity of how bilingual students navigate different writing systems and their associated rules. Furthermore, lower NIV values suggest higher graphomotor automatization, indicating that enhanced graphomotor automatization is related to better spelling performance

The study underscores the importance of examining the interaction between cognitive skills, such as reading fluency, and kinematic indicators, like NIVs, when evaluating spelling performance in bilingual students. The nuanced dynamics of these relationships call for further research to deepen our understanding of how bilingualism shapes spelling abilities across varied linguistic frameworks.

Additionally, the findings suggest that the predictive power of NIVs—specifically NIV1 and NIV2—for spelling performance is limited, as they do not significantly enhance predictive accuracy beyond the null model. This implies that NIVs alone are not robust predictors of spelling abilities in bilingual student. This observation aligns with studies of motor skills and spelling in monolingual students suggesting that while motor skills, such as fine motor coordination, may support spelling, they do so most effectively in conjunction with other cognitive factors rather than in independently (Khoury-Metanis & Khateb, 2022; Salameh-Matar et al., 2024).

Although the model including both NIVs explains a modest 31% of the variance in spelling performance, the adjusted $R^2$ indicates potential overfitting. The lack of statistical significance, with a p-value of 0.27, reinforces the idea that NIVs may not be a strong predictor of second spelling in bilingual students, but is an important variable that research should focus on.

Overall, while NIVs were expected to influence German spelling performance same as Persian spelling, this study suggests they do not significantly contribute beyond the null model. This highlights the need for further research or attention on other variable that may play important roles in the cognitive and linguistic factors that may more strongly affect graphmotor and spelling skills in bilingual contexts, especially among students dealing with different writing systems like Persian and German.

One variable that may positively impact students' motor and cognitive performance is the length of exposure to the second language.

The findings suggest that the Number of Velocity Inversions (NIVs) combined with the duration of immigration can serve as predictor variables for spelling performance. The inclusion of duration of immigration significantly enhances the model's predictive power, with the $R^2$ increasing to 0.84, indicating strong statistical significance. This suggests a high likelihood of accurately predicting spelling performance.

The inclusion probability for immigration is notably high at 0.94, indicating its critical importance in predicting spelling outcomes. The mean effect size for immigration is 0.38 with a small standard deviation of 0.12, reflecting a relatively stable impact. While NIV1 and NIV2 have lower inclusion probabilities (0.53 and 0.40, respectively), they still contribute meaningfully to the model.

Overall, the NIV was confirmed as a predictor of spelling in the Persian model, while the evidence for its influence on German spelling performance was weak, it appears that the length of time students has spent in German schools may alter the impact of graphmotor skills on their writing performance. This suggests that as students spend more time in a German educational environment, the role of motor processes like NIV in their spelling abilities may shift, possibly increasing its influence.

In summary, these findings provide evidence for the final hypothesis. The results reveal that both orthographic knowledge and motor skill variables, such as Number of Velocity Inversions (NIV), significantly predict spelling performance in bilingual students, with both the Persian and German models showing large effect sizes. This finding suggests that these cognitive and motor predictors play a crucial role in spelling proficiency across languages. However, the slightly higher effect size observed in the German model indicates that the predictors may have a more pronounced influence in the German context, possibly due to the specific demands and structure of German orthography, which is more transparent and rule-based compared to Persian. This difference could mean that bilingual students might rely more on orthographic and motor skills when spelling in German, as the language's clearer orthographic rules allow for stronger application of learned spelling patterns (Gan, 2024).

These findings underscore the importance of developing bilingual literacy programs that adapt instruction to each language's unique orthographic demands, which can ultimately enhance spelling performance by addressing the nuanced cognitive and motor skills needed in different linguistic contexts.

## 5.2 Conclusion

In this study, we aimed to explore the predictive power of cognitive (reading, vocabulary, and orthographic processing) and motor skills (graphomotor, specifically NIV) on the spelling performance of bilingual Persian-German children. Our primary objective was to investigate whether linguistic variables, such as vocabulary and reading fluency, alongside graphomotor skills, could predict spelling ability in both the first (Persian) and second (German) languages. We also examined whether the predictors of spelling performance in the first language (L1) would differ from those in the second language (L2), considering the distinct orthographies of Persian and German.

The results from our study align with previous findings in bilingual literacy research, which suggest that orthographic knowledge, reading fluency, and vocabulary are robust predictors of spelling performance. Similar to the studies by (Chung et al., 2018, 2023) and (O'Brien et al., 2020), which explored the within-language and cross-language influences of orthographic processing on spelling, our findings confirmed that linguistic variables play a significant role in predicting spelling in both languages. Specifically, we found that reading fluency strongly predicted spelling performance in Persian, which shares some similarities with research on children learning languages with Roman scripts (Chung et al., 2023).

When considering graphomotor skills, our results suggest that the number of velocity inversions (NIVs) alone did not significantly predict spelling performance beyond the influence of cognitive factors such as vocabulary and reading in second language. This finding is consistent with previous studies on monolingual students that emphasize the primacy of linguistic factors in spelling development (Khoury-Metanis & Khateb, 2022; Salameh-Matar et al., 2024). However, when NIV was combined with cognitive variables, the model's predictive power increased modestly. This suggests that motor skills might contribute to spelling performance, but they do appear to play as same role as linguistic variables like orthographic processing and reading.

The effect size of German orthographic and graphomotor skills appears to be greater than that of Persian orthographic and graphomotor skills, a finding that aligns with existing research. For instance, Turkish–Dutch children performed better on Dutch tasks assessing phoneme awareness and vocabulary than on corresponding Turkish tasks. This suggests that language proficiency in the adopted language can rapidly surpass that of the native language, particularly in contexts lacking formal instruction in the first language (Janssen et al., 2013). The interplay between cognitive and motor skills in both the first and second languages is complex; when children primarily engage with their second language, cognitive and motor skills associated with their first language may not develop fully. Furthermore, the cognitive and motor areas of the brain are interconnected, and the strengthening of skills in one language can influence the development of skills in another. Consequently, the hypothesis of this study—that the effect size of Persian orthographic and graphomotor skills would exceed that of German skills—is not supported by the data. This highlights the need for further investigation into the factors influencing the development of these skills across different languages and contexts.

## 5.3 Limitation and further research

This research represents the first study to focus specifically on the motor skills underlying cognitive-linguistic abilities in bilingual children. While much previous research has examined the influence of language and cognitive factors on literacy development, this study uniquely integrates the role of graphomotor skills—specifically the number of velocity inversions (NIV)—as a predictor of spelling performance. By investigating how motor abilities contribute to spelling, reading fluency, vocabulary, and orthographic processing across two languages (Persian and German), this research provides a novel perspective on bilingual literacy development.

In this research, several limitations should be acknowledged. First, the sample size of bilingual children was relatively small, which may limit the generalizability of the findings to a broader population. A larger and more diverse sample would provide stronger evidence and allow for more robust statistical analysis. Second, the study was cross-sectional, meaning it only captured a snapshot of the children's performance at a specific point in time. A longitudinal design would offer a deeper understanding of how graphomotor skills, spelling, reading fluency, vocabulary, and orthographic processing develop over time and interact across different languages.

Another limitation involves the use of specific language measures and tools, which might not fully capture the nuances of bilingual children's cognitive-linguistic and motor skills across both languages. The study primarily focused on Persian and German, so the findings may not be directly applicable to bilingual children with other language pairs, especially those with greater or simpilar differences in orthographic depth.

Additionally, while the study explored the role of graphomotor skills in spelling performance, it did not account for other motor or sensory variables that could influence writing, such as sensory feedback during handwriting. These factors could further elucidate the relationship between motor skills and language processes.

Lastly, these limitations suggest the need for future research to employ longitudinal designs, larger samples, and a more comprehensive range of assessment tools to better understand the complexities of bilingual literacy development.

Further research is needed to explore the precise relationships and interaction between graphomotor skills and cognitive-linguistic processes in bilingual children. Investigating how

variations in writing systems impact the development of graphomotor abilities could provide valuable insights into effective instructional strategies. Additionally, examining the role of graphomotor skills in facilitating spelling accuracy and reading fluency across different languages may contribute to a more comprehensive understanding of bilingual literacy development. Future studies could also consider the implications of these findings for designing targeted interventions that support children in mastering both the cognitive and motor aspects of writing, while recognizing the critical role that both sensory and motor functions play in these processes. Key research questions include: How do interactions between graphomotor skills, language factors, and cognitive functions influence writing quality and accuracy? What brain areas and cognitive functions are involved in these processes? Understanding these interactions will provide valuable insights for educational practices and theoretical models, potentially leading to improved instructional strategies for bilingual children and for addressing neurodevelopmental disorders such as developmental coordination disorders, dysgraphia, and dyslexia.

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## Appendix

The Linear Regression model analysis from R, table

Table A- 1: : The Linear Regression model 1: Spelling of Persian

| | Estimate | Std.Error | t-Value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | -195.22 | 50.75 | -3.84 | 0.01 * |
| GOK.P | 1.56 | 0.57 | 2.77 | 0.04 * |
| WOK.P | 2.85 | 1.09 | 2.6 | 0.04 * |
| Reading.P | 1.35 | 0.41 | 3.25 | 0.02 * |
| Vocabulary.P | -0.59 | 0.31 | -1.88 | 0.11 |

Table A- 2: : The Linear Regression model 1: Spelling of Perian

| Statistic | Value |
|---|---|
| Residual Standard Error | 10.49 |
| Multiple R-squared | 0.88 |
| Adjusted R-squared | 0.80 |
| F-statistic | 10.2 |
| p-value | 0.01 |

Table A- 3: : The Linear Regression model 2: Spelling of Perian

| | Estimate | Std.Error | t-Value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | -142.94 | 71.49 | -1.99 | 0.1 |
| GOK.P | 1.31 | 0.67 | 1.96 | 0.1 |
| WOK.P | 2.51 | 1.28 | 1.95 | 0.1 |
| Reading.P | 0.95 | 0.43 | 2.18 | 0.1 |
| Vocabulary.P | -0.67 | 0.5 | -1.34 | 0.2 |

| | | | | |
|---|---|---|---|---|
| NIV7 | -18.06 | 13.16 | -1.37 | 0.2 |
| NIV8 | 11.81 | 7.36 | 1.6 | 0.2 |

Table A- 4: : The Linear Regression model 2: Spelling of Persian

| Statistic | Value |
|---|---|
| Residual Standard Error | 9.33 |
| Multiple R-squared | 0.94 |
| Adjusted R-squared | 0.84 |
| F-statistic | 8.97 |
| p-value | 0.04 |

Table A- 5: : The Linear Regression model 1: Spelling of German

| | Estimate | Std.Error | t-Value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | -0.85 | 37.9 | -0.02 | 0.9 |
| GOK.G | 0.26 | 0.25 | 1.04 | 0.3 |
| WOK.G | -0.26 | 0.42 | -0.61 | 0.5 |
| Reading.G | 0.09 | 0.2 | 0.46 | 0.6 |
| Vocabulary.G | 1.4 | 1.26 | 1.11 | 0.3 |

Table A- 6: : The Linear Regression model 1: Spelling of German

| Statistic | Value |
|---|---|
| Residual Standard Error | 4.38 |
| Multiple R-squared | 0.91 |
| Adjusted R-squared | 0.85 |
| F-statistic | 13.97 |
| p-value | 0.006 |

Table A- 7: : The Linear Regression model 2: Spelling of German

| | Estimate | Std.Error | t-Value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 81.69 | 77.88 | 1.04 | 0.3 |
| GOK.G | -0.29 | 0.52 | -0.55 | 0.6 |
| WOK.G | -0.27 | 0.43 | -0.63 | 0.5 |
| Reading.G | 0.48 | 0.39 | 1.22 | 0.3 |
| Vocabulary.G | -0.41 | 1.99 | -0.2 | 0.8 |
| NIV1 | -1.44 | 4.51 | -0.32 | 0.77 |
| NIV2 | -4.47 | 3.57 | -1.25 | 0.2 |

Table A- 8: : The Linear Regression model 2: Spelling of German

| Statistic | Value |
|---|---|
| Residual Standard Error | 4.46 |
| Multiple R-squared | 0.94 |
| Adjusted R-squared | 0.84 |
| F-statistic | 9.03 |
| p-value | 0.04 |

Table A- 9:: The Linear Regression model 3: Spelling of German

| | Estimate | Std.Error | t-Value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 51.66 | 9.82 | 5.26 | 0.001 ** |
| NIV1 | 11.79 | 7.59 | 1.55 | 0.1 |
| NIV2 | -10.45 | 6.25 | -1.67 | 0.1 |

Table A- 10: : The Linear Regression model 3: Spelling of German

| Statistic | Value |
|---|---|

| | |
|---|---|
| Residual Standard Error | 10.74 |
| Multiple R-squared | 0.31 |
| Adjusted R-squared | 0.11 |
| F-statistic | 1.57 |
| p-value | 0.27 |

Table A- 11: : The Linear Regression model 4: Spelling of German

| | Estimate | Std.Error | t-Value | Pr(>\|t\|) |
|---|---|---|---|---|
| (Intercept) | 52.79 | 6.68 | 7.89 | 0.0005 *** |
| NIV2 | -6.36 | 2.26 | -2.8 | 0.03 * |
| NIV1 | -6.41 | 3.24 | -1.97 | 0.1 |
| Immigration | -0.21 | 0.15 | -1.35 | 0.2 |
| NIV1*Immigrassion | 0.59 | 0.12 | 4.62 | 0.005 ** |

Table A- 12: : The Linear Regression model 4: Spelling of German

| Statistic | Value |
|---|---|
| Residual Standard Error | 2.63 |
| Multiple R-squared | 0.97 |
| Adjusted R-squared | 0.94 |
| F-statistic | 40.77 |
| p-value | 0.0005 |