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SYNTACTIC COMPLEXITY IN READING COMPREHENSION: AN EYE-TRACKING  
STUDY OF TEXT PROCESSING AMONG BILINGUALS AND MONOLINGUALS

by

Guoqin Ding

A dissertation submitted in partial fulfillment  
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Education

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2022

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## ABSTRACT

Syntactic Complexity in Reading Comprehension: An Eye-tracking Study of Text  
Processing Among Bilinguals and Monolinguals

by

Guoqin Ding, Doctor of Philosophy

Utah State University, 2022

Major Professors: Kathleen A. J. Mohr, Ed.D.; Ronald B. Gillam, Ph.D.  
Department: School of Teacher Education and Leadership

This exploratory study examined text processing of Chinese-English bilingual and English-monolingual children while reading passages varied in textual features (i.e., reading difficulty level and syntactic complexity) via eye-tracking techniques. Participants were randomly assigned to one of the two reading tasks and asked to read four topical passages. Each topical passage had two versions (i.e., syntactically simple vs. complex structures) and each reading task contained one of the two versions. Behavioral and eye-tracking data, including accuracy of true/false questions, reading speed, and first fixation duration were analyzed in (logistic) multilevel regression models to determine whether language group (bilingual vs. monolingual), reading difficulty level (easy vs. hard), and syntactic complexity (simple vs. complex) predicted text processing performance. Additionally, language test scores were added as fixed factors to examine the effects of linguistic capacities on the relationship between textual features and eye-

tracking performance (i.e., reading speed and first fixation duration). Behaviorally, both bilingual and monolingual groups answered the true/false questions with sufficient accuracy, indicating basic understanding of the brief passages. The results of eye-tracking performance revealed that bilinguals read more slowly and fixated longer across all passages than monolinguals; such findings align with prior studies. In addition to these expected results, there were surprising and interesting findings that may challenge interpretations. First, a lack of significant speed differences for bilinguals when reading easy or hard passages suggests that bilinguals' reading speed may not have been influenced by text difficulty level. Second, for first fixation duration, the findings that the regression slope for monolinguals was greater in processing complex-structure passages, but greater for Chinese bilinguals in processing simple-structure passages may indicate the influence of first-language transfer (e.g., the unfamiliarity of English complex structures). Third, in this study of online reading processing, the word-level competencies were more strongly related to passage reading outcomes than were language and reading proficiency measures. The findings suggest the importance of understanding word-level competencies underlying more holistic reading tasks. Therefore, the consideration of variables, including word-level competency, language proficiency, or L1-L2 structural comparisons, can and likely elucidate the complexity of reading comprehension among monolingual and bilingual readers.

## PUBLIC ABSTRACT

Syntactic Complexity in Reading Comprehension: An Eye-tracking Study of Text  
Processing Among Bilinguals and Monolinguals

Guoqin Ding

For Chinese students, studying in a country with different cultural components and language structures is challenging. Compared to English, the Chinese prefers shorter and simple sentence structure and allows for two sentences to be stated side by side. Different sentence structures in Chinese may influence native-Chinese readers' understanding of English sentences and even a whole text. This exploratory study examined whether there were any differences between English monolingual and Chinese-English children while reading varied English texts with simple or complex structures at different reading difficulty levels. This study explored the differences across texts and readers, as well as the possible effect of first-language transfer on text comprehension behavior.

Behavioral and eye-tracking data, including accuracy of true/false questions, reading speed, and first fixation duration were analyzed. For true/false questions, both groups answered the questions with sufficient accuracy, indicating basic understanding of the brief passages. For reading speed and first fixation duration, as expected, monolinguals read faster with shorter fixations than bilinguals across all passages and monolinguals revealed faster reading speed for easy passages than for hard passages. However, no difference was found between easy and hard passage reading for bilinguals,

which was surprising, suggesting that vocabulary difficulty may not have influenced reading speed. Additionally, the findings that no differences for reading difficulty or syntactic complexity between or within each group in first fixation duration were unexpected. To examine whether participants' offline behavioral test scores (i.e., language, reading and cognitive capacity) influenced the relationship between first fixation duration and syntactic complexity or reading difficulty, the offline behavioral test scores were added into analysis. According to the results, monolinguals performed expectedly with stronger influence of reading and cognitive capacities on complex structure passages. However, bilinguals appeared to attend to the simple structure passages as expected, but not complex passages. Results suggest that English complex structures may have been too difficult for bilinguals to apply reading knowledge or cognitive ability for text processing or bilinguals were less responsive to the syntactic complexity due to their first-language transfer.

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As the youngest child with four siblings who was born after the delivery of the “one-child” policy in China, I have known the pressure and difficult challenges faced by parents. My dad had to pay a year’s salary as a fine to let me be legally registered and able to go to school. At that time, most of my parents’ friends and relatives had the belief that the most important thing for a girl was to marry a good person—not to pursue higher education. They tried to persuade my parents to let the girls in our family go to a vocational high school (instead of an academic one) so that we could join the work force early. But my parents believed that a girl also has the right to get a higher education, and they tried their best to support our studies. First, I want to say thank you to my parents. I thank them for giving me life and the opportunity to be educated. Without their support, I could not go this far and get my PhD.

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# CHAPTER 1

## INTRODUCTION

Students entering the adult world and living in the 21<sup>st</sup> Century need advanced levels of literacy skills. According to Moore et al. (1999), large amounts of information from multiple domains (e.g., jobs, households, and personal lives) require people to be able to read and comprehend a variety of texts. However, a large proportion of students is not well prepared in key literacy skills. A report of the National Commission on Adult Literacy (2008) noted that 55% of students could not access 4-year colleges or universities because of low literacy levels characterized by insufficient reading and writing capacities. Students need to develop their reading comprehension abilities at elementary and secondary levels to increase the probabilities of attending post-secondary education (Moore et al., 1999). Based on the report of National Center for Educational Statistics (2015), among students who graduate from high school, approximately 60% of them are graduating with inadequate reading skills. Moreover, students with English as their second language (L2) often face a greater challenge than monolinguals. Kanno and Cromley (2018) found that the opportunity for L2 English learners to go to 4-year colleges or universities in the U.S. is highly limited, with only 19% attending compared to 45% of monolinguals in 2013.

Among students who are English learners (ELs), those from China are increasing their attendance in U.S. schools. According to U.S. Immigration and Customs Enforcement (2016), Chinese students in elementary schools reached 2,450 in 2015 compared to 500 in 2011, and the number of Chinese students enrolled in secondary

schools nearly tripled, from 17,914 to 46,028 over the same period. A report of the Institute of International Education (IIE, 2017) showed that the frequency of Chinese students enrolled in American high schools rose by 48% between 2013 and 2016, and about two in five high-school international students were from China. China is also the largest source of international students for U.S. universities' enrollments. As the IIE reported, over 360,000 Chinese students enrolled in 2017-2018 school year.

Studying in a country with different cultural components, Chinese students face a variety of challenges. A qualitative study conducted by Heng (2018) with 18 undergraduates over 1 year found that language skills including speaking, reading and writing were the most challenging aspects faced by Chinese students. Heng highlighted that challenges centered on phrasing ideas orally, building mental representations in reading, and constructing strong logical flow in writing. Additionally, Chinese and English are disparate languages, including differences in written systems (logographic or alphabetic), rhythmic patterns (tonal or intonational), verb tense (uninflected or inflected verb forms), and syntactic structures (paratactic or hypotactic; topic-dominated or subject-dominated; Huang & Liao, 1997, 2007, 2017). All these differences likely contribute to the challenges faced by Chinese students. As a paratactic language, Chinese tends to reduce the use of cohesive devices (e.g., connectives) and allow for two sentences to be stated side by side (Yu, 1993). Whereas, connectives, including *because*, *so*, *but*, *before*, or *after* play an important role in English reading and writing as they are used to integrate the text into a more coherent whole. Accordingly, Chinese readers may ignore the presence of cohesive devices while comprehending meaning and making



inferences of syntactically complex structures because of the syntactic features of their first language (L1). In comprehending simple sentences, for example, Chinese readers may benefit from Chinese paratactic structures to make inferences (without the facilitation of cohesive devices). Therefore, determining whether Chinese students process syntactically simple or complex sentence structures similarly to native-English speakers is important to understanding the influence of potential first language (L1) syntactic transfer on English comprehension and overall text processing.

### **Statement of the Problem**

Learning from text in a second language (L2) can be daunting. L2 readers can struggle learn another language that differs markedly from their L1. For example, languages that are in the Indo-European family such as Dutch, Spanish, and English are much more closely related than languages outside the family, such as Korean, Arabic, and Chinese (Kim & Helphenstine, 2017; Walqui, 2000). Kim and Helphenstine argue that language distance is an important factor to consider when examining challenges faced by L2 learners.

There is a tendency for L2 readers to use their L1 processing strategies, which although providing some assistance, may also lead to interference in L2 understanding and production. As Fenck-Mestre and Pynte (1997) highlighted, English-French speakers showed hesitation in reading unambiguous sentences in French because comparable sentences would have been ambiguous in their L1 English. The ambiguous sentences in English (e.g., Every time the dog obeyed the pretty little girl showed her

approval) contained the verb that can be used either transitively or intransitively (e.g., obey), however, in French, the sentences are unambiguous because the verb is obligatorily intransitive. Similarly, compared to English-native speakers' higher sensitivity to canonical or noncanonical word order, Japanese beginning-English learners (ELs) tended to use animacy cues to determine the role of actor in all testing structures (i.e., noun-verb-noun, noun-noun-verb, and verb-noun-noun; Harrington, 1987). The tendency to choose animate nouns as actors resembled Japanese monolinguals' reliance on animacy cues when assessed on Japanese sentences. Prior research on language production has shown that compared to native-English speakers, Chinese-speaking novice ELs may underuse of the definite article *the* and more skillful learners may overuse *the* (Robertson, 2000). The author suggested that under- and overuse of *the* among Chinese learners reflects that the definite article is lacking in Chinese.

In contrast to interference, L1 transfer may help L2 processing. Koda (2008) proposed that metalinguistic skills (e.g., phonological awareness, morphological awareness) developed in L1 can facilitate the development of such skills in L2. For example, Keung and Ho (2009) found a significant unique contribution of Chinese (Cantonese) rhyme awareness for English phonemic awareness among second graders in Hong Kong. All participants were asked to complete phonological tasks both in Chinese and English. Results showed that after controlling for the effect of English-rhyme awareness, Chinese-rhyme detection was significantly correlated with English initial-phoneme deletion. Additionally, Li et al. (2012) reported that language skills such as spelling, word reading, and rapid automatized naming in Chinese were highly correlated

with these skills in English among 10-year-old Chinese-English children in Hong Kong despite the large differences between languages. However, limited studies have been conducted to investigate whether L1 sentence structures have a positive influence in L2 processing.

Chinese differs syntactically from English in various ways. For example, in addition to the preferred paratactic structure, relative clauses in Chinese tend to be shorter and less complex compared with English (Lin, 2011). It is plausible that different syntactic structures in Chinese may influence L1 Chinese speakers' understanding of sentences and even a whole English text. However, few studies have examined differences in text processing between Chinese-English readers and English monolinguals based on varying syntactic structures in the two languages. More specifically, the effect of L1 syntactic transfer may be negative because it might let Chinese students ignore the role of cohesive devices in sentences creating difficulties in understanding clauses, or such transfer may be positive because parataxis might facilitate Chinese students' comprehension of syntactically simple sentences when relationships are implied.

Syntactically complex structures are used increasingly in academic texts across grade levels and this complexity entails multiple aspects, including sentence length, frequency of clauses, passive-voice constructions, and subordinations (Carroll, 2008). Research shows that texts with more complex sentence structures can complicate comprehension (Jasinska & Pettito, 2013; Montgomery et al., 2016). However, complex structures may also facilitate the depth of comprehension if the presence of cohesive

devices help readers integrate text units and generate logical inferences (Arya et al., 2011; Koornneef et al., 2016). Therefore, investigating the role of syntactic complexity in reading comprehension using a series of variables including sentence length, number of embedded clauses, canonical or noncanonical order, and the presence of cohesive devices could illuminate L2 syntactical processing among Chinese-English readers.

### **Research Methods for Investigating Syntactic Complexity and Comprehension**

Studies addressing the influence of syntactic structures on reading comprehension have been conducted via offline and online methods. Traditionally, offline methods measure reading performance with comprehension questions or reading times (e.g., Sanders & Noordman, 2000). These common offline methods allow researchers to focus on final outcomes of reading performance but fail to detect the cognitive processes during reading (Luegi et al., 2011). With the development of the eye-tracking techniques, researchers are now able to observe moment-to-moment reading behaviors (Rayner, 1998). Additionally, values exported from eye-tracking data are good measures for capturing dynamic cognitive processes during reading (Rayner, 1998), including commonly used temporal or count scales (e.g., fixation duration or saccade count) or less used spatial scales (e.g., scanpath or heatmap). Temporal and count scales are typically focused on answering specific research questions (i.e., *when* and *how long* questions for temporal, and *how often* questions for count scales) and spatial scales focus on answering questions concerning *where* and *how* (Lai et al., 2013). However, most studies examining

the role of syntactic complexity have utilized offline methods and those using readers' eye movements during online reading tasks have typically examined reading of single sentences or short texts. Reading in the real world requires more than single word or sentence understanding. Comprehension of extended texts is the critical and more authentic task, which warrants extended eye-tracking research.

Compared to reading single sentences or short texts, according to Hyönä and Kaakinen (2019), reading longer passages increases the cognitive demands because readers need not only to identify the words and parse the sentences, but also construct a mental representation and integrate textual units into a coherent whole (Kintsch, 1991). Research has shown that while reading longer text, integration processing happens at both sentence and text levels, which leads to increased rereading rates of words and longer average fixation duration of words (Radach et al., 2008). In addition to average fixation duration of words, greater saccade amplitudes have also been observed during passage reading. Thus, using eye-tracking methods to investigate the influence of syntactic complexity on text reading could inform results of prior studies, which targeted sentence-level processing. The use of longer texts in reading research could examine the role of syntactic complexity of both textual and sentential-level integration and the influence of syntactic complexity on both sentence and passage comprehension.

### **Significance of the Problem**

Students need to develop their comprehension abilities to maximize their experiences with academic texts. Compared to nonacademic texts, academic texts differ

in vocabulary difficulty, sentence complexity, and text structures, which makes academic texts more challenging to comprehend (Alderson, 2000; Curran 2020). Improving students' reading comprehension of academic texts should be a prime objective for educators because understanding complex texts influences students' success in school, opportunities for higher education, and access to promising jobs (Biancarosa & Snow, 2004).

Understanding academic texts requires the ability to process syntactically complex structures. Being familiar with complex sentence structures facilitates comprehension by helping readers apply the knowledge of syntax to parse sentences into meaningful segments, which is essential in understanding texts (Alderson 2000). Therefore, investigating the role of syntactic complexity in text comprehension can provide insights when examining responses to comprehension questions, interpreting reading speed, or other comprehension-performance measures such as recall of textual information. Research targeting the impact of syntactic complexity on related cognitive processing patterns is needed to elucidate how readers process texts with more or less complex sentences and how syntactic complexity relates to comprehension. In recent years, a growing number of studies have applied eye-tracking techniques to examine cognitive processing; however, "eye-tracking has not been fully exploited in investigating text comprehension processes" (Hyönä & Kaakinen, 2019, p. 266). Eye-tracking measures serve to broaden the lens of inquiry into global processing of longer texts which could extend the current understanding of the role of syntactic complexity in reading both locally (within) and globally (across texts).

### **Purpose of the Study**

The purpose of this study was to examine whether there were any differences in processing texts with syntactically simple or complex sentences between readers with different language backgrounds (i.e., English monolinguals and Chinese-English bilinguals). To examine how Chinese readers process syntactically simple or complex sentence structures while reading varied English texts, the study examined the text processing of Chinese-English bilingual and English monolingual children with texts at different levels of difficulty. This study explored the differences across texts and readers, as well as the possible effect of L1 transfer on text processing with passages dominated by syntactically simple or complex sentence structures.

Specifically, this research used eye-tracking methods to understand cognitive processing of bilinguals and monolinguals in extended texts on different topics and levels of difficulty. The goal of the study was to explore what selected eye-tracking measures could reveal about the role of syntactic complexity in text reading and determine any correlations between eye-tracking measures and readers' performances on tests of language and working memory.

### **Research Question**

Reading comprehension is a complex process and compared to non-academic texts, academic text reading is more challenging to students, especially those with English as their L2 (Alderson, 2000). Syntactically complex sentence structures play an important role in academic text reading comprehension (Alderson, 2000). This study

sought to examine whether Chinese-English bilinguals processed texts with different syntactic complexity levels similarly to English monolinguals and whether their L1 was a factor that correlates with processing behaviors measured by eye tracking.

Behavioral and eye-tracking measures (i.e., comprehension question accuracy, reading speed, and first fixation duration) were selected to examine how Chinese-English bilingual and English monolingual children process passages with different levels of reading difficulty and syntactic complexity.

The research question guiding this study was “To what extent do measures of English language proficiency (i.e., grammatical judgment), reading behavior (i.e., word identification and passage comprehension), and cognitive capacity (i.e., auditory working memory) predict eye-tracking measures of reading (i.e., reading speed and first fixation duration) of bilingual and monolingual children reading texts containing simple or complex sentence structures at different levels of reading difficulty”?



## **CHAPTER 2**

### **LITERATURE REVIEW**

Reading comprehension ability is crucial in developing as a literate person and being successful throughout life in the modern world. However, reading comprehension is challenging because it entails multiple text and reader characteristics (Kintsch & Van Dijk, 1978). For one thing, the readability of a text the result of many variables, chiefly content density, vocabulary, coherence within and across sentences, and syntactic complexity (Botel & Granowsky, 1972). Additionally, reader characteristics such as language proficiency, background knowledge, working memory capacity, and comprehension capability can influence overall reading comprehension performance (Kintsch, 1991; Nation & Snowling, 2000). Because second-language (L2) readers are generally less proficient in L2 skills compared with first-language (L1) readers, it is assumed that reading comprehension should be more challenging to L2 readers than to L1 readers. More specifically, it has been argued that difficulties in comprehending syntactically complex sentences are associated with academic achievement for both L1 and second language L2 readers, with lower performance associated with highly complex structures (Barrot, 2013; Jasinska & Petitto, 2013; Montgomery, et al., 2016). However, prior studies have shown contrary results. For example, Arya et al. (2011) found no effect of syntactic complexity (indicated by including embedded structures or not) on reading performance among third-grade monolingual and bilingual children. To investigate the role of syntactic complexity in reading comprehension, this review synthesized studies addressing both L1 and L2 readers and examined how syntactic complexity influences

comprehension.

To gather the relevant research, a search of available resources included the following databases: *Education Source*, *ERIC*, *Professional Development Collection*, *Psychology and Behavioral Sciences Collection*, *PsycINFO*, and *ScienceDirect*. The initial search of the databases included variations of key terms: *syntactic complexity*, *sentence complexity*, *complex sentence*, *complex syntax*, *comprehension*, *reading*, *eye tracking*, and *eye movement*. In a subsequent search, keywords were organized using the Boolean operators *AND*, *OR* and *NOT*. Terms related to syntactic complexity (*syntactic complexity*, *sentence complexity*, *complex sentence*, *complex syntax*), reading (*reading*, *comprehension*), or eye tracking (*eye tracking*, *eye movement*) were combined in various configurations. The Boolean operator *NOT* was used to combine terms to exclude less-relevant foci (e.g., *writing*, *dyslexia*, and *disability*). Articles that were subsequently reviewed more fully met the following criteria: (1) involving elements of syntactic complexity and comprehension; syntactic complexity and eye tracking; or comprehension and eye tracking, (2) not targeting participants diagnosed with learning disabilities and language impairment; (3) appearing in a peer-reviewed journal or dissertation. Then, the search engine Google Scholar was used to check for other studies fitting the search criteria. The initial search produced over 500 results. The researcher also screened titles, abstracts, and references manually to identify appropriate studies to include in this review. As a result, 85 papers were identified for this review.

This review addresses (1) theories and research associated with syntactic complexity in reading comprehension processes for L1 and L2 readers; (2) analyses of

sentence structures in English and Chinese; and (3) eye tracking used to examine reading comprehension.

### **Theoretical Premises**

Reading theorists (Goodman, 1967; Rosenblatt, 2013; Rumelhart, 1979) in past decades have proposed reading models that feature bottom-up or top-down processes influencing reading comprehension. However, reading comprehension can also be viewed as an interactive process that includes both bottom-up and top-down effects (Kintsch & Kintsch, 1998; Rumelhart, 1979). From an interactive perspective, understanding a text requires constructing relationships between smaller units like words, clauses, or sentences and integrating them with reader knowledge (Cozijn, 2000). This process of building coherent relationships and their integration with a reader's knowledge, as Kintsch and van Dijk (1978; Van Dijk & Kintsch, 1983) proposed is known as the construction-integration (C-I) process. According to this theory, readers construct a representation consisting of three levels: a surface representation, a textbase representation, and a situation model, which include different processes such as activating word meanings, forming propositions, and producing inferences and elaborations to construct a coherent model of the text (Kintsch, 1991).

### **Landscape Model**

Similar to C-I model, the landscape model (van den Broek et al., 1999) is another cognitive explanation of the interaction between textual linguistic features and a reader's knowledge. The model highlights four potential activation sources: the text that is

currently being processed, carryover from the activation of the immediately preceding cycle, reactivation of earlier preceding cycles, and the availability of pertinent background knowledge. In this model, the reading process is characteristically incremental. Eye-tracking studies have shown that reactivation of the preceding cycle could be observed with longer pause times at sentence boundaries and in regressive fixations to a preceding clause or sentence during the process of integrating sentence meaning (Hyönä, 1995; Rayner et al., 2000).

Prior studies have also shown that sentences with explicitly indicated cohesive relationships can facilitate the integration process (Cain & Nash, 2011; Canestrelli et al., 2013). Readers typically rely on cohesive devices such as ellipses, collocations, connectives, and relative pronouns to establish coherence and infer logical relations (Halliday & Hasan, 2014). It is reasonable to assume that comprehension of syntactically complex sentences that include more cohesive devices than simple sentences might require fewer inferences. The question is whether readers who are less aware of cohesive devices or readers whose syntactic-structure knowledge from a native language that is different from the target language process syntactically more or less complex sentences similarly to native readers.

### **First-Language Transfer**

Researchers focusing on the role of readers' knowledge in generating inferences have proposed that readers' perceive and understand textual information depending on their individual knowledge structures (Graesser et al., 1994). Noordman and Vonk (1998) considered inferencing to be a pattern-matching process in which the "propositions in the

current input are matched to propositions in the memory representation of the previous discourse but also to knowledge structures in long-term memory” (p. 192). Knowledge structures in long-term memory include the knowledge gained via worldly experience or a specific subject (Noordman & Vonk, 1998), as well as the knowledge about linguistic structures (Cunningham & Graham, 2000; Robertson, 2000).

Therefore, first language (L1) background may predict the difficulty of second language (L2) acquisition because of the likelihood of L1 transfer (Gast & König, 2018). Positive transfer may occur when the two languages share similar features such as the transfer of cognate knowledge from Spanish to English (Cunningham & Graham, 2000); whereas negative transfer may occur when the two languages (e.g., Chinese vs. English) have very different language structures (Robertson, 2000). Chinese and English are considered disparate languages, including differences in written systems, rhythmic patterns, verb tense, and syntactic structures (Wang, 1945). For example, passive sentence structures in Chinese follow a patient-agent-verb order and instead of using the passive construction (i.e., be + past participle), Chinese passive sentences use a marker (i.e., *bei*) between patient and agent to indicate passive voice without tense inflections of the verb as used in English. It is plausible to assume that the comprehension of English sentence structures could be challenging to Chinese-English readers who are less aware of such differences.

Based on the transfer facilitation model (Koda, 2008) some factors, such as reading comprehension strategies, can be transferred from L1 to L2. Chen (2006) found that Chinese-English readers, especially those with less advanced language skills

preferred to use semantic cues rather than syntactic information to rate the difficulty of clauses in English. To investigate the processing strategies of relative clauses in Chinese (L1) and L2 (English) among Chinese speakers, Chen (2006) asked three groups of adult participants (i.e., English native speakers, less advanced, and advanced Chinese-English bilinguals) to rate the complexity level of relative clauses with animate or inanimate noun subjects. Their results showed that for less advanced English learners, a subjective clause with an inanimate noun subject as agent (e.g., The movie that pleased the director received a prize at the film festival.) would be rated as more difficult than an objective clause with an animate noun subject as agent (e.g., The director that the movie pleased received a prize at the film festival.). However, compared to less advanced learners, advanced learners tended to use both syntactic and semantic cues to determine the difficulty levels of each sentence, as English native speakers did. The findings indicated that L1 transfer may be influenced by L2 proficiency. Additionally, the transfer of L1 strategies may also depend on readers' L1 proficiency. Koda (2008) suggests that L1 transfer may not occur for younger L2 learners, and they may perform similarly to native speakers if their L1 is still developing and not readily available for transfer. Similarly, research addressing the comparison between monolingual and bilingual children in L2 processing (e.g., Kim & Helphenstine, 2017) found that younger bilinguals tend to activate neural regions during L2 processing similar to monolinguals in L1 processing. If L1 transfer is less influential for developing L2 learners, there is a need to examine how younger Chinese-English readers process English sentences that are syntactically complex versus simple and compare that with monolinguals' processing patterns.

To investigate the role of syntactic complexity in comprehending English passages and to examine whether L1 transfer is a factor in text processing, this review addresses studies targeting syntactic complexity in both L1 and L2 reading and the influence of L1 syntactic knowledge in L2 reading, specifically the comparison of comprehension outcomes between Chinese and English syntactic structures.

### **Syntactic Complexity and Reading Comprehension**

Syntax is the way in which words combine to make sentences (Brown et al., 1991). Reading comprehension requires readers to apply knowledge of syntax because the ability to process specific syntactic structures is essential in understanding text (Alderson, 2000). In addition to simple sentence structures, students need to be familiar with complex sentence structures because academic texts (narrative or expository) entail more syntactically complex structures, such as conditionals, parallel clauses, and passive sentences compared to non-academic texts (Alderson, 2000; Scarcella, 2003). In a study examining the rate of complex sentences in first-, third-, and fifth-grade elementary science curriculum, Curran (2020) found that complex sentences were evident in all grade-levels texts and the rate of complex sentences increased with each grade. Prior studies have noted that the complexity level of syntax is associated with reading performance for both children and adolescents (Curran, 2020; Nation & Snowling, 2000). This trend warrants attention to the need for increasing awareness of sentential complexity, which may be accomplished via explicit instruction or frequent exposure to complex language use.

## **Role of Syntactic Complexity in L1 Reading**

According to Ortega (2003), syntactic complexity “refers to the range of forms that surface in language production and degree of sophistication of such forms” (p. 492). Researchers have employed various formulas (Ellis, 2009; Spache, 1953) to measure syntactic difficulty and sentence length is generally considered a common index of syntactic complexity (Sahiruddin, 2019). Researchers have argued that longer sentences that contain more words, multiple modifiers or prepositions require greater working memory, thus, processing longer sentences is likely more impactful on comprehension (Kintsch & Kintsch, 1998; Lennon & Burdick, 2004). However, sentence length only provides limited information of syntactic complexity (Anderson & Davison, 1986). For example, in a study using sentence stimuli with comparable sentence lengths but different sentence complexity (e.g., simple sentences with adjectival or adverbial modifiers or complex sentences with one or two embedded clauses), Montgomery et al. (2009) found that both traditionally developing (TD) children and those identified with specific language impairment (SLI) comprehended complex sentences with one clause better than with two clauses. Similarly, to examine the influence of sentence length in sentence processing, Montgomery (2000a, 2000b, 2004) conducted studies among children with or without SLI and asked them to identify pictures that matched the sentences with varying lengths read orally (e.g., longer sentence: *The little boy who is standing is hitting the little girl who is sitting*; shorter sentence: *The boy standing is hitting the girl sitting*.). Montgomery found that although SLI children performed poorly with longer sentences, TD children performed comparably for sentences with shorter and longer lengths. The



results indicated that compared to factors such as number of embedded clauses, sentence length had limited effect on TD children. Thus, in addition to sentence length, syntactic complexity is a multi-faceted concept that entails multiple factors.

Accordingly, researchers need to consider multiple variables when examining the effect of sentence complexity on reading, including word order and word count. Two simple sentences with the same length or two relative clauses with the same length and number of clauses may have different difficulty levels because of the positions of agent and patient. For example, in studies targeting syntax and syntactical variations, canonical and noncanonical sentence structures have been widely used to examine the effect of word order on sentence processing (Ferreira, 2003; Jasinska & Petitto, 2013). Canonical structures are sentences following the agent-verb-patient order with the noun-agent appearing first (e.g., subject-verb-object; SVO and subject relative clauses; SR), whereas noncanonical structures follow the patient-verb-agent order with the noun functioning as patient appearing first (e.g., passive sentences and object relative clauses; OR). Ferreira asked university students to identify the thematic roles of agents in active and passive sentences. Results showed that the sentence type (active vs. passive) influenced the accuracy of agent identification. Similarly, the study by Montgomery et al. (2016) demonstrated word order effect on sentence processing. They used sentences of the same length and removed all semantic cues of sentences by using inanimate nouns for both agent and patient with the only variable being the word order of agent in sentences. The authors found that SVO and SR structures that follow the unmarked canonical template were easier to process than passive and OR sentences that follow the noncanonical

template. Therefore, in addition to sentence length, syntactic structures such as passive sentence structures and sentences with more than one clause also contribute to syntactic complexity.

It is reasonable to assume that processing syntactically more complex sentences (e.g., noncanonical sentences and sentences containing more clauses) can complicate comprehension. However, Arya et al. (2011) found contrary results. Arya and colleagues conducted a study to investigate the effect of syntactic complexity on science comprehension among 142 third graders (49 of them were ELs). They used modified elementary science texts with four topics that contained either complex sentences (indexed by multiple embedded clauses) or simple sentences and 10 comprehension questions that included five multiple-choice-answer options and five short-answer questions after each text. They found no effect of syntactic complexity on comprehension performance for both groups, regardless of topic. One possible explanation suggested by the authors is that syntactically simple sentences may actually require more effort to make inferences or to create logical links while reading. Syntactically complex sentences, on the other hand “usually consist of syntactically connected clauses with conjunctions or other markers of connection” (Anderson & Davison, 1986, p. 21). Connectives or conjunctions (e.g., because, but, after) that function as cohesion signals in a text or discourse can help readers relate linguistic units to each other to better understand the text (Leech & Svartvik, 2013). The presence of connectives may lead to better performance in comprehension and faster text reading (Cain & Nash, 2011; Sanders & Noordman, 2000), help readers integrate concepts sententially and formulate textual units into a coherent

whole (Millis & Just, 1994), and improve less-skilled readers' performance more than more proficient readers (Koornneef et al., 2016). Cain and Nash found that 8- and 10-year-old native speakers read English text more quickly with the presence of appropriate connectives in two-clause sentences. Similarly, Millis and Just reported positive effects of connectives on text processing. In their study that examined the impact of connectives on English-sentence comprehension among American college students, Millis and Just concluded that sentences with two clauses linked by a connective led to faster probe-verb recognition and higher accuracy of comprehension questions. Koornneef et al. also observed a significant influence of connectives in Dutch on reading performance among university students in an eye-tracking study. The authors found that readers with lesser working memory capacities were more likely to use explicit connective cues to identify causality, which was indicated by shorter reading time of the whole sentences and more regressions to the regions before connectives. Thus, apart from sentence length, number of embedded clauses, and word order, explicit or implicit use of cohesion devices is an additional variable in understanding the role of syntactic complexity in comprehension.

A reader's comprehension ability is also a factor influencing the effect of syntactic complexity on comprehension. Readers vary in their abilities to determine the main idea and relate details to it while recognizing words and processing in sentences. Nation and Snowling (2000) used a word-order correction paradigm to assess the impact of syntactic complexity (indicated by active vs. passive structures) on comprehension in children. Results showed that both adequate and poor comprehenders performed less well with passive sentences. Comprehension performance for active sentences was similar for

both groups, whereas adequate readers outperformed poor readers for passive sentences. Similarly, Crain and Shankweiler (1988) found that poor comprehenders in third grade made more errors in comprehension and recall of relative clauses than better comprehending peers. Poor readers may be more challenged by the complexity of sentences because of their limited capacity in working memory or limited vocabulary as compared with good readers (Crain & Shankweiler, 1988). As Kintsch (1991) noted, working memory is crucial in that it enables readers to carry out processes including decoding words, activating word meanings, forming propositions, integrating propositions and making inferences during reading comprehension. Indeed, working memory capacity is a good predictor of comprehension (Daneman & Merikle, 1996). In a longitudinal study among children aged 8, 9, and 11 years, Cain et al. (2004) examined the relations between working memory capacity and reading comprehension skills, observing a strong correlation. They assessed children's comprehension ability (measured by detecting inconsistencies in text) and working memory performance (measured by sentence-span and digit-span tasks). Working memory explained a significant percent of unique variance in comprehension after controlling for word reading and verbal ability. In sentence processing, working memory is important for word transformation, meaning integration, and inference production (Cain et al., 2004).

To reiterate, the readability of a sentence is associated with syntactic variables (e.g., number of embedded clauses, canonical or noncanonical word order, and implicit or explicit use of cohesive devices) and readers' characteristics (e.g., language proficiency, comprehending ability, and working memory capacity). Studies have shown that

syntactically complex structures are more challenging to L1 speakers with less advanced language proficiency, comprehending ability, or working memory capacity (Cain et al., 2004; Crain & Shankweiler, 1988; Daneman & Merikle, 1996). Importantly, compared to native speakers, L2 learners are generally less proficient in L2 skills, including vocabulary and grammatical knowledge. It is generally assumed that syntactic complexity may be a critical factor that affects L2 reading.

### **Syntactic Complexity in Second-Language (L2) Reading**

A complex sentence expresses more than one proposition, manifesting as “passive sentences, complements, coordination, relative clauses, and subordinations” (Carroll, 2008, p. 293). Syntactic complexity is important in L2 research because of the assumption that the development of L2 proficiency is associated with L2 learners’ growth in using and understanding syntactically complex structures appropriately (Ortega, 2003). According to Polio (2001), with the growth of L2 proficiency, L2 learners tend to produce more syntactically complex structures such as sentences with more words, embedded clauses, and sophisticated structural elements (e.g., passives, paired conjunctions, and appositives, etc.) and L2 learners’ capacity to produce syntactically complex structures is an effective predictor of their comprehension of academic texts. Karami and Salahshoor (2014) found that university L2 learners’ comprehension performance on the International English Language Testing System (IELTS) academic reading was positively correlated with their writing scores demonstrating greater facility with complex language.

Thus, understanding complex sentences relies on linguistic knowledge that

accrues over time and language experiences that entail more sophisticated structures (e.g., noncanonical word-order templates, multiple embedded clauses, logical links or cohesive devices). L2 proficiency may be a main factor that affects the extent of syntactic complexity's influence on L2 reading comprehension (Chang & Wang, 2016). As Geva (1992) states, "an L2 learner who has difficulty processing basic lexical and syntactic information should find it more difficult to attend to text integration of larger chunks of discourse and the realization of text structure" (p. 743). In examining the influence of L2 proficiency on English sentence processing, Chang and Wang conducted a study among 40 late Chinese-English bilingual adults with higher or intermediate L2 proficiency. The participants were asked to read passive sentences with or without semantic or syntactic violation (e.g., The violin was made by my father; The violin was cooked by my father; The violin was make by my father) and asked to decide the plausibility of each sentence. Results showed a positive correlation between L2 proficiency and comprehension performance. The high-proficient group demonstrated shorter reaction times and higher accuracy rates. Likewise, the findings of Sahiruddin (2019) also indicated that L2 readers' proficiency was a profound predictor of comprehension performance. To examine the effect of L2 proficiency and syntactic complexity on reading comprehension, Sahiruddin asked 148 Indonesian college students (classified as high and low English proficiency groups) to answer multiple-choice questions after reading four 250- to 300-word texts with different syntactic complexity levels. The results showed that the high proficiency group outperformed the low proficiency group in both text types with high or low syntactic complexity. Additionally, better reading performance was observed in

reading texts with low syntactic complexity for both groups, which indicated that processing syntactically complex structures is more challenging for L2 learners.

Specifically, neuroscientific research has shown that complex sentence structures may lead to greater processing efforts. Investigating the impact of SR and OR in sentence processing in a functional Near Infrared Spectroscopy (fNIRS) study, Jasinska and Pettito (2013) asked bilingual and English monolingual children and adults to judge the plausibility of sentences and found that all groups showed greater neural recruitment for ORs compared with SRs. Apart from the comparison between SR and OR, SVO and passive structures are two other commonly compared sentence types in sentence-processing studies (Ferreira, 2003). Yokoyama et al. (2006) conducted a Functional Magnetic Resonance Imaging (fMRI) study to examine brain activities in processing active and passive sentences in Japanese (L1) and English (L2) among late Japanese-English adult learners. The authors used a sentence plausibility judgment task and found greater activation of left pars orbitalis in processing English passive sentences compared to active structures, but not in Japanese. The authors suggested that the more active left pars orbitalis in processing English passive sentences indicates a higher difficulty level of English passive sentences than active sentences. At the same time, researchers argued that the use of the auxiliary verb *be* in English passive sentences which is lacking in Japanese led to the greater activation of left pars orbitalis in English, but not in Japanese. Therefore, processing syntactically more complex sentences is challenging to L2 speakers, especially if the structures in L2 are less frequent or different than those of the L1.

### Comparisons Between Chinese and English Syntactic Structures

Languages are commonly compared in terms of phonological, morphological, and semantic characteristics, but differences in syntax and pragmatics also merit attention. Chinese and English differ in various ways with regard to several sentence structures. For example, tense inflections of verbs are lacking in Chinese, and Chinese tends to omit connectives in favor of a paratactic structure.

Decades ago, Wang (1943, 1945) proposed that English is a hypotactic language and Chinese is paratactic language. As a paratactic language, Chinese evidences reduced use of function words such as connectives (Yu, 1993). Consider the following sentence in Chinese:

他不老实，我不能相信他。

He not honest, I cannot trust him.

He is not honest, *so* I cannot trust him.

In the example above, Chinese does not include an equivalent of the causal connective *so* to connect the two clauses. Chinese commonly expresses ideas in a natural order that relies on context; therefore, although there are connectives to indicate causal, adversative, and sequential relations, the Chinese language tends to express such relations implicitly, particularly in oral language (Xu & Zhang, 2006). In a corpus study to investigate the use of causal connectives in famous English and Chinese novels as well as Chinese translations of those English novels, Xu and Zhang (2006) found that compared to English novels, Chinese novels used a lower rate of connectives per hundred sentences and per million words. In the study, two novels written in English (i.e., *Pride and*



*Prejudice, The Last of the Mohicans*) and seven Chinese novels were analyzed, and the results showed that on average, English-written novels contained 6.87 causal connectives per 100 words whereas Chinese contained 2.75 causal connectives per 100 words. Therefore, the presence of connectives in English sentences may not readily facilitate text processing for Chinese-English readers (Li et al., 2017).

Relative clauses are sentence structures that have been widely used to examine sentence processing in monolinguals and bilinguals (Caplan, 2001, 2007). The two common types of relative clauses most often compared are subject-extracted relative clauses (SRs, as shown in Example 1 below) and object-extracted relative clauses (ORs, as shown in Example 2 below; Gibson & Wu, 2013; Keenan & Comrie, 1977). SRs in English follow the canonical thematic templates with the unmarked agent-verb-patient order and ORs follow the noncanonical patient-agent-verb order. However, in Chinese, ORs follow the dominate agent-verb-patient order, as shown in the following examples.

1. SR: 帮助学生的张老师今天没来。  
 Help the student **Ms. Zhang** today not come. (literal translation)  
**Ms. Zhang**, who helps the student, didn't come today. (interpretation)
2. OR: 张老师帮助的学生今天没来。  
 Ms. Zhang help **the student** today not come. (literal translation)  
**The student** whom Ms. Zhang helps didn't come today. (interpretation)

In Chinese, RCs are placed initially, and the SR is in verb-patient-agent order instead of following the canonical thematic templates. Moreover, as illustrated, RCs in Chinese tend to be shorter and less complex compared with English. Lin (2011) conducted a textual analysis to compare relative clauses in Chinese or English original texts and their corresponding English or Chinese translations. The author found that on

average Chinese texts (i.e., originals or the Chinese translations from English) contained 6.63 or 7.32 syllables respectively as compared to 11.28 or 13.47 syllables in English texts (originals or English translation from Chinese). The average number of relative clauses embedded in other relative clauses in English texts was three or four whereas the average number of embedded clauses in Chinese texts was practically zero. Because of the differences between English and Chinese RCs in placement, length, and complexity, it is reasonable to assume that Chinese bilinguals may encounter some difficulty when processing relative clauses in English.

In addition to differences in RC structures and sentence forms (paratactic vs. hypotactic) between Chinese and English, there are unique grammatical features of English that are lacking in Chinese, including inflected verbs (Yan et al., 2016). Take passive sentence structure as an example; unlike English passive sentences that follow the noncanonical patient-verb-agent order, Chinese passive sentences follow patient-agent-verb order and the passive construction and tense inflections of the verb are lacking (see below).

猫被狗追。

Cat **by** dog chase. (literal translation)

The cat was chased by the dog. (interpretation)

In the Chinese example above, instead of using the passive construction (i.e., be + past participle), Chinese passive sentences use a marker (i.e., 被/by) between the patient and agent to indicate a passive voice. Thus, some common English grammatical features (e.g., the passive construction including “to be” and inflected verbs) are not found in Chinese. To investigate how Chinese-English bilinguals processed English inflected

verbs that are lacking in Chinese, Yan et al. (2016) asked proficient late Chinese-English bilingual adults to decide whether the word presented first (regular or irregular inflected verbs) was semantically consistent with the second presented word (verb stems or other unrelated words). These researchers, using a semantic consistency judgment task in a fMRI study, found that Chinese bilinguals employed greater activation in regions of inferior frontal gyrus, superior temporal gyrus, middle temporal gyrus, supramarginal gyrus, and basal ganglia to process regular compared to irregular inflected verbs, which was similar to the way English native speakers did. However, although Chinese-English speakers elicited English native-like neural activity, they recruited greater neural regions in bilateral dorsal lateral prefrontal cortex to process L2 syntax, indicating higher cognitive load in L2 processing.

In addition to using neuroscientific measures, including fMRI, EEG (electroencephalogram) and fNIRS, researchers have utilized eye-tracking technology based on subjects' eye movements in online reading tasks to investigate reading processes among monolingual and bilingual speakers. Eye-tracking techniques provide insights into the investigation of cognitive processes involved in reading and enables researchers to observe moment-to-moment reading behaviors to capture dynamic cognitive processes during reading (Rayner, 1998).

### **Eye-Tracking Techniques and Reading Comprehension**

#### **Eye-Movement Measures Used in Reading**

Eye tracking has become the gold standard in reading processing studies because

eye-movement measures are reliable and sensitive for examining in situ reading processes (Hyönä & Kaakinen, 2019). Researchers have identified and utilized different types of eye movements, such as saccades, regressions, scanpath, and fixations to analyze cognitive activities (Lai et al., 2013).

Temporal measures (e.g., fixation duration) can capture word-processing time, whereas measures computed by focusing on sentence or discourse processing tend to examine processing time across the units (Rayner et al., 2006). In studies examining reading processes, Rayner et al. suggested that if the research question focuses on single-word processing, measures like first-fixation duration, single-fixation duration, gaze duration, and total fixation time should be reported. If the research question focuses on sentence or discourse processing, eye-movement measures such as first-pass reading time, the total reading time, and go-past time (or regression-path duration) are more typical. The definition of each measure is delineated in Table 2.1.

**Table 2.1**

*Eye-Movement Measures and Definitions*

Category	Eye movement measures	Corresponding definition
Focusing on single-word processing	First fixation duration	The duration of the first fixation on a word independent of the number of fixations on the word
	Single-fixation duration	Cases when only one fixation is made on a word
	Gaze duration	The sum of all fixations on a word prior to moving to another word
Focusing on sentence or discourse processing	First-pass reading time	The sum of all fixation durations in a region until the eyes move in a forward or backward direction
	Total reading time	The sum of all fixations in the region
	Go-past reading time (Regression-path duration)	The sum of all fixations from first entering a region until exiting in the forward direction, including any regression out of the region prior to moving forward in the text

*Note.* The corresponding definition of each eye-movement measure was adopted from Rayner et al. (2006).

## Eye Movements and Syntactic Processing

Many eye-tracking studies have examined the effect of predictability of syntactic structure on sentence processing. Clifton and Staub (2011) suggest that “material is read more quickly in a context in which syntactic structures are highly predictable” (p. 899). For example, a series of eye-tracking studies showed that the explicit use of connectives sped up students’ text processing, especially the regions following the connectives (Cozijn et al., 2011). Van Silfhout et al. (2015) conducted a study of eighth graders reading Dutch narrative and expository texts. They used eye tracking to examine the influence of the presence of Dutch connectives equivalent to *moreover*, *after*, and *because* on online reading processing as well as offline comprehension. Three basic eye-movement measures, first-pass reading time, regression path duration, and total reading time were calculated. Results from these eye-tracking measures evidenced a positive effect of the presence of connectives on text processing. In texts with explicit use of connectives, participants demonstrated faster processing of the subsequent information and shorter total reading and rereading times. Similarly, Cozijn et al. conducted an eye-tracking study among university students to examine the effect of the Dutch causal connective *omdat* (because) in text processing by measuring first-pass reading time, forward reading time, and go-past reading time. Results demonstrated that texts containing the causal connective led to faster processing at words immediately following the connective, which indicates that the presence of the connective can facilitate integrative processing.

Additionally, the effect of working memory capacity on reading has been an

ongoing interest among cognitive researchers. Sentence structures that are more grammatically complex can make extra demands on working memory, which influences language comprehension (Just & Carpenter, 1980). Gordon et al. (2006) conducted an eye-tracking study among native-English-speaking adults to investigate the relationship between memory capacity and complex sentence processing in an acceptability judgment task. Participants were asked to read four types of sentences (SR and OR with nouns as either a description or a name) and then decide whether the sentence was acceptable or not. Eye-tracking measures included gaze duration, right-bounded reading times, rereading times, first-pass regression ratios, and regression path duration. Results showed that compared to SR structures, processing OR sentences demonstrated longer right-bounded times, rereading times, and regression path durations, as well as greater first-pass regression ratios, which showed higher working memory demand in OR processing. The researchers highlighted that one possible source of the additional memory demand is likely due to the increased number of intermediate syntactic nodes between the patient and the verb, which means there was likely interference from the agent in retrieving the patient of the verb. As noted previously, Finney et al. (2014) also found children's working memory was a significant predictor of OR comprehension.

However, it is usually insufficient to understand a single sentence; and as Hyönä and Kaakinen (2019) noted, readers need to integrate the meaning of sentences and comprehend whole texts. Therefore, eye-movement patterns for reading texts are different from those when reading single sentences.

## **Eye Movements and Processing of Extended Texts**

As noted above, processing a whole text includes not only word recognition and sentence parsing, but also the integration of the meanings of text segments to construct a coherent model of the entire passage. This global integrative process influences eye-movement patterns at both word and sentence levels (Radach et al., 2008; Rayner et al., 2000). Radach et al. noted that initial decoding of words in a text was faster (indexed by shorter gaze duration) than in unrelated single sentences, but the rereading time was longer which indicated time allocated to the integrative process. Additionally, compared to sentence processing, wrap-up times (i.e., increased fixation times on the last word of a sentence,) were longer in text reading likely because of the effortful integration across sentences (Rayner et al., 2000).

Examining eye movements at the text level can facilitate differentiation of good and poor comprehenders, experts and novices, or readers with different language proficiencies. Research has found that good comprehenders tend to read specific, informative parts of text directly and initiate more look-backs to those parts compared to poor comprehenders (van den Broek et al., 2009). Similarly Abundis-Gutiérrez et al. (2018) used eye tracking to compare regressions and reading comprehension between groups of low- and middle-proficient college readers. Results showed that despite no overall significant correlations between regressions and reading comprehension, the more-skilled readers demonstrated more regressions than less-skilled readers suggesting that the skilled readers were more engaged in integration processes.

As evident in some of the research summaries noted above, use of eye-tracking

techniques aids the examination of differences in reading patterns among readers with high- and low-prior knowledge, and greater and lesser language proficiency. Because L2 readers are generally less proficient in L2 skills and may be influenced by L1 structures, it is plausible to assume that L2 readers would generate different reading patterns compared with L1 readers. Therefore, tracking and comparing both L1 and L2 readers' eye-movement behaviors may be an efficient way to investigate similarities and differences between L1 and L2 readers.

### **Summary**

The effect of syntactic complexity within a text or discourse and its impact on reading comprehension have been of interest for some time (Anderson & Davison, 1986; Arya et al., 2011; Montgomery et al., 2016). Previous research has noted that syntactic complexity influences comprehension and readers face more challenges in comprehending syntactically complex structures (Ferreira, 2003; Jasinska & Petitto, 2013). A considerable number of existing studies has examined the influence of syntactic complexity on both L1 and L2 comprehension. Prior studies suggest that the complexity level of sentence structures is associated with comprehension, but the extent to which syntactic complexity influences reading processes such as differences in reading patterns between monolinguals and bilinguals and within each group using syntactically simple or complex structures is still less well studied. Specifically, Chinese-English bilingual readers may process complex sentences differently from English monolinguals because compared to English, Chinese tends to reduce the use of cohesive devices in lieu of



paratactic structures. Additionally, compared to English relative clauses, Chinese relative clauses are less complex. Thus, studies addressing the role of syntactic complexity in reading processes, especially within or between monolinguals and bilinguals are needed to better understand cognitive processing of readers who are expected to comprehend complex texts in different languages.

Eye-tracking technology as utilized in more-recent studies enables researchers to study the moment-to-moment process of reading and test hypotheses derived from different reading theories (Hyönä & Kaakinen, 2019). However, prior eye-tracking studies addressing reading have mostly focused on single-sentence processing. Whole-text reading has not yet been well researched. Compared to single-sentence reading, whole-text reading requires readers to integrate the meaning of successive sentences to construct a representation of the whole text (Kintsch, 1991), therefore, more eye-tracking studies addressing whole text reading could be fruitful.

## **CHAPTER 3**

### **METHODS**

The study described here was part of a larger investigation designed to use multi-modal techniques (behavior, fNIRS, and eye-tracking) to examine language and reading abilities in monolinguals and bilingual participant groups. The present study used eye-tracking to examine the role of syntactic complexity in text processing in Chinese-English bilinguals and English monolinguals. As language systems, Chinese and English use different syntactic structures related to connection markers, verb inflections, and relative clauses. Unlike prior studies that mostly focused on sentence-level reading, this study examined what eye-tracking measures reveal about the role of syntactic complexity in extended texts. Because making meaning while reading is considered incremental, comprehension of longer texts requires readers to understand each single sentence and to construct a mental representation of the text by integrating sentences into a coherent model (Kintsch, 1991). Eye-tracking techniques that capture moment-to-moment reading behaviors afford efficient examination of dynamic cognitive processes (Rayner, 1998). Thus, using eye tracking is a productive way to investigate reading pattern differences among readers with different characteristics such as language background and language proficiency and across passages with differential features such as vocabulary difficulty and syntactic complexity.

#### **Participants**

With approval from the Institutional Review Board at Utah State University,

participants (aged 9- 12) were recruited via flyers distributed at local elementary schools and via word of mouth. Participants were healthy children with normal or corrected-to-normal vision, normal hearing, with no known cognitive deficits. Eligible participants were assigned to two groups: Chinese-English bilinguals and English monolinguals. Participants were identified as Chinese-English bilinguals if their first language was Chinese, they spoke English at school, and reported more than three hours of daily use of both languages. Monolingual participants were native English-speaking children who did not speak another language. Students were not eligible if they had any of the following conditions based on their parental-report: (1) developmental disability or intellectual impairment; (2) emotional, psychological, or behavioral disturbances; or (3) motor deficits or frank neurological signs.

Parents of child participants were asked to complete an initial intake form with basic developmental and educational information, including family annual income, maternal education, whether or not they speak another language at home, age of L2 acquisition, and amount of daily language use in the second language (if applicable). Only monolingual English and bilingual students with reported proficiency in Chinese and English were selected. Family annual income was coded on a scale of 1-11, which were (1) 0-\$7,000, (2) \$8,000-\$12,000, (3) \$13,000-\$15,000, (4)\$16,000-\$19,000, (5) \$20,000-\$22,000, (6) \$23,000-\$25,000, (7) \$26,000-\$29,000, (8) \$30,000-\$36,000, (9) \$37,000-\$50,000, (10) \$51,000-\$75,000, and (11) \$76,000+. Maternal education was coded on a scale of 1-5 including (1) high school, (2) 2-year college, (3) 4-year college, (4) graduate school, and (5) professional degree (e.g., RN, Ph.D.). All participants and

their parents signed IRB-approved consent forms and received minimal monetary compensation for participating.

Nineteen monolingual English children (female = 9, mean age = 11.8) and 15 Chinese-English bilingual children (female = 7, mean age = 11.5) participated in the study. No differences were found among bilingual and monolingual participants in age and family income, but a significant difference in maternal education was found ( $\chi^2_{(32)} = 14.88, p = .021$ ), as delineated in Table 3.1.

**Table 3.1**

*Participants' Demographic Information*

Heading Demographic terms	Monolingual ( $n = 19$ )		Bilingual ( $n = 15$ )		$p$ value
	$n$	%	$n$	%	
Gender					1
Male	9	47.4	7	46.7	
Female	10	52.6	8	53.3	
Income					0.123
\$0 - \$7,000	0	0	0	0	
\$80,00 - \$12,000	0	0	0	0	
\$13,000 - \$15,000	3	15.8	2	13.3	
\$16,000 - \$19,000	0	0	0	0	
\$20,000 - \$22,000	0	0	1	6.7	
\$23,000 - \$25,000	0	0	0	0	
\$26,000 - \$29,000	0	0	1	6.7	
\$30,000 - \$36,000	4	21.1	1	6.7	
\$37,000 - \$50,000	0	0	3	20	
\$51,000 - \$75,000	3	15.8	0	0	
\$76,000+	8	42.1	7	46.7	
Not reported	1	5.3	0	0	
Mother's Education					0.021*
High School	2	10.5	0	0	
2-year college	4	21.1	0	0	
4-year college	7	36.8	3	20	
Graduate school	5	26.3	9	60	
Professional (e.g., Ph.D., M.D.)	0	0	3	20	
Not reported	1	5.3	0	0	

\* Chi-square test  $p < .05$

## **Overview of Procedures**

Participants were asked to complete a battery of tests to measure their language proficiency, reading comprehension, vocabulary knowledge and working memory capacity. All tests were administered individually in a university language lab.

### **Language and Cognitive Ability Tests**

#### ***English Proficiency***

English proficiency was measured with the Grammaticality Judgment task of the Comprehensive Assessment of Spoken Language-2<sup>nd</sup> Ed. (CASL-2; Carrow-Woolfolk, 2017). The CASL-2 is suitable for subjects aged 3 to 21. The administrator spoke grammatically correct or incorrect sentences aloud without supplying any pictures and the participant was asked to judge the correctness of the sentences after hearing them. Following any ungrammatical sentence identification, the participant was asked to fix the sentence by changing one word without altering overall sentence meaning. Scores were calculated according to the scoring rules.

#### ***Reading Comprehension Test***

The passage comprehension subtest of the Woodcock Johnson Mastery Test (3<sup>rd</sup> ed., WRMT-III, Woodcock, 2011) was used to assess reading comprehension. The WRMT-III is suitable for subjects aged 4 to 79 with difficulty levels from 1-12+. During the test, participants were asked to read a sentence or short passages silently and fill in a missing blank in sentences with an appropriate word. Completion of the task requires

understanding the sentence and the passage as a whole. The average test time was seven minutes for each participant. Scores were calculated according to the scoring rules.

### ***Word Identification***

The word identification subset of the Woodcock Johnson Mastery Test (3<sup>rd</sup> ed., WRMT-III, Woodcock, 2011) was used to assess word reading achievement. The word identification subtest is suitable for subjects aged 6 years to adults with difficulty levels from 1-12+. The test requires participants to read words of increasing difficulty printed in the stimulus book without having to demonstrate comprehension of the words presented. The average test time was two minutes. Scores were determined according to the scoring rules.

### ***Working Memory Test***

Working memory was tested via Auditory Working Memory (AWM) subset of the Woodcock-Johnson Tests of Cognitive Abilities (WJ-III; Schrank, 2005). The WJ-III is an assessment for participants ages 2-90. The examiner asked the participant to listen to trials with numbers and object names in a random order. The participant needed to repeat back each trial in the respective order. The task begins with two items (single object and single number) and increases to eight items (4 objects and 4 numbers). The participant received one point for the correct sequence of objects and another point for correctly sequenced numbers. A possible raw score of two points is given on each trial. Final scores were determined according to the scoring rules.

### ***Nonverbal Short-Term Memory***

The Symbolic Memory of the Universal Nonverbal Intelligence Test-2<sup>nd</sup> ed. (UNIT2; Bracken & McCallum, 2015) was used to measure short-term memory. The examiner used the eight universal administration gestures and administered the task completely nonverbally. SyM includes 10 response cards (5 green, 5 black), which depicts a sequence of universal symbols for baby, girl, boy, woman, and man, arranged according to the participant's dominant hand. After five seconds of exposure to a sequence of the universal human symbols presented on a stimulus plate, the participant was required to recreate the sequence of the universal human symbols. A raw score of one point was given on correct response. The examiner discontinued the task after three consecutive incorrect scores. Scores were determined according to the scoring rules.

## **Instrumentation and Experimental Task**

### **Eye-Tracking Instruments**

After completing the behavioral tests, participants were asked to complete the online reading task. Participants sat comfortably in front of a computer monitor at a table with a chin-rest to make sure they could move their eyes without moving their heads. The lighting in the room was set at a level of 30FC+/-5FC, and the viewing distance from the chin-rest to the computer screen was controlled within 55-60 cm. The screen was a Dell P 22 x 10 x 22 with a resolution of 1920 x 1080 pixels.

The SensoMotoric Instruments (SMI) Experiment Center 3.6, the SMI iView X system and the SMI BeGaze software were used to record and analyze gaze-tracking

data. The SMI Experiment Center was used to create each stimulus text and present stimuli to participants during the reading tasks. Eye-tracking procedures were controlled by SMI iView Red using a 9-point calibration. A 4-point validation was presented in this subsystem. SMI BeGaze collected default eye-tracking data.

### **Reading Passages**

The purpose of this study was to examine the effect of syntactic complexity in text processing among monolinguals and bilinguals; thus, we assumed that the variables to consider were different language backgrounds, the percentage of complex sentence structures, and the relationships between language background and comprehension of complex sentences. The reading materials included four texts revised from the Gray Silent Reading Test (Wiederholt & Blalock, 2000). Two versions of each text were prepared for Reading 1 and 2 tasks: one dominated by simple structures, and one dominated by complex structures (see Appendix for the two versions of the four passages). Passages with simple structures were dominated by simple and canonical sentences. Passages with complex structures contained more embedded clauses and instances of passive voice. Each Reading task contained one of the two versions of each topical passage. The *Lion* texts described a party game in which 12 girls tried to pin a ribbon on the picture where the lion's tail should be while wearing large paper bags over their heads. The *Pet Day* texts describe a pet day fair and animal parade. The *Marco Polo* texts introduces Marco Polo's experiences in China. The *Baseball* text tells the story of a baseball player. Pedro's mental journey in an important game. To accommodate the variation of readers in each group (aged 9-14), the four texts were adapted to represent



two difficulty levels based on the Coh-Metrix word concreteness score, Flesch-Kincaid Grade Level formula, and TextEvaluate academic vocabulary, word unfamiliarity, word concreteness, and complexity scores. For this study, the *Lion* and *Pet Day* texts (Grade 4 level) were easier passages, and the *Marco Polo* and *Baseball* texts (Grade 8 level) were harder passages. Statistics and psycholinguistic variables of modified expository texts are delineated in Table 3.2.

**Table 3.2***Statistics for Psycholinguistic Variables of the Stimulus*

Psycholinguistic variables	Easy				Hard			
	Lion		Pet Day		Marco Polo		Baseball	
	Level of complexity				Level of complexity			
	Less	More	Less	More	Less	More	Less	More
Text								
Variables								
Word count	101	106	110	117	129	127	165	159
Sentence count	12	7	11	8	12	8	17	9
Sentence length (# of words)	8.33	15	9.9	14.5	10.67	15.75	9.65	17.56
Word length (# of letters)	3.8	3.8	4.0	4.0	4.9	4.8	4.8	4.8
Percent multiple-clauses	8.3	85.7	18	87.5	16.7	75	23.5	88.9
Coh-metrix								
Syntactic simplicity (%ile)	92.36	55.96	89.97	34.83	91.77	59.87	94.18	48.01
Word concreteness (%ile)	99.96	100	99.59	99.27	45.62	76.42	53.19	78.81
Flesch reading ease	92.87	88.86	91.96	87.13	53.59	52.12	74.42	64.56
Flesch-Kincaid grade level	2.27	4.19	2.9	4.7	8.1	9.2	5.29	8.21
TextEvaluate								
Syntactic complexity	29	46	38	50	38	52	36	54
Academic vocabulary	6	5	16	16	70	68	61	64
Word unfamiliarity	26	26	43	44	46	59	84	84
Word concreteness	87	82	77	70	47	46	41	36
Complexity score	160	180	440	580	590	760	780	960

*Note.* Higher values of syntactic complexity, academic vocabulary, word unfamiliarity, Flesch-Kincaid grade level, and complexity score indicate higher complexity. Lower values of syntactic simplicity, word concreteness, and Flesch reading ease indicate higher complexity.

As shown in Table 3.2, the texts ranged between 7 and 12 sentences, with the lower difficulty level texts (i.e., Lion vs. Pet Day) including 101-117 words, while the higher difficulty level texts (i.e., Marco Polo vs. Baseball) ranged from 127-165 words. Regarding the impact of background knowledge, Chinese-English bilingual children may be not as familiar as English-monolingual children with the topic Baseball because people in China rarely watch baseball games and mostly do not understand baseball although it was introduced to China since 1870s (<https://factsanddetails.com/china/cat12/sub78/item1846.html>). As Droop and Verhoeven (1998) highlighted, background knowledge familiarity influenced reading performance including reading efficiency, reading comprehension, and retelling. It may facilitate reading if the topic is familiar to readers. Therefore, it is plausible to assume that passages the baseball topic may be more challenging to Chinese-English bilingual children.

### **Experimental Task**

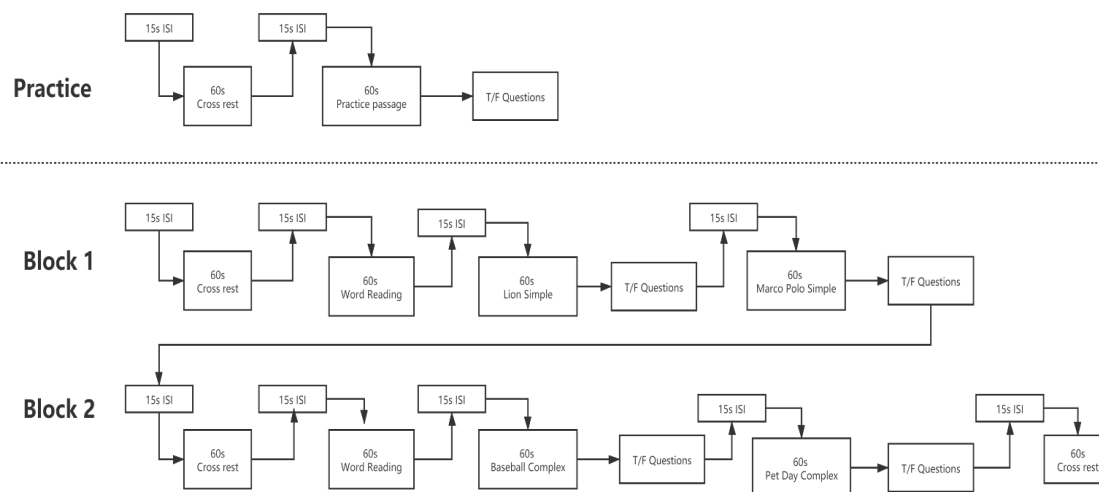
All participants were tested individually during the computer-reading task. Both eyes were sampled at a rate of 250 Hz (1 sample every 4 milliseconds). Before beginning the reading task, the administrator explained the testing procedures, positioned the participant to ensure that the eye measures met threshold requirements. Each passage was displayed on one slide with approximately 100 to 160 words. There were two reading task conditions: The Reading 1 task included Lion (easy) and Marco Polo (hard) with simple sentence structures, and Pet Day (easy) and Baseball (hard) with complex structures. The Reading 2 task included the alternative versions of the texts and in reverse order, that is Lion (easy) and Marco Polo (hard) with complex structures, and Pet Day

(easy) and Baseball (hard) with simple structures.

Participants in each group were randomly assigned to the Reading 1 or Reading 2 orders. The experimental task presentation and trial order were controlled with Psyscope and/or SensoMotoric Instruments (SMI) Red250m eye-tracking system (Teiwes, 1991). A practice section was presented before the beginning of the experiment, including one short text stimulus and five true/false comprehension questions. After the practice section, a 4-point validation and 9-point calibration were presented to register eye movements and capture the gaze patterns of each participant. Each stimulus text was presented on a single screen after the calibration and the onset time of each text was 60 s. Participants were instructed to read silently. After 60 s for text reading, a screen followed the passage with five true/false comprehension questions. The participant was instructed to complete the questions by telling the administrator the answers aloud. After answering all five questions, the administrator pressed the keyboard to proceed to the following screen as delineated in Figure 3.1. Because the study was part of a larger project that collected fNIRS and eye-tracking data simultaneously, passages were presented in two blocks that each began with a 60 s rest period. Each block included one word-reading screen and two passage screens with 15 s inter-stimulus interval (ISI) before each screen. The participants were instructed to repeatedly read the passages until the screen disappeared. Therefore, it is possible for a participant to read the short passages more than once within 60 s.

### **Eye-Tracking Data Collection and Measures**

Eye-tracking data collected through SMI BeGaze were checked before analysis

**Figure 3.1***Experimental Design of Online Reading Task 1*

*Note.* Before each reading task, one practice text with five practice reading comprehension questions was presented. The Reading 1 task included the Lion and Marco Polo texts dominated by simple sentence structures and Baseball and Pet Day texts dominated by complex structures. The Reading 2 task included the alternative versions of the texts in reverse order of Reading 1.

and if a participant did not show active participation, the data were excluded from further analysis. Any poor-quality data due to technical problems, or other factors, such as too-thick glasses worn by participants, too frequent blinking, or lazy eyes, were also excluded from the analyses. In this study, one bilingual participant's eye-tracking data was excluded from analysis due to the poor quality.

To examine the reading speed of participants, first-time total reading times were collected if the participants finished reading each passage. If the participant was not able to complete reading the whole text, the total number of words read within 60 s was calculated. Then, the reading speed was calculated by dividing the total number of words read by the total reading time of the first-time reading and reported as words read per

second (wps).

The eye-tracking data for first fixation duration were collected and analyzed. For statistical analysis, first fixation duration was based on word level: each word was considered as an area of interest (AOI).

### **Eye-Tracking Data Export**

All statistical eye-tracking measure values were exported from the default system. The researcher manually watched each individual's scanpath video to check the quality of eye-movement data and to record each individual participant's time for reading each passage. If the participant did not finish the reading within 60 s, the researcher recorded the last word that was read for the calculation of reading speed. Then the researcher exported both eyes' movement measure values for each participant from the Export Metrics using the first reading time of each passage. The final values of first fixation duration were determined based on the data of each individual's dominant eye (i.e., the eye that leads reading or the preferred eye that relays objects' location more accurately) which was tested before the online reading task.

## CHAPTER 4

### RESULTS

This study used eye-tracking techniques to examine how Chinese-English bilinguals and English monolinguals read passages with syntactically simple or complex structures at different levels of difficulty. Behavioral (i.e., comprehension question accuracy) and eye-tracking measures (i.e., reading speed and first fixation duration) were utilized to investigate reading processes of monolinguals and bilinguals, guided by the following research question.

To what extent do measures of English language proficiency (i.e., grammatical judgment), reading behavior (i.e., word identification and passage comprehension), and cognitive capacity (i.e., auditory working memory) predict eye-tracking measures of reading (i.e., reading speed and first fixation duration) of bilingual and monolingual children reading texts containing simple or complex sentence structures at different levels of reading difficulty?

#### **Language and Cognitive Ability Tests Results**

Behavioral tests were used to measure participants' language proficiency in English, reading behavior, and cognitive capacity. A series of *t* tests compared language scores between monolingual and bilingual groups, including grammatical judgment, passage comprehension, word identification, auditory working memory, and symbolic memory between monolingual and bilingual groups, as shown in Table 4.1.

**Table 4.1***Behavioral Test Scores for Monolingual and Bilingual Groups*

Behavioral tests	Monolingual		Bilingual		<i>t</i> test	<i>p</i> value
	Mean	<i>SD</i>	Mean	<i>SD</i>		
Grammatical judgment	57.2	6.6	39.4	20.0	3.31	.004**
Passage comprehension	26.2	6.0	20.1	6.1	2.92	.006**
Word identification	35.7	4.3	30.7	6.5	2.71	.011*
Auditory working memory	25.8	4.4	22.3	6.5	1.33	.194
Symbolic memory	15.5	4.7	15.1	3.7	0.26	.794

\*  $p < .05$ .\*\*  $p < .01$ .

A significant group difference was found for grammatical judgment, passage comprehension, and word identification, but no significant group differences were found for auditory working memory or symbolic memory. As delineated above, the monolingual group performed significantly better than the bilingual group on the tests of English language and reading proficiency, but there were no significant group differences on the two working memory tests. However, the effect size for the group differences was moderately large for the auditory working memory subtest (Hedges  $g = .65$ ). The effect size for the group differences for symbolic memory was quite small (Hedges  $g = .02$ ).

### **True/False Comprehension Question Accuracy**

After completing the language and cognitive ability tests, participants were randomly assigned to Reading1 (RT1) or 2 (RT2) task and asked to read four passages (RT1 and RT2 utilized alternative versions and orders of the four passages). As described previously in the experimental design, participants responded to five true/false questions

after reading each passage. The true/false comprehension questions were used to encourage effortful reading.

### Descriptive Statistics

Accuracy percentages for answering the true/false questions and reading speed were analyzed as behavioral data. Table 4.2 provides a summary of the true/false questions' descriptive statistics.

**Table 4.2**

*Accuracy Proportions of Each True/False Question for Each Passage*

True/false questions	Easy				Hard			
	Lion		Pet Day		Marco Polo		Baseball	
	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%	<i>n</i>	%
Question 1								
Correct	30	88.2	33	97.1	27	79.4	29	85.3
Incorrect	4	11.8	1	2.9	7	20.6	5	14.7
Question 2								
Correct	34	100	27	79.4	31	91.2	28	82.4
Incorrect	0	0	7	20.6	3	8.8	6	17.6
Question 3								
Correct	<b>4</b>	<b>11.8</b>	<b>10</b>	<b>29.4</b>	25	73.5	22	64.7
Incorrect	30	88.2	24	70.6	9	26.5	12	35.3
Question 4								
Correct	25	73.5	20	58.8	29	85.3	27	79.4
Incorrect	9	26.5	14	41.2	5	14.7	7	20.6
Question 5								
Correct	32	94.1	29	85.3	30	88.2	27	79.4
Incorrect	2	5.9	5	14.7	4	11.8	7	20.6

*Note.* The bold items show the low accuracy rates of Question 3 for the two easy passages.

As shown in Table 4.2, the accuracy rates of Questions 1, 2, 4, and 5 for both easy and hard passages, as well as Question 3 for hard passages ranged from 55.8% to 100%,



much higher than for Question 3 for the two easy passages (i.e., 11.8% and 29.4% respectively). These anomalously low accuracy rates (much lower than 60%) of Question 3 for easy passages mean these questions' answers were not sufficiently valid to compare the differences between groups. Therefore, the scores for these questions were removed before the following analysis.

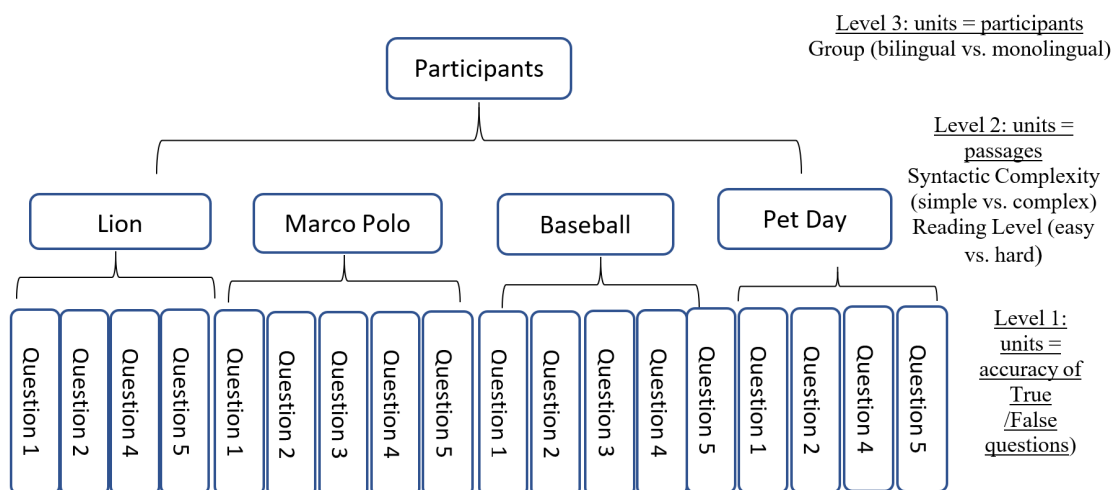
### **Logistic Multilevel Modeling Analysis**

To compare differences in comprehension question accuracy between groups, by reading levels, or syntactic complexity levels, a three-level general logistic multilevel regression model was used to examine whether bilinguals performed differently from monolinguals in behavioral true/false questions. The dependent variable was the accuracy of each comprehension question (a dichotomous variable: correct and incorrect). Each question was a unit within level one of the models. These questions were nested within passages that comprised the units of level two with four passage topics (Lion, Marco Polo, Baseball, and Pet Day), with associated fixed effects for reading level (easy vs. hard) and syntactic complexity (simple vs. complex). These passages were further nested within participants, with associated fixed effects for group (monolingual vs. bilingual). Figure 4.1 displays the random effects regarding these levels. Table 4.3 shows the fit model by using a likelihood ratio test (LRT).

Table 4.3 indicates that Models 1 and 2 were not significantly better than the null model (Model 0) with lower AIC and BIC values and better log likelihoods. The follow-up logit scale and odds ratio scale tests showed that none of the fixed factors (group,

**Figure 4.1**

*Three-level Nested General Logistic Multilevel Regression Models for Accuracy of True/False Questions*



*Note.* The Lion and Pet Day were easy passages (4th-grade level) and the Marco Polo and Baseball were more difficult (8th-grade level) passages. Syntactic complexity varied for the passages: that is participants assigned to RT1 read the Lion and Marco Polo passages with simpler sentence structures and the Baseball and Pet Day passages with more complex sentence structures. Participants assigned to RT 2 read the alternative versions of the texts (i.e., Lion and Marco Polo passages with more complex sentence structures; Baseball and Pet Day passages with simpler sentence structures).

**Table 4.3**

*Logistic Multilevel Model Fit for Accuracy*

Fit models	AIC	BIC	Log likelihood	$\chi^2$	$\chi^2$ difference	<i>p</i> value
<b>Model 0</b> accuracy ~ 1 + (1 participant/passage) + (1 question)	<b>550.22</b>	<b>567.89</b>	<b>-271.11</b>			
Model 1 accuracy ~ group + reading level + complexity + (1 participant/passage) + (1 question)	551.72	582.64	-268.86	4.5053	4.5053	.212
Model 2 accuracy ~ group* reading level*complexity + (1 participant/passage) + (1 question)	559.00	607.58	-268.50	5.2273	0.7220	.948

*Note.* AIC = Akaike information criterion; BIC = Bayesian information criterion.

reading level, or complexity) was a significant predictor of accuracy, as delineated in Table 4.4. Therefore, the null model (Model 0) was deemed the best fit model.

**Table 4.4**

*Logit Scale and Odds Ratio Scale Tests for Model 0 and Model 1*

Model	Models			
	Model 0: accuracy ~ 1 + (1 participant/passage) + (1 question)		Model 1: accuracy ~ group + reading level + complexity + (1 participant/passage) + (1 question)	
	Logit scale	Odds ratio scale (95% CIs)	Logit scale	Odds ratio scale (95% CIs)
(Intercept)	1.75 (0.29)***	5.74 [3.23; 10.20]*	2.21 (0.38)***	9.09 [4.28; 19.30]*
Group			-0.43 (0.34)	0.65 [0.33; 1.26]
Syntactic complexity			-0.39 (0.23)	0.68 [0.43; 1.07]
Reading level			-0.13 (0.25)	0.88 [0.54; 1.43]

*Note.* For logit scale: \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ ; for odds ratio: \* Null hypothesis value outside the confidence interval.

Using the formula:  $\text{probability} = \exp(5.74)/(1+\exp(5.74))$ , the overall probability of choosing correct answers for all participants was over 85% with a significant  $p$  value. Both logit scale and odds ratio scale tests indicated no significant differences between groups, reading levels, or syntactic complexity for question accuracy. These findings indicate high comprehension question accuracy rates for easy and hard passages by children in both groups. However, because the true/false questions were used to encourage effortful reading and measured basic understanding of the texts, the similar accuracy on the comprehension questions for both groups does not necessarily mean similar reading ability. Therefore, to examine cognitive reading processes, we used two eye-tracking measures (i.e., reading speed and first fixation duration) to assess in-the-

moment reading and to examine whether there were significant reading performance differences between groups, reading levels, or syntactic complexity levels.

### **Reading Speed**

As noted previously in the description of psycholinguistic variables of the stimuli, the four passages varied in length (i.e., the number of words ranging from 101-165). The possibility of rereading parts of the shorter passages (i.e., Lion and Pet Day) was higher than of the longer passages (i.e., Marco Polo and Baseball). Moreover, the longer passages were of greater difficulty level (i.e., 8th-grade) and some participants were unable to complete reading the entire passage in the given time frame (i.e., 60 s). To avoid analyzing data from the repeated reading (more specifically data for first fixation duration), the eye-tracking measures employed in this study were calculated from the first total reading time needed to initially read the passage given the 60 s time allowance.

### **Descriptive Statistics**

Reading speed was calculated as the number of words read per second (wps) within the first total reading time. If the participant did not complete reading the whole passage within 60 s, we recorded the last word that the participant read and then counted the number of words that had been read. Table 4.5 displays the summary of descriptive statistics for reading speed by passage and group.

Table 4.5 shows that the reading speed of bilinguals (ranging from 2.7 to 3.5 wps) was consistently slower than the monolinguals' reading speed (ranging from 3.7 to 4.9 wps). The faster mean speed of bilinguals in easier passage reading (i.e., 3.5 wps) was

mathematically slower than the slowest mean speed of monolinguals in harder passage reading (i.e., 3.7 wps).

**Table 4.5**

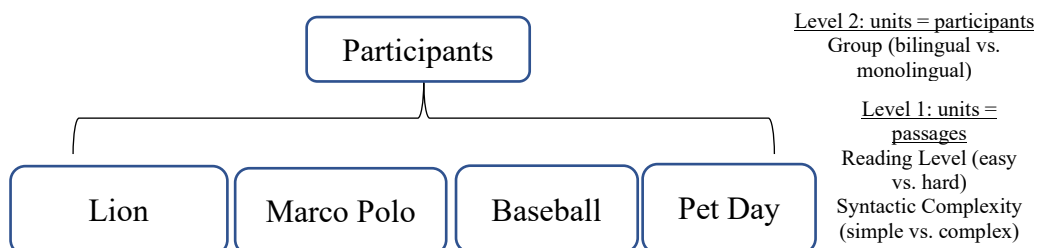
*Summary of Descriptive Statistics for Reading Speed*

Syntactic complexity	Reading level	Passage	Monolingual		Bilingual	
			Mean	<i>SD</i>	Mean	<i>SD</i>
Complex syntactic structure	Easy	Lion	4.6	1.7	3.5	1.2
		Pet Day	4.6	1.1	3.2	1.2
	Hard	Baseball	4.1	0.9	2.7	1.0
		Marco Polo	3.8	1.0	3.5	1.3
Simple syntactic structure	Easy	Lion	4.9	1.3	2.7	0.9
		Pet Day	4.7	1.6	3.5	1.5
	Hard	Baseball	3.7	1.2	3.1	1.2
		Marco Polo	3.9	1.0	3.2	1.0

*Note.* Each passage has two versions (syntactically complex or simple) with comparable reading difficulty levels.

### Multilevel Modeling Analysis

To examine whether the reading speed for monolinguals was significantly faster than that of the bilinguals, a two-level nested multilevel regression model (MLM) was used to analyze the data (see Figure 4.2) with reading speed as the dependent variable. Each passage was a level one unit with associated fixed effects for reading level (easy vs. hard) and syntactic complexity (simple vs. complex). The level-two unit was participant, with associated fixed effects for group (monolingual vs. bilingual). Table 4.6 shows the model fit for reading speed models of interest.

**Figure 4.2***Two-Level Nested Multilevel Regression Models for Reading Speed*

*Note.* The information for reading difficulty level, syntactic complexity, and the assignment of reading tasks (1 or 2) for each passage was the same as noted above (see the note of Figure 4.1).

**Table 4.6***Crossed Random Effects of the Multilevel Model Fit for Reading Speed*

Fit models	AIC	BIC	Log likelihood	$\chi^2$	$\chi^2$ difference	<i>p</i> value
Model 0 Reading speed ~ 1 + (1 participant)	373.92	382.62	-183.96			
Model 1 Reading speed ~ group + reading level + complexity + (1 participant)	349.24	366.63	-168.62	30.683	30.683	9.9e-07***
<b>Model 2</b> Reading speed ~ group*reading level + complexity + (1 participant)	<b>340.16</b>	<b>360.44</b>	<b>-163.08</b>	41.762	11.0795	<b>.00087</b> ***
Model 3 Reading speed ~ group*reading level*complexity + (1 participant)	343.99	372.97	-161.99	43.93	2.1719	.5375

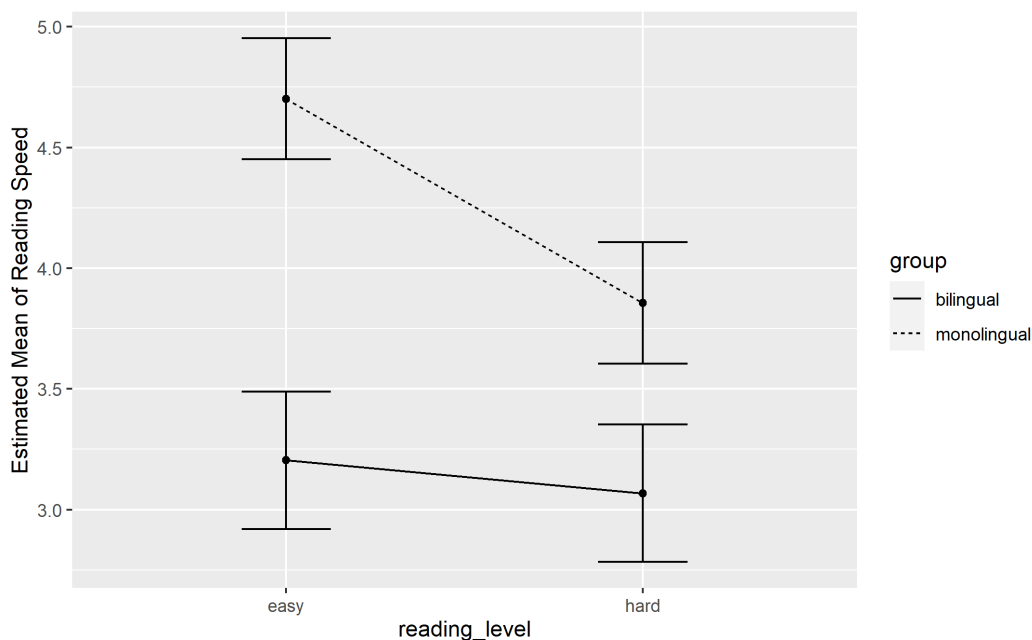
*Note.* AIC = Akaike information criterion; BIC = Bayesian information criterion; \*\*\*  $p < .001$ .

The two-way interaction model (Model 2) with lower values of AIC and better log likelihood value fit the data significantly better than the other three models. The

model of reading speed revealed main effects of group [ $F_{(1,33.99)} = 9.81, p < .01$ ], reading level [ $F_{(1,99.92)} = 22.47, p < .001$ ], and the interaction of group by reading level [ $F_{(1,99.92)} = 11.72, p < .001$ ], but no main effects of syntactic complexity or interactions were found, as shown in Figure 4.3. In general, the reading speed of monolinguals was significantly faster than bilinguals ( $p = .004$ ) and monolinguals were significantly faster than bilinguals in reading both types of passages (easy:  $p < .001$ ; hard:  $p = .049$ ). Moreover, the speed for reading easy passages was significantly faster than for hard passages' reading ( $p < .001$ ). For the main effect of group by reading level interaction, a post hoc comparison showed that monolinguals read easy passages much faster than hard passages ( $p < .001$ ). Importantly, there was no indication of reading speed difference in reading easy and hard passages for bilinguals.

**Figure 4.3**

*Estimated Reading Speed Mean for Easy and Hard Passages for Each Group*



Monolinguals demonstrating significantly faster reading speeds for both types of passages are consistent with the language and reading behavioral findings. The bilinguals demonstrated weaker English language skills and read slower than monolinguals. We expected that bilinguals' lower proficiency in language skills would lead to slower reading speeds on harder passages. However, the results showed that within the bilingual group, there were no significant differences in reading speed for easy and hard passages. To further test whether participants' reading speed was related to their cognitive, language, and reading behavior abilities, cognitive and linguistic tests were used as fixed factors and added to the MLM model to examine the moderation effect of language abilities on reading speed.

### **MLM with Behavior Tests as Fixed Factors**

As delineated above, the monolingual group performed significantly better than the bilingual group on the tests of English language proficiency and reading behaviors, with no significant group differences on the two working memory tests. Poorer performances on the language and reading behavioral tests likely correspond with the bilinguals' lower proficiency in English and reading skills as measured (i.e., grammar, word identification, and passage comprehension). However, it is possible that lower proficiency in one aspect, such as grammar, relates to poorer performance on the other tests (e.g., word identification and passage comprehension). Therefore, we generated correlation metrics for each group to examine the correlations among the behavioral tests.



***Correlations Among Language, Reading,  
and Cognitive Ability Measures***

Tables 4.7 and 4.8 present the correlation metrics of behavioral test scores for each group. The correlation metrics show that for both monolingual and bilingual groups, the relationships among English language and reading behavioral tests (i.e., grammatical judgment, word identification, and passage comprehension) were significantly large. For example, the correlations between word identification and grammatical judgment ( $r = 0.609$  for monolinguals vs.  $r = 0.717$  for bilinguals) as well as with passage comprehension ( $r = 0.735$  for monolinguals vs.  $r = 0.802$  for bilinguals) were high.

**Table 4.7**

*Correlations Between Behavioral Test Scores for the Monolingual Group*

Behavioral tests	1	2	3	4	5
1. Grammatical judgment	1.00				
2. Word identification	0.609**	1.00			
3. Passage comprehension	0.544*	0.735***	1.00		
4. Auditory working memory	0.453	0.524*	0.492*	1.00	
5. Symbolic memory	0.488	0.407	0.421	0.407	1.00

Note. \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ .

**Table 4.8**

*Correlations Between Behavioral Test Scores for the Bilingual Group*

Behavioral tests	1	2	3	4	5
1. Grammatical judgment	1.00				
2. Word identification	0.717**	1.00			
3. Passage comprehension	0.787***	0.802***	1.00		
4. Auditory working memory	0.496	0.326	0.424	1.00	
5. Symbolic memory	0.408	0.204	0.321	0.492	1.00

Note. \*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$ .

Because of the high correlations between language and reading competencies, the effects of language and reading behaviors on the online reading task performance may be similar. Therefore, to avoid the possibilities of washing out main effects because of the high correlations among various test scores, we added each test score to the model individually and generated separate fit models based on the likelihood ratio test.

To examine the moderation effect of each test, several interactions were tested in the model. Results showed that grammatical judgment, word identification, and passage comprehension were significant predictors that may have influenced the relationship between reading difficulty level and reading speed, but not auditory working memory or symbolic memory.

***Fit Models for Grammatical Judgment, Word Identification, and Passage Comprehension***

As Tables 4.9, 4.10, and 4.11 display, the two-way interaction model (Model 2 for each test) with lower values of AIC and better log likelihood value fit the data significantly better than the other three models.

In addition to the main effect of reading level and significant two-way interaction of reading level by group found from the MLM without behavioral tests as fixed factors, the two-way interaction models with grammatical judgment, word identification, and passage comprehension as fixed factors revealed significant two-way interactions: reading level by grammatical judgment [ $F_{(1,99.79)} = 5.36, p = .023$ ] (see Figure 4.4 [A]); reading level by word identification [ $F_{(1,100.07)} = 7.73, p < .01$ ] (see Figure 4.4 [B]); and reading level by passage comprehension [ $F_{(1,99.92)} = 4.23, p = .042$ ] (see Figure 4.4 [C]).

**Table 4.9***Fit Models for Reading Speed with Grammatical Judgment as Fixed Effect*

Fit models	AIC	BIC	Log likelihood	$\chi^2$	$\chi^2$ difference	<i>p</i> value
Model 1 Reading speed ~ group + reading level + complexity + grammatical judgment + (1 participant)	343.28	363.57	-164.64			
<b>Model 2</b> Reading speed ~ group*reading level + reading level*grammatical judgment + complexity + (1 participant)	<b>331.87</b>	<b>355.05</b>	<b>-157.93</b>	<b>13.418</b>	<b>13.418</b>	<b>.0002***</b>
Model 3 Reading speed ~ group*reading level*grammatical judgment + complexity + (1 participant)	330.80	362.67	-154.40	20.487	7.069	.069
Model 4 Reading speed ~ group*reading level*complexity*grammatical judgment + (1 participant)	340.88	393.04	-152.44	24.407	3.92	.789

Note. AIC = Akaike information criterion; BIC = Bayesian information criterion; \*\*\*  $p < .001$ .

**Table 4.10***Fit Models for Reading Speed with Word Identification as Fixed Effect*

Fit models	AIC	BIC	Log likelihood	$\chi^2$	$\chi^2$ difference	<i>p</i> value
Model 1 Reading speed ~ group + reading level + complexity + word identification + (1 participant)	338.53	358.82	-162.27			
<b>Model 2</b> Reading speed ~ group*reading level + reading level* word identification + complexity + (1 participant)	<b>324.00</b>	<b>350.08</b>	<b>-153.00</b>	<b>18.532</b>	<b>18.532</b>	<b>9.46e-05***</b>
Model 3 Reading speed ~ group*reading level* word identification + complexity + (1 participant)	327.13	359.01	-152.56	19.402	0.87	.647
Model 4 Reading speed ~ group*reading level*complexity* word identification + (1 participant)	338.72	390.88	-151.36	21.812	2.41	.934

Note. AIC = Akaike information criterion; BIC = Bayesian information criterion; \*\*\*  $p < .001$ .

**Table 4.11***Fit Models for Reading Speed with Passage Comprehension as Fixed Effect*

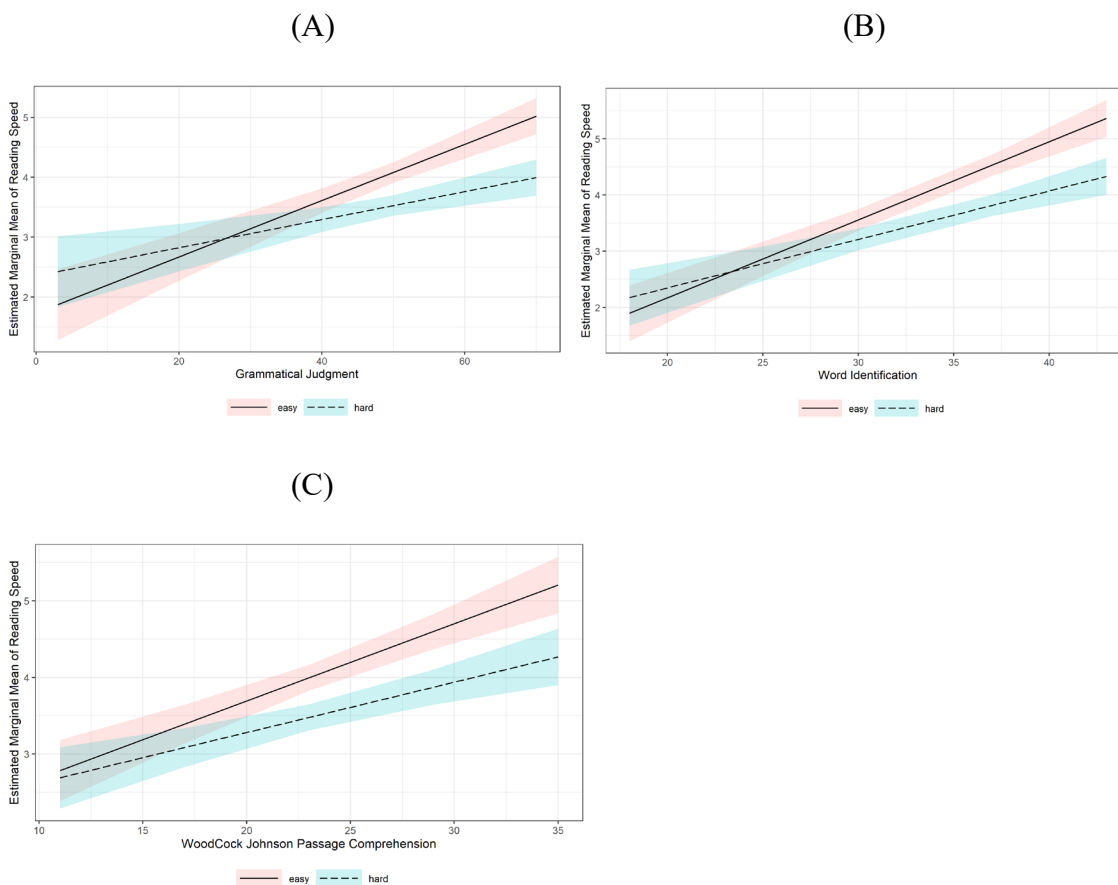
Fit models	AIC	BIC	Log likelihood	$\chi^2$	$\chi^2$ difference	<i>p</i> value
Model 1 Reading speed ~ group + reading level + complexity + passage comprehension + (1 participant)	343.06	363.35	-164.53			
<b>Model 2</b> Reading speed ~ group*reading level + reading level* passage comprehension + complexity + (1 participant)	<b>331.84</b>	<b>357.92</b>	<b>-156.92</b>	<b>15.219</b>	<b>15.219</b>	<b>.0005***</b>
Model 3 Reading speed ~ group*reading level* passage comprehension + complexity + (1 participant)	334.90	366.78	-156.45	16.159	0.94	.624
Model 4 Reading speed ~ group*reading level*complexity* passage comprehension + (1 participant)	346.25	398.41	-155.12	18.819	2.66	.934

*Note.* AIC = Akaike information criterion; BIC = Bayesian information criterion; \*\*\*  $p < .001$ .

Figure 4.4 demonstrates positive associations between reading speed and grammatical judgment, word identification and passage comprehension. These positively associated relationships were more marked for easy passages and less distinct for hard passages. A follow-up slope analysis for the interactions showed that for easy passage reading, a 1 unit increase in grammatical judgment, word identification, or passage comprehension was associated with greater increase in reading speed (grammatical judgment:  $\beta = 0.047$ ,  $SE = 0.012$ ,  $p < .001$ ; word identification:  $\beta = 0.139$ ,  $SE = 0.03$ ,  $p < .001$ ; passage comprehension:  $\beta = 0.101$ ,  $SE = 0.029$ ,  $p < .001$ ), than for hard passage reading (grammatical judgment:  $\beta = 0.023$ ,  $SE = 0.012$ ,  $p = .061$ ; word identification:  $\beta = 0.086$ ,  $SE = 0.03$ ,  $p < .01$ ; passage comprehension:  $\beta = 0.066$ ,  $SE = 0.029$ ,  $p = .027$ ). This

**Figure 4.4**

*The Interactions of Reading Level by Grammatical Judgment, Word Identification, and Passage Comprehension Based on the Fit Models for Reading Speed*



*Note.* (A) presents the two-way interaction of reading level by Grammatical Judgment; (B) displays the two-way interaction of reading level by Word Identification; and (C) shows the two-way interaction of reading level by Passage Comprehension.

positive association indicates that individuals with higher test scores (i.e., grammatical judgment, word identification, and passage comprehension) tended to demonstrate faster reading speeds, and individuals with lower test scores tended to demonstrate slower reading speeds across groups

Comparing the slopes ( $\beta$  value) of interactions between offline behavioral tests

and reading speed, Table 4.12 shows that although each test was positively associated with reading speed for both easy and hard passages, the association was stronger for word identification and passage comprehension than for grammatical judgment. The results may indicate more association between reading competencies (i.e., word identification & passage comprehension) and reading speed than between language proficiency and reading speed.

**Table 4.12**

*Slope Analysis Summary of Language and Reading Behavior Tests by Reading Level Interactions for Reading Speed*

Interactions	Slope ( $\beta$ Value)	
	Easy passage	Hard passage
Grammatical Judgment* Reading Level	$\beta = 0.047^{***}$	$\beta = 0.023$
Word Identification* Reading Level	$\beta = 0.139^{***}$	$\beta = 0.086^{**}$
Passage Comprehension* Reading Level	$\beta = 0.101^{***}$	$\beta = 0.066^*$

\*  $p < .05$ .

\*\*  $p < .01$ .

\*\*\*  $p < .001$ .

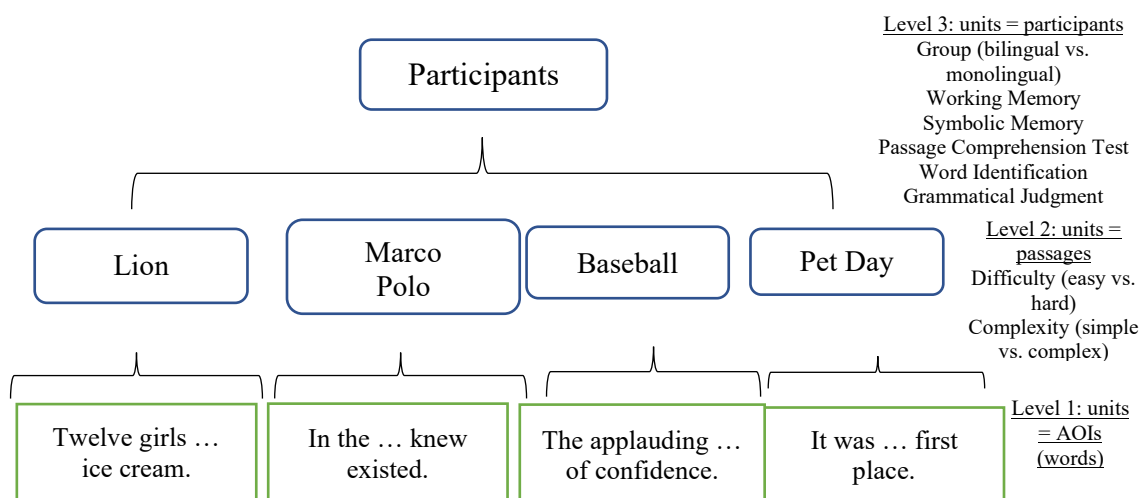
### First Fixation Duration

First fixation duration was used to examine the immediate information processes of bilinguals and monolinguals while reading passages varied in reading difficulty and syntactic complexity. A series of three-level nested multilevel regression models (MLM) was conducted to analyze the eye-tracking measure of first fixation duration. To increase the statistical power of this model, each word in passage was coded as an area of interest (AOI). That is, each word in the passage, was a unit within level one of the MLM model.

These words were nested within passages, which constituted the level-two units with associated fixed effects for reading level (easy vs. hard) and syntactic complexity (simple vs. complex). These passages were further nested within participants, with associated fixed effects for group (monolingual vs. bilingual). Finally, language, reading behavior, and cognitive ability scores (i.e., grammatical judgment, word identification, passage comprehension, auditory working memory, and symbolic memory respectively) were entered as fixed factors to examine how these scores might predict eye-tracking performance. Figure 4.5 displays the random and fixed effects associated with these levels.

**Figure 4.5**

*Three-Level Nested Multilevel Regression Models for the Eye-Tracking Measures*



*Note.* The information for reading difficulty level, syntactic complexity, and the assignment of reading tasks (1 or 2) for each passage was the same as noted above (see the note of Figure 4.1).

### The Multilevel Model Without Language and Cognitive Ability Test Predictors

To examine whether the language group, reading level, or syntactic complexity were significant predictors of first fixation duration, we conducted null, one-way, two-way interaction, and three-way interaction crossed random effects models and found the best fit model by using likelihood ratio test comparison, as shown in Table 4.13.

**Table 4.13**

*Crossed Random Effects Multilevel Model Fit for First Fixation Duration*

Fit models	AIC	BIC	Log likelihood	$\chi^2$	$\chi^2$ difference	<i>p</i> value
Model 0 First fixation ~ 1 + (1 participant) + (1 passage/aoi)	209937	209976	-104964			
Model 1 First fixation ~ group + reading level + complexity + (1 participant) + (1 passage/aoi)	209938	209999	-104961	5.62	5.62	.132
<b>Model 2</b> First Fixation ~ group*reading level + complexity + (1 participant) + (1 passage/aoi)	<b>209930</b>	<b>209999</b>	<b>-104956</b>	15.70	10.09	<b>.001**</b>
Model 3 First Fixation ~ group*reading level*complexity + (1 participant) + (1 passage/aoi)	209935	210027	-104956	16.34	0.64	.537

*Note.* AIC = Akaike information criterion; BIC = Bayesian information criterion.

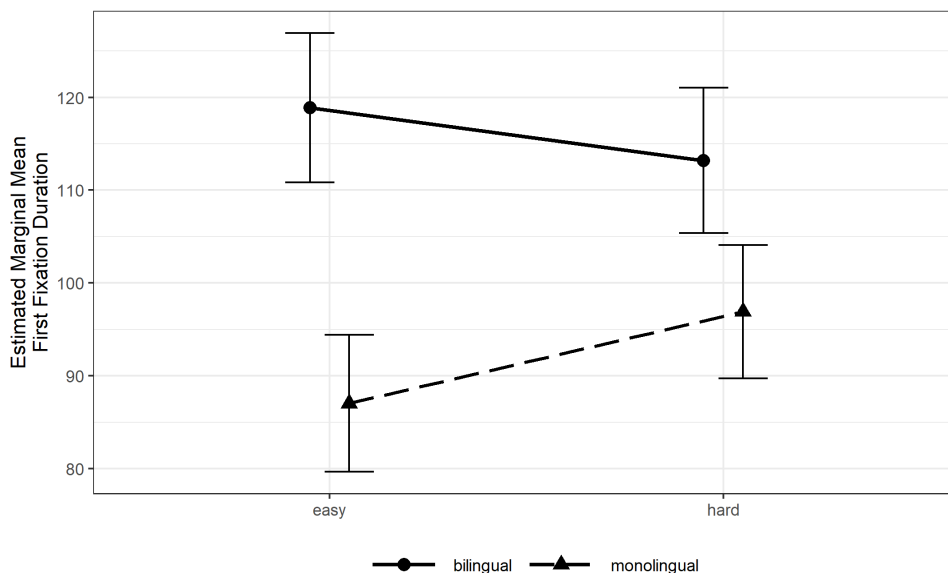
\*\*\**p* < .01

The two-way interaction model (Model 2) was the best-fitting model. There was a significant main effect for group [ $F_{(1,32.1)} = 6.38, p = .017$ ] and a significant group by reading level interaction [ $F_{(1,15384.5)} = 10.09, p < .01$ ] (see Figure 4.6). No significant difference was found for syntactic complexity.



**Figure 4.6**

*First Fixation Duration of Group by Reading Level Interaction*



A post hoc pairwise comparison showed that bilinguals revealed significantly longer first fixation durations than monolinguals for all passages ( $p = .012$ ). For the interaction of group by reading level, the first fixation durations for bilinguals were significantly longer than monolinguals ( $p < .001$ ) for the easier passages. However, surprisingly, no difference was found between monolinguals and bilinguals for harder passage reading. Additionally, Figure 4.6 demonstrates a mathematically although not significantly longer first fixation duration among bilinguals for easy passage reading as compared with harder passages, which is interesting and difficult to interpret. Compared to easier passages (ranging 101-117 words), harder passages were longer (ranging 127-165 words). The limited reading time (60 s) may have resulted in screen scanning for bilinguals, which may have led to less effortful reading, corresponding to shorter first

fixation duration on the harder passages. To examine the influence of cognitive, linguistic, and reading abilities on first fixation duration, each offline behavioral test (i.e., the same predictors used with reading speed) was included as a fixed factor and added to the MLM model to examine any moderation effect of language, reading, and cognitive capacities on first fixation duration.

### **The Multilevel Model With Language, Reading Behavior, and Cognitive Tests Predictors**

As in the reading speed MLM, the moderation effects of language ability (as measured by grammatical judgment), reading behaviors (as measured by word identification and passage comprehension), and cognitive ability (as measured by auditory working memory and symbolic memory) on first fixation duration were analyzed for various interactions. After comparing different models for each test, results showed that grammatical judgment, word identification, passage comprehension, and auditory working memory were significant predictors, but symbolic memory was not.

As presented in Table 4.14, the two-way interaction model (Model 2) with grammatical judgment as the fixed factor with lower values of AIC and better log likelihood value fit the data significantly better than the other three models. Tables 4.15 and 4.17 show that the two- and three-way interaction model (Model 3) with word identification and auditory working memory as the fixed factor respectively was the fit model. The model with passage comprehension as the fixed factor showed that the three-way interaction model (Model) fit the data significantly better (see Table 4.16).

**Table 4.14***Fit Models for First Fixation Duration with Grammatical Judgment as Fixed Effect*

Fit models	AIC	BIC	Log likelihood	$\chi^2$	$\chi^2$ difference	<i>p</i> value
Model 1 First fixation ~ group + reading level + complexity + grammatical judgment + (1 participant) + (1 passage/aoi)	209938	210007	-104960			
<b>Model 2</b> First fixation ~ group*reading level + reading level* grammatical judgment + complexity + (1 participant) + (1 passage/aoi)	<b>209923</b>	<b>210000</b>	<b>-104951</b>	<b>16.95</b>	<b>16.95</b>	<b>3.83e-05***</b>
Model 3 First Fixation ~ group*reading level* grammatical judgment + group*complexity* grammatical judgment + (1 participant) + (1 passage/aoi)	209929	210052	-104948	23.03	6.08	.41
Model 4 First Fixation ~ group*reading level*complexity* grammatical judgment + (1 participant) + (1 passage/aoi)	209934	210088	-104947	25.52	2.49	.64

Note. AIC = Akaike information criterion; BIC = Bayesian information criterion; \*\*\**p* < .01.

**Table 4.15***Fit Models for First Fixation Duration with Word Identification as Fixed Effect*

Fit models	AIC	BIC	Log likelihood	$\chi^2$	$\chi^2$ difference	<i>p</i> value
Model 1 First fixation ~ group + reading level + complexity + word identification + (1 participant) + (1 passage/aoi)	209934	210003	-104958			
Model 2 First fixation ~ group*reading level + group*complexity + group* word identification + reading level* word identification + complexity* word identification + (1 participant) + (1 passage/aoi)	209921	210028	-104946	23.05	23.05	.0003***
<b>Model 3</b> First Fixation ~ group*reading level + reading level* word identification + group*complexity* word identification + (1 participant) + (1 passage/aoi)	<b>209918</b>	<b>210033</b>	<b>-104944</b>	27.99	4.95	<b>.026*</b>
Model 4 First Fixation ~ group*reading level*complexity*word identification + (1 participant) + (1 passage/aoi)	209919	210072	-104939	37.28	9.28	.098

Note. AIC = Akaike information criterion; BIC = Bayesian information criterion; \*\*\**p* < .001; \**p* < .05

**Table 4.16***Fit Models for First Fixation Duration with Passage Comprehension as Fixed Effect*

Fit models	AIC	BIC	Log likelihood	$\chi^2$	$\chi^2$ difference	<i>p</i> value
Model 1 First fixation ~ group + reading level + complexity + passage comprehension + (1 participant) + (1 passage/aoi)	209938	210007	-104960			
Model 2 First fixation ~ group*reading level + group*complexity + group* passage comprehension + reading level* passage comprehension + complexity* passage comprehension + (1 participant) + (1 passage/aoi)	209934	210034	-104954	11.36	11.36	.0228*
<b>Model 3</b> Frist Fixation ~ group*reading level + group*complexity* passage comprehension + (1 participant) + (1 passage/aoi)	<b>209906</b>	<b>210014</b>	<b>-104939</b>	41.43	30.07	<b>4.169e-08***</b>
Model 4 First Fixation ~ group*reading level*complexity* passage comprehension + (1 participant) + (1 passage/aoi)	209910	210064	-104935	49.27	7.84	.250

Note. AIC = Akaike information criterion; BIC = Bayesian information criterion; \*\*\**p* < .001; \**p* < .05.

**Table 4.17***Fit Models for First Fixation Duration with Auditory Working Memory as Fixed Effect*

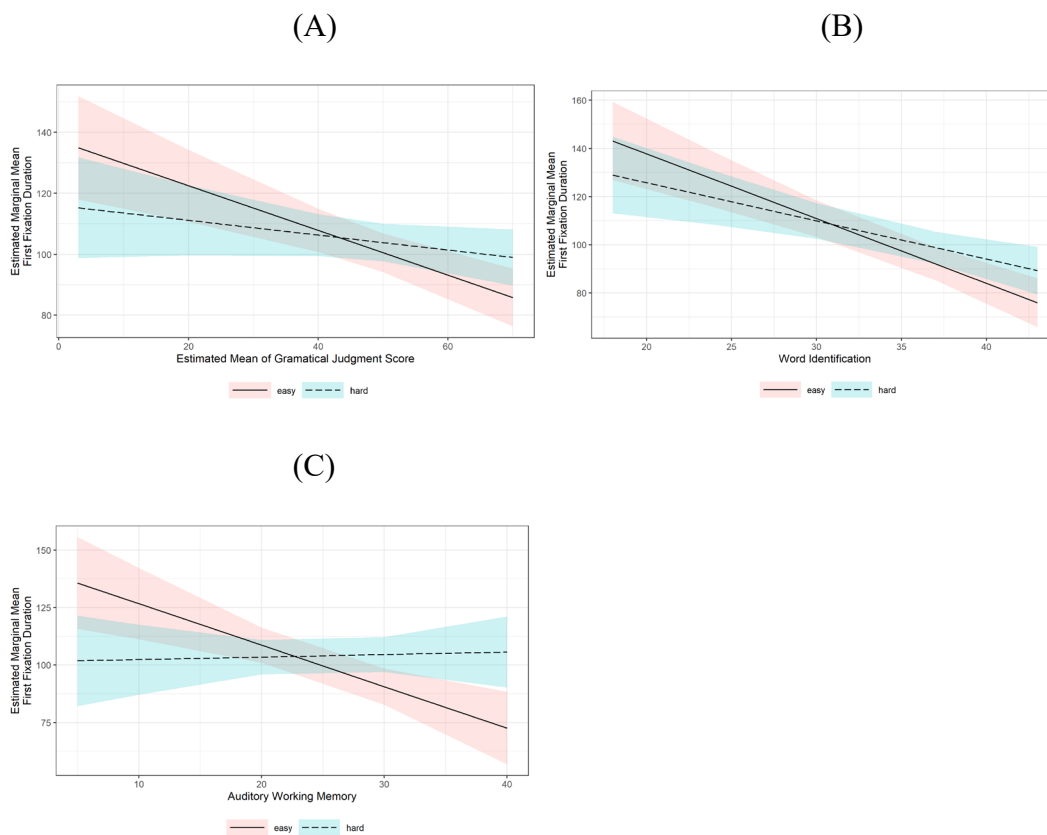
Fit models	AIC	BIC	Log likelihood	$\chi^2$	$\chi^2$ difference	<i>p</i> value
Model 1 First fixation ~ group + reading level + complexity + auditory working memory + (1 participant) + (1 passage/aoi)	209939	210008	-104961			
Model 2 First fixation ~ group*reading level + group*complexity + group* auditory working memory + reading level* auditory working memory + complexity* auditory working memory + (1 participant) + (1 passage/aoi)	209923	210023	-104949	23.76	23.76	8.911e-05***
<b>Model 3</b> Frist Fixation ~ group*reading level + reading level* auditory working memory + group*complexity* auditory working memory + (1 participant) + (1 passage/aoi)	<b>209903</b>	<b>210010</b>	<b>-104937</b>	46.45	22.69	<b>1.904e-06***</b>
Model 4 First Fixation ~ group*reading level*complexity* auditory working memory + (1 participant) + (1 passage/aoi)	209909	210063	-104935	51.90	5.45	.488

Note. AIC = Akaike information criterion; BIC = Bayesian information criterion; \*\*\**p* < .001.

In addition to the main effect of group and a significant group by reading level interaction found from the multilevel model without behavioral tests as predictors, the two-way interaction model with grammatical judgment as the fixed factor revealed a significant reading level by grammatical judgment interaction [ $F_{(1,15466.6)} = 16.96, p < .001$ ], as displayed in Figure 4.7 (A).

**Figure 4.7**

*The Interaction of Reading Level by Grammatical Judgment, Word Identification, and Auditory Working Memory Based on the Fit Models for First Fixation Duration*



*Note.* (A) presents the two-way interaction of reading level by Grammatical Judgment; (B) displays the two-way interaction of reading level by Word Identification; and (C) shows the two-way interaction of reading level by Auditory Working Memory.

The two- and three-way interaction model with word identification as the fixed factor revealed a significant reading level by word identification [ $F_{(1,15488.7)} = 5.87, p = .015$ ] interaction (see Figure 4.7 [B]), and a three-way interaction for group by reading level by word identification [ $F_{(1,15509.0)} = 4.96, p = .026$ ] (see Figure 4.8 shown later in this chapter).

The fit model with passage comprehension as the fixed factor revealed a significant three-way interaction for group by reading level by passage comprehension [ $F_{(1,15509.0)} = 4.96, p = .026$ ], as shown in Figure 4.9 later in this chapter. The interaction models with auditory working memory as the predictor revealed a significant two-way reading level by auditory memory interaction [ $F_{(1,15272.4)} = 20.51, p < .001$ ] (see Figure 4.7 [C]), and a significant three-way interaction for group by reading level by auditory memory [ $F_{(1,13594.0)} = 20.77, p < .001$ ], as shown in Figure 4.10 later in this chapter.

### ***Two-Way Interactions of Reading Level by Grammatical Judgment, Word Identification, or Auditory Working Memory***

Figure 4.7 displays the two-way interactions revealed by the models with grammatical judgment, word identification, or auditory working memory as fixed factors.

Figure 4.7 demonstrates a significant negative association between grammatical judgment, word identification, or auditory memory and first fixation duration. This relationship was more marked for easy passages. A follow-up slope analysis for the interactions showed that for easy passage reading, a 1-unit increase in grammatical judgment, word identification, or auditory memory was associated with larger decrease in first fixation duration (grammatical judgment:  $\beta = -0.793, SE = 0.334, p = .023$ ; word

identification:  $\beta = -2.686$ ,  $SE = 0.906$ ,  $p = .005$ ; auditory memory:  $\beta = -1.803$ ,  $SE = 0.958$ ,  $p = .068$ ), than for hard passage reading (grammatical judgment:  $\beta = -0.198$ ,  $SE = 0.330$ ,  $p = .552$ ; word identification:  $\beta = -1.586$ ,  $SE = 0.889$ ,  $p = .083$ ; auditory memory:  $\beta = 0.111$ ,  $SE = 0.945$ ,  $p = .907$ ). These negative associations indicate that individuals with lower grammatical judgment, word identification, or auditory memory test scores tended to demonstrate longer first fixation durations and individuals with higher grammatical judgment test scores tended to demonstrate shorter first fixation durations.

Comparing the slopes ( $\beta$  value) of interactions between offline behavioral tests and first fixation duration, Table 4.18 shows that although each test was negatively associated with first fixation duration for both easy and hard passages, the association was stronger for word identification than for auditory memory and grammatical judgment. The results may indicate more association between reading competencies (i.e., word identification) and first fixation duration than between cognitive ability or language proficiency and first fixation duration.

**Table 4.18**

*Slope Analysis Summary of Language and Reading Behavior Tests by Reading Level for First Fixation Duration*

Interactions	Slope	
	Easy Passage	Hard Passage
Grammatical judgment*reading level	$\beta = -0.793^*$	$\beta = -0.198$
Word identification* reading level	$\beta = -2.686^{**}$	$\beta = -1.586$
Auditory working memory* reading level	$\beta = -1.803$	$\beta = 0.111$

\*  $p < .05$ .

\*\*  $p < .01$ .

***There-Way Interactions of Group by Syntactic Complexity by Word Identification, Passage Comprehension, or Auditory Working Memory***

Apart from the significant two-way interactions, the fit models revealed a significant group by complexity by word identification, passage comprehension, or auditory working memory three-way interaction, as displayed in following figures.

As Figure 4.8 shows, word identification was negatively associated with first fixation duration regardless of language group and syntactic complexity, indicating individuals with lower word identification scores had longer first fixations. Figure 4.8 (A) presents the comparison between monolingual and bilingual children when reading syntactically simple versus complex passages. As the figure illustrates, for syntactically complex passage reading, this negatively associated relationship was stronger for monolinguals ( $\beta = -2.129$ ,  $SE = 1.373$ ,  $p = .129$ ), but less distinct for bilinguals ( $\beta = -1.010$ ,  $SE = 1.061$ ,  $p = .347$ ). Conversely, for syntactically simple passage reading, the negative association was more distinct for bilinguals ( $\beta = -3.016$ ,  $SE = 1.054$ ,  $p = .007$ ), but less distinct for monolinguals ( $\beta = -2.062$ ,  $SE = 1.375$ ,  $p = .142$ ).

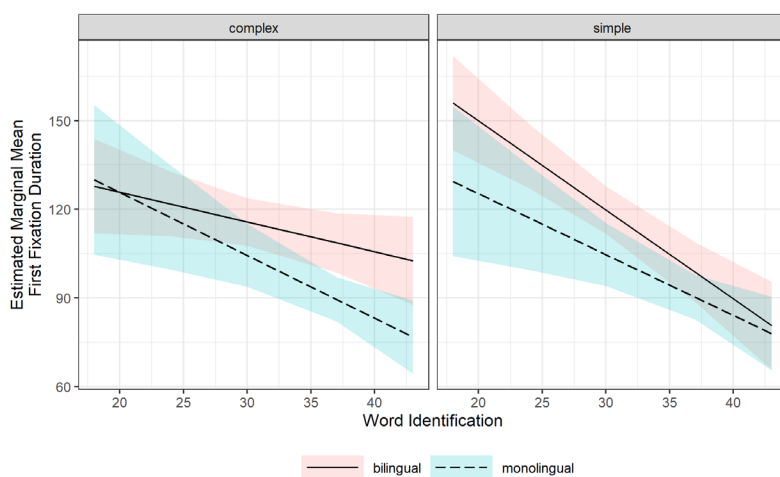
Comparing the relationships between first fixation duration and syntactically simple versus complex passage reading within each group, bilinguals and monolinguals manifested different processing patterns related to syntactic complexity. As Figure 4.8 (B) shows, monolinguals performed similarly in terms of first fixation duration when reading passages with simple or complex structures ( $\beta = -2.062$ ,  $SE = 1.375$ ,  $p = .142$  for simple vs.  $\beta = -2.129$ ,  $SE = 1.373$ ,  $p = .129$  for complex). Whereas, for bilinguals, this negatively associated relationship was stronger for reading passages with simple



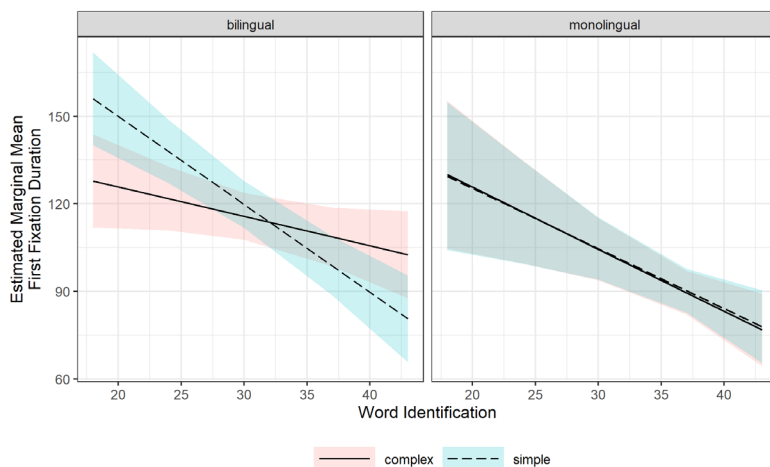
**Figure 4.8**

*The Three-Way Interaction of Group by Syntactic Complexity by Word Identification Based on the Fit Model*

(A)



(B)



*Note.* Figure (A) presents the three-way interaction from the perspective of a between-group comparison; (B) presents the three-way interaction from the perspective of within-group comparison.

structures ( $\beta = -3.016$ ,  $SE = 1.054$ ,  $p = .007$ ) than for passages with complex structures ( $\beta = -1.010$ ,  $SE = 1.061$ ,  $p = .347$ ). Thus, the bilingual participants, as a group, demonstrated a different and unexpected pattern when reading the more complex passages.

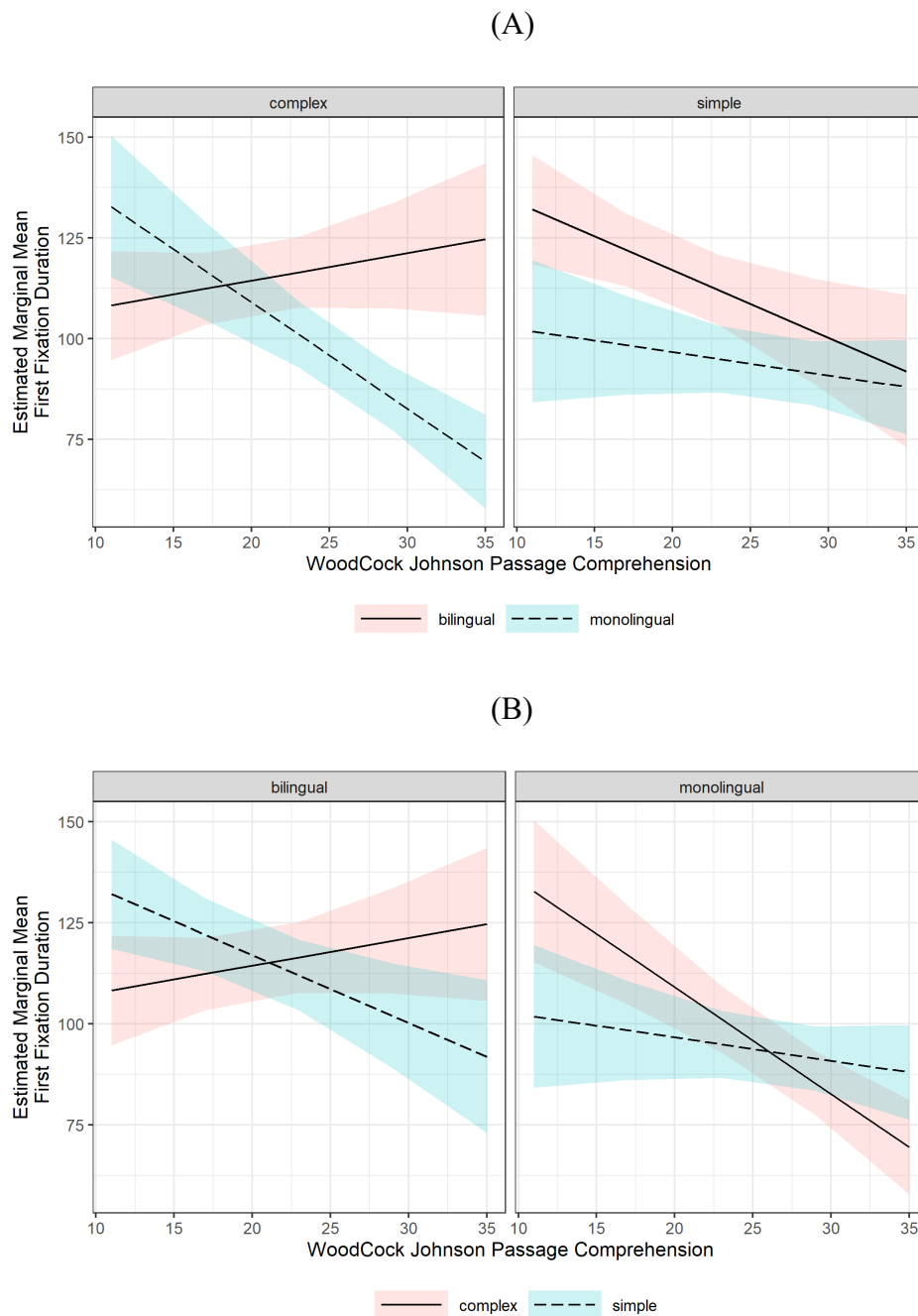
Figure 4.9 (A) shows the comparison between monolingual and bilingual children when reading syntactically simple or complex passages. For passages with complex structures, passage comprehension scores were associated with first fixation duration negatively for monolinguals ( $\beta = -2.637$ ,  $SE = 1.038$ ,  $p = .016$ ), but positively for bilinguals ( $\beta = 0.684$ ,  $SE = 1.161$ ,  $p = .560$ ). Conversely, for syntactically simple passage reading, passage comprehension scores were negatively associated with first fixation duration for both groups. The negative association was more distinct for bilinguals ( $\beta = -1.675$ ,  $SE = 1.159$ ,  $p = .157$ ), and less distinct for monolinguals ( $\beta = -0.575$ ,  $SE = 1.043$ ,  $p = .585$ ).

Figure 4.9 (B) shows the comparison between syntactically simple or complex passages reading within each group. For the monolingual group, passage comprehension scores were negatively associated with first fixation duration regardless of syntactic complexity, with more distinct association for complex-structure passages ( $\beta = -2.637$ ,  $SE = 1.038$ ,  $p = .016$ ) than for simple-structure passages ( $\beta = -0.575$ ,  $SE = 1.043$ ,  $p = .585$ ). However, the bilingual children processed syntactically simple or complex passages in different patterns. For bilinguals, passage comprehension scores were associated with first fixation duration negatively for simple-structure passage reading ( $\beta = -1.675$ ,  $SE = 1.159$ ,  $p = .157$ ), but positively for complex-structure passage reading ( $\beta = 0.684$ ,  $SE = 1.161$ ,  $p = .560$ ).

Figure 4.10 (A) shows another comparison between monolingual and bilingual children when reading syntactically simple or complex passages. For syntactically complex passages, auditory working memory scores were negatively associated with first

**Figure 4.9**

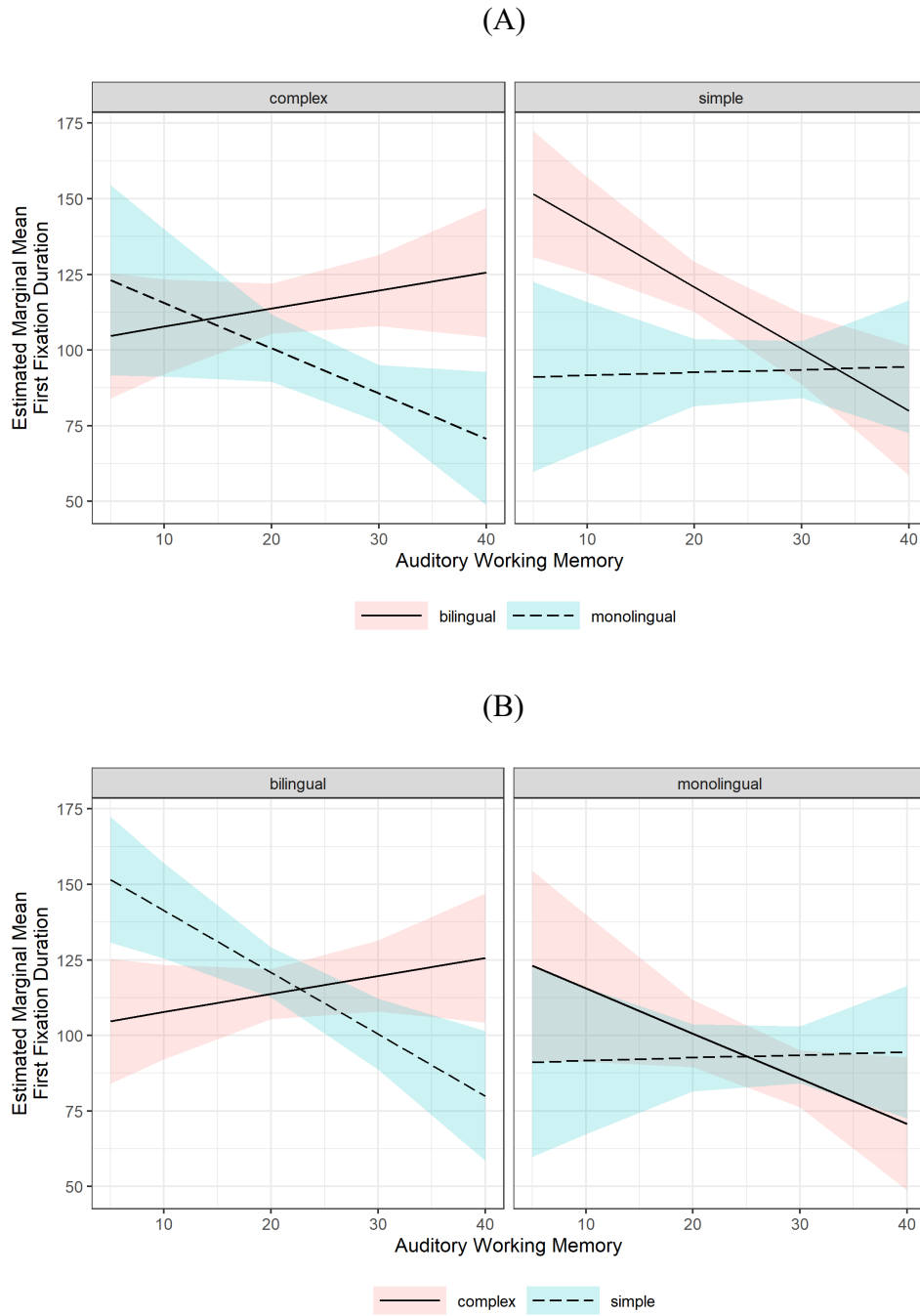
*The Three-Way Interaction of Group by Syntactic Complexity by Passage Comprehension Based on the Fit Model*



*Note.* Figure (A) presents the three-way interaction from the perspective of a between-group comparison; (B) presents the three-way interaction from the perspective of a within-group comparison.

**Figure 4.10**

*The Three-Way Interaction of Group by Syntactic Complexity by Auditory Working Memory Based on the Fit Model*



*Note.* Figure (A) presents the three-way interaction from the perspective of a between-group comparison; (B) presents the three-way interaction from the perspective of a within-group comparison.

fixation duration for monolinguals ( $\beta = -1.494$ ,  $SE = 1.468$ ,  $p = .316$ ), but positively for bilinguals ( $\beta = 0.599$ ,  $SE = 1.112$ ,  $p = .594$ ). Conversely, for syntactically simple passages, auditory memory scores were negatively associated with first fixation duration for bilinguals ( $\beta = -2.046$ ,  $SE = 1.118$ ,  $p = .075$ ), but positively for monolinguals, even though the positive association was slight ( $\beta = 0.095$ ,  $SE = 1.467$ ,  $p = .949$ ).

Figure 4.10 (B) shows the within-group comparison between syntactically simple or complex passage reading, demonstrating that bilingual and monolingual children processed syntactically simple and complex passages in different patterns. For monolinguals, auditory working memory scores were negatively associated with first fixation duration for syntactically complex passage reading ( $\beta = -1.494$ ,  $SE = 1.468$ ,  $p = .316$ ), but positively for syntactically simple passage reading ( $\beta = 0.095$ ,  $SE = 1.467$ ,  $p = .949$ ). However, for bilinguals, auditory memory scores were negatively associated with first fixation duration for simple-structure passage reading ( $\beta = -2.046$ ,  $SE = 1.118$ ,  $p = .075$ ), but positively for complex-structure passage reading ( $\beta = 0.599$ ,  $SE = 1.112$ ,  $p = .594$ ).

Table 4.19 presents for between- and within-group three-way interactions of group by syntactic complexity by word identification, passage comprehension, or auditory working memory.

As Table 4.19 displays, the negatively associated relationship between word identification and first fixation duration regardless of syntactic complexity and participant's group indicates higher word identification scores corresponding to shorter first fixation durations. In the between-group comparison, the negative association was

**Table 4.19**

*Slope Analysis Summary of Group by Syntactic Complexity by Behavioral Tests for First Fixation Duration*

Interactions	Slope			
	Syntactically simple passage		Syntactically complex passage	
	Monolinguals	Bilinguals	Monolinguals	Bilinguals
Group*Syntactic Complexity*Word Identification	$\beta = -2.062$	$\beta = -3.016^{**}$	$\beta = -2.129$	$\beta = -1.010$
Group*Syntactic Complexity*Passage Comprehension	$\beta = -0.575$	$\beta = -1.675$	$\beta = -2.637^*$	$\beta = 0.684$
Group*Syntactic Complexity*Auditory Working Memory	$\beta = 0.095$	$\beta = -2.046$	$\beta = -1.494$	$\beta = 0.599$

\*  $p < .05$ .

\*\*  $p < .01$ .

stronger for bilinguals for syntactically simple passage reading, but stronger for monolinguals for syntactically complex passage reading, indexed by the larger  $\beta$  value. In the within-group comparison, monolinguals performed similarly for both syntactically simple and complex passage reading, whereas bilinguals demonstrated a stronger association between word identification and first fixation duration for simple-structure passage than for complex-structure passage.

Similarly, in the between-group comparison, when passage comprehension served as the fixed factor, higher passage comprehension scores related to shorter first fixation durations for monolinguals when reading syntactically complex passages, and for bilinguals when reading syntactically simple passages. However, in the within-group comparison, the model with passage comprehension as the fixed factor showed that the negative association was stronger for monolinguals in complex-structure passage reading.

This differs from the findings about similar performance for monolinguals with word identification as the predictor.

The association between auditory working memory scores and first fixation duration, although not significant, was negative for monolinguals with complex-structure passage reading, and for bilinguals with simple-structure passage reading. The finding aligns with the results that contain word identification or passage comprehension as the fixed factor. Importantly, by comparing slopes using behavioral test scores, the results revealed greater association between word identification and first fixation duration than between passage comprehension or auditory working memory and first fixation duration.

### **Summary**

This study analyzed data both from offline (i.e., behavioral comprehension questions) and online (i.e., eye-tracking results) measures. The behavioral results of the reading comprehension measure revealed no significant differences for true/false question accuracy. Data for the eye-tracking measures (i.e., reading speed and first fixation duration) were analyzed to better understand the ongoing reading process. Results showed a significant difference for reading speed, with monolinguals reading the English passages significantly faster than bilinguals regardless of passage reading difficulty or sentence complexity. By examining the moderation effects of language, reading, and cognitive behavioral tests, grammatical judgment, word identification, and passage comprehension were significant predictors of the relationships between reading difficulty level and reading speed. The positive association between reading speed and

each behavioral test for both easy and hard passages indicate higher test scores corresponding to faster reading, which was expected. Additionally, results manifest stronger association between reading speed and reading behavioral measures (i.e., word identification and passage comprehension) than between reading speed and language proficiency measure (i.e., grammatical judgment).

For first fixation duration, main effects of group and a group by reading level interaction were found before adding language tests as fixed factors. Bilinguals demonstrated significantly longer first fixation durations than monolinguals, which was expected. Surprisingly, no main effect of syntactic complexity was found. To examine whether participants' language, reading behavior or cognitive abilities were factors influencing the relationship between textual features (i.e., reading difficulty level or syntactic complexity) and first fixation duration, the offline behavioral test scores were added to the multilevel models. A series of multilevel models with two-way or three-way interactions was conducted with each behavioral test functioning as a fixed factor. Regarding significant two-way interactions, results manifest negative associations between first fixation duration with grammatical judgment, word identification, and auditory working memory, being more distinct for easy passages. The results highlighted that individuals with lower grammatical judgment, word identification, and auditory working memory scores tended to have longer first fixation durations, especially for easier passages. Moreover, results revealed greater association between first fixation duration and word identification than between first fixation duration and grammatical judgment or auditory working memory.



Regarding the significant three-way interactions, the negative association between first fixation duration and word identification, passage comprehension, or auditory working memory indicates higher test scores were associated with shorter fixation durations, which was expected. In the between-group comparison, these negative associations were stronger for monolinguals when reading complex passages, and stronger for bilinguals when reading simple passages. However, in the within-group comparison, monolinguals demonstrated similar reading patterns regardless of the syntactic complexity of the passage when using word identification as the fixed factor. But monolinguals revealed stronger association with complex passage reading when using passage comprehension or auditory working memory as the fixed factor. Different from monolinguals, bilinguals demonstrated greater associations between first fixation duration and word identification, passage comprehension, or auditory working memory when reading simple passages. Thus, most of the findings presented here are intuitive. However, some were not expected or easily interpreted. Chapter 5 will discuss the contradictory results and share possible explanations for the different processing patterns between or within groups.

## CHAPTER 5

### DISCUSSION

The purpose of this study was to explore the passage processing of Chinese-English bilingual and English-monolingual children to determine whether they read English passages with simple and complex syntactic structures differently. Via behavioral and eye-tracking measures, the study sought to determine whether language group (bilingual vs. monolingual), reading difficulty level (easy vs. hard), syntactic complexity (simple vs. complex), language (grammatical judgment), reading (word identification & passage comprehension), or cognitive capacity (working memory) predicted text processing performance. The study also examined the possible effect of first language (L1) transfer on second language (L2) text reading of less or more challenging text passages dominated by syntactically simple or complex sentence structures. This chapter includes (1) a summary and interpretation of major findings based on behavioral and eye-tracking measures; (2) possible limitations; (3) research and theoretical implications; and (4) conclusions.

#### **Behavioral Results for Passage Reading**

To examine the performance of Chinese-bilingual and English-monolingual children (ages 9-14) on passage reading tasks, behavioral data included accuracy for answering true/false comprehension questions. Because poorer performance on the language and reading behavioral tests (i.e., grammatical judgment, word identification, passage comprehension) might correspond with bilinguals' less proficient English

language or reading skills, we expected that English monolinguals would perform better on the true/false comprehension questions. However, results showed that both groups evidenced at least 85% probability for choosing correct answers across the 20 questions, thus, no significant differences were found between groups on the simple comprehension measure regardless of text difficulty level or syntactic complexity.

One possible explanation for this unexpected finding—a lack of differences on the comprehension measure—likely relates to the initial intent of the experimental design. The larger study of which this project was a part included fNIRS data collection and was designed to investigate potential differences in cognitive processing differences between Chinese-bilingual and English-monolingual children while reading passages with simple or complex syntactic structures. Participants were asked to read four brief passages with the length ranging from 101 to 165 words. The true/false questions that followed each passage were used to encourage effortful reading, rather than function as a robust measure of comprehension. The simple questions functioned as a minimal measure of comprehension and the true/false format allowed for guessing. Therefore, the similar performance on the true/false questions likely indicates that both groups demonstrated basic comprehension of the brief passages, or the true/false questions were answerable with background knowledge. These questions or retell protocols were likely inadequate in measuring more discreet aspects of comprehension. Alternate forms of measuring comprehension, for example, multiple-choice comprehension questions could have afforded a more nuanced look at the participants' comprehension of the passages with potentially different outcomes across groups.

Behavioral results (i.e., accuracy percentage), as Luegi et al. (2011) argued, are final products of reading comprehension and analyzing the final products can be insufficient for examining the incremental cognitive reading processes. Using eye-tracking data can offset the limitations of behavioral data for understanding the incremental processing of connected texts. Accordingly, the present study analyzed eye-tracking data to determine whether cognitive processing of passages varied because of related factors including language group, reading difficulty level, or syntactic complexity.

### **Eye-Tracking Results for Passage Reading Tasks**

#### **Reading Speed**

Reading speed (words per second) was one of two eye-tracking measures used in this study to examine passage reading performance. After converting the calculated reading speeds measured in seconds to a word-per-minute (wpm) metric (a more common reading measure), both bilingual and monolingual groups demonstrated faster reading than norms reported for U.S. fourth through eighth graders (Hiebert et al., 2014). The slower mean speed for bilinguals while reading *Baseball* and *Lion* in this study (i.e., 2.7 wps corresponds to 162 wpm) exceeded the mean (50<sup>th</sup> percentile) silent reading rates (i.e., 153 and 158 wpm) reported for typical fourth-grade U.S. students (Hiebert et al., 2014; Taylor et al., 1960). Additionally, the slower mean speed for participating monolinguals while reading *Baseball* (i.e., 3.7 wps corresponding to 222 wpm) was higher than the mean silent reading rate (i.e., 204 wpm) for typical eighth-grade U.S. students (Taylor et al., 1960). As noted earlier, the study used the time needed to initially

read the passage (first total reading time) instead of the whole 60 s to calculate reading speed to avoid analyzing data from any repeated reading. The participants in the current study may have felt that one minute was not a lot of time, so they rushed and read the on-screen passages very quickly, although not encouraged to do so. Therefore, reading speed results may be influenced by the participants' tendency to scan first and then read, which may have led to faster reading rates than mean comprehension-based silent reading rates reported elsewhere. (However, this study used individual scan paths to ensure participants covered most of the passage within the first total reading time.) The mean reading speeds for bilinguals (ranging from 162 to 210 wpm) and monolinguals (ranging from 222 to 294 wpm) in this study also suggest that most participants were able to complete reading the passages in their entirety. Again, these bilingual and monolingual groups demonstrated generally good scores on the true/false comprehension questions, which indicates both groups demonstrated basic comprehension of the passages. Therefore, analyzing participants' initial processing of the passages was rational based on the above two facts.

As expected, we found a main effect of language group, with reading speed for monolinguals significantly faster than for bilinguals when reading both easy and hard passages. The significantly higher reading speeds of monolinguals corroborate the language and reading behavioral findings that monolinguals were more proficient in English language and reading skills compared to the bilinguals. Additionally, for monolinguals, the reading speeds for easy passages were significantly faster than for hard passages, which indicates the effect of text difficulty level on reading speed.

Accordingly, if bilinguals read significantly slower than monolinguals because of their lower proficiency in language and reading skills, easy passages with less difficult vocabularies should correspond to relatively faster reading for bilinguals. Contrary to this expectation, although bilinguals read easier passages mathematically faster than harder passages, the difference between the passage levels was not significant. This contradictory finding—a lack of significant reading speed difference between easy and hard passages among bilinguals—suggests that other factors may have been more influential than text reading level (indexed by vocabulary difficulty) on reading speed.

Bilinguals' L2 proficiency was likely one of the influential factors. Research (Geva, 1992) has shown that less-proficient L2 learners “who ha[ve] difficulty processing basic lexical and syntactic information should find it more difficult to attend to text integration of larger chunks of discourse” (p. 743). Therefore, to examine whether bilinguals with varied proficiency levels performed different reading patterns in reading speed, this study conducted moderation analyses of offline language, reading, and cognitive behavioral test scores as possible moderators. A moderator, as Baron and Kenny (1986) argued, is a “variable that affects the direction and/or strength of the relation between an independent or predictor variable and a dependent or criterion variable” (p. 1174). Moderator effects indicate the significant influence of the interactions of the independent variables and the moderator (Baron & Kenny, 1986).

### ***Behavioral Tests and Reading Level***

Specifically, this study explored the possibility that language, reading, and cognitive abilities might moderate the relationship between reading difficulty level and

reading speed. Results revealed two-way interactions of reading level by grammatical judgment, by word identification, or by passage comprehension. As expected, results manifested positive associations between reading speed and grammatical judgment, word identification, or passage comprehension, indicating that individuals with higher language and reading test scores tended to read faster. The findings support the hypothesis that readers' linguistic and reading skills influence the reading performance of passages with different difficulty levels (easy vs. hard). In addition, the slope analyses showed that these positively associated relationships were more distinct for easy passages. As noted in Chapter 3, the harder passages had higher overall difficulty levels than easy passages mainly indexed by the vocabulary difficulty (calculated as word length, word concreteness, or word familiarity). More distinct associations for easier passages suggest that the participating readers' language and reading capacities may have been sufficient for texts with less difficult vocabulary but less sufficient for texts with more difficult vocabulary across both groups.

The findings here align with prior research (e.g., Sahiruddin, 2019) that highlighted the importance of word knowledge in applying language or reading skills in reading comprehension. For example, regarding the effect of grammatical knowledge on reading performance, Sahiruddin examined the relationship between readers' grammatical knowledge and lexical frequency levels and their influence on adult bilinguals' reading outcomes. The author found that grammatical knowledge explained 22% of the reading performance variance for texts with highly frequent vocabularies but 8% for texts with less frequent vocabularies. Regarding the effect of word identification,

which corresponds to basic reading skills, research has shown that comprehending passages with unfamiliar or low-frequency words requires greater effort in not only word identification but also meaning extraction (Coltheart & Rastle, 1994; Rastle & Coltheart, 1998). Therefore, the influence of word identification may be less distinctive on texts with more difficult words than on texts with more familiar or high-frequency words. The findings of more distinct positive associations for easier passages than for harder passages align with the prior research. Passage comprehension performance also relates to the extent of word understanding (Milton et al., 2010). As Milton et al. suggested, demonstrating 60% of comprehension was associated with understanding 95% of vocabulary and 75% comprehension was associated with almost 100% vocabulary knowledge. Harder passages containing more difficult words should require more effort in word understanding, which may have led to less effect of passage comprehension skills. Thus, the findings of less distinct positive associations between passage comprehension and reading speed for harder passages in this study were consistent with prior research.

### ***Behavioral Tests and Syntactic Complexity***

Compared to reading difficulty level, syntactic complexity (simple vs. complex sentence structures) was not a significant predictor in explaining variation in reading speed across passages in this study, and no interactions were found between syntactic complexity and offline behavioral tests. The findings may suggest that syntactic complexity, as presented in the selected passages, may not have influenced reading speed or that the participants did not adjust their speed based on text complexity. One possible



reason for a lack of significant effect for syntactic complexity in the current study may be related to whole-text comprehension. As noted earlier, comprehending a whole text requires not only recognizing words and parsing sentences, but also integrating text segment meanings into a coherent whole. A passage with complex sentences usually contains conjunctions or other cohesive devices (Anderson & Davison, 1986) that can help readers relate linguistic units and support understanding (Leech & Svartvik, 2013). Therefore, comprehending syntactically complex passages, especially across brief texts, may require fewer inferences, which may lead to similar performances to comprehending syntactically simple passages. The nonsignificant effects of syntactic complexity in this study are consistent with some prior studies such as Arya et al. (2011) and Sahiruddin (2019), which showed no effect of syntactic complexity (indexed by the number of embedded clauses) on comprehension performance. Arya et al. (2017) found that both monolingual and English-bilingual third graders answered multiple-choice or short-answer comprehension questions for texts containing complex or simple sentences with similar performances. Sahiruddin (2019) also found that syntactic complexity was not a significant contributor to reading performance for bilinguals in college, especially after accounting for the effect of lexical frequency.

### **First Fixation Duration**

To investigate the cognitive processes during reading, we analyzed another eye-tracking measure (i.e., first fixation duration) to ascertain possible effects of language background, passage difficulty and complexity on text processing. Different from reading speed that reflects whole text processing, first fixation duration, according to Holmqvist

(2011), “coincides with the very first intake and processing of the attended part (each individual word in the current study) of the stimulus and reflects the immediate information processing” (p. 384). Thus, first fixation duration indicates “the time taken for fast processes such as recognition and identification” (Holmqvist, 2011, p. 385), and in the current study, each individual word was the attended part. As expected, bilinguals demonstrated longer first fixation durations than monolinguals across all passages, which is consistent with the reading speed findings that bilinguals read significantly slower than monolinguals. Different from the findings for reading speed that showed faster reading for easy passages than for hard passages, especially for monolinguals, no differences were found for first fixation durations between easy and hard passages within either group. The non-significant findings suggest that differences in time fixated on individual words were not significant regardless of text difficulty within each group. In addition, regarding within- and between-group comparisons, no significant difference was found in first fixation duration. A lack of significant findings for first fixation duration may indicate that reading difficulty level or syntactic complexity may not have been a significant predictor in explaining variation in immediate information processing of these relatively short texts. However, previous research has shown that the effect of textual features (reading difficulty level or syntactic complexity) on reading processes can relate to readers’ linguistic knowledge and comprehension ability (Eslami, 2014; Nation & Snowling, 2000). In a study to investigate the effect of syntactic complexity on reading comprehension, Eslami asked 257 English learners to read syntactically modified passages with three versions (i.e., reduced embedded clauses, original, or expanded

embedded clauses). The researcher found significant reading performance differences across the three versions for low or mid-proficient readers, but not for highly proficient readers. Similarly, Nation and Snowling found that the impact of active (simple canonical structure) or passive sentences (complex noncanonical structure) on comprehension was more distinctive for poor comprehenders as compared with adequate comprehenders. Thus, to examine the effect of textual features and how first fixation duration varies as a function of language, reading, or cognitive abilities, this study evaluated the potential moderation effects in various interaction analyses.

### ***Two-Way Interactions***

As reported in Chapter 4, for first fixation duration, two-way interactions (i.e., reading level by grammatical judgment, by word identification, or by auditory working memory) demonstrated significant main effects. Results manifested negative associations between the first fixation duration and each offline behavioral test (i.e., grammatical judgment, word identification, or auditory working memory). The findings indicate that individuals with higher test scores demonstrated shorter fixations while reading, especially for easier passages, which aligns with reading speed findings that participants with higher scores read faster.

Regarding the effects of grammatical knowledge or word identification, the more distinct association for easier passages also suggests the importance of word knowledge and the influence of vocabulary difficulty in applying language or reading skills for reading comprehension. For the relationship between auditory working memory and first fixation duration, results revealed greater negative association for easier passages. The

finding indicates that the contribution of working memory to text reading performance with lower text difficulty may be larger than for passages with higher text difficulty. As noted above, first fixation duration, which relates to the immediate processing of word identification or recognition, likely reflects a complex cognitive interaction that involves simultaneous word decoding, meaning retrieval, and meaning integration. Prior studies have shown that working memory plays an important role in facilitating this complex cognitive interaction (e.g., Christopher et al., 2012; Daneman & Merikle, 1996; Just & Carpenter, 1980). Thus, the negative association between auditory working memory and first fixation duration (indicating higher auditory working memory scores correspond to shorter fixations) is in line with the findings of previous research. Essentially, passages with higher vocabulary difficulty pose increased challenges in word decoding, meaning retrieval, and meaning integration, which tax working memory. The heavy demand may have led to lesser effect of working memory on comprehension, which is in line with the current study's finding that auditory working memory was less influential for harder passages, indexed by greater  $\beta$  values.

### ***Three-Way Interactions***

In addition to two-way interactions (i.e., reading level by grammatical judgment, by word identification, or by auditory working memory), several three-way interactions were significant. These three-way interactions include group by syntactic complexity by word identification, group by syntactic complexity by passage comprehension, and group by syntactic complexity by auditory working memory. Interaction slope analysis examined differences in first fixation duration between syntactically simple or complex

passages, using within or between bilingual and monolingual group comparisons.

### **Between-Group Comparisons.**

For the between-group comparisons with language, reading and cognitive test scores as the fixed factors, monolinguals demonstrated greater  $\beta$  values than bilinguals when reading complex-structure passages. Bilinguals demonstrated greater  $\beta$  values than monolinguals when reading simple-structure passages. One explanation for different performances between monolingual and bilingual groups may relate to bilinguals' lower proficiency in language and reading skills. However, as discussed regarding previously, bilinguals had basic passage comprehension indexed by high accuracy on true/false questions. Most bilinguals have completed a reading of entire texts within the first total reading time (the reading speed ranging from 162 to 210 wpm). Therefore, it is reasonable to assume that bilinguals were proficient enough to read the passages in this study and their L2 proficiency likely support comprehension. In addition, in the current study, a lack of significant findings between easy and hard passages in reading speed and first fixation duration for bilinguals may indicate that text difficulty was not a predictor in text processing. Thus, it is possible that the contradictory findings may relate to bilinguals' insensitivity to English complex structures.

Chinese structures, featuring more paratactic structures, are typically shorter and less complex than English structures. Parataxis allows for two simple sentences to be stated side-by-side, which likely corresponds with English syntactically simple passage reading. Processing different sentential structures likely challenges bilingual readers. Accordingly, the Chinese-preferred simple and less complex structures may contribute to

bilinguals' insensitivity to English complex sentences regardless of vocabulary difficulty. In the current study, the effects of reading or cognitive capacity were greater for monolinguals on complex-structure text reading, as expected, but greater for bilinguals on simple-structure text reading. Bilinguals demonstrated differentiated reading patterns compared to the monolinguals, which is consistent with the hypothesis that Chinese-English bilinguals' L1 syntactic structure may have influenced reading performance while reading passages with syntactically complex structures.

### **Within-Group Comparisons**

Regarding the relationship between word identification and reading comprehension, reading research has shown that word identification was associated with vocabulary difficulty level, including word familiarity and frequency (Coltheart & Rastle, 1994; Rastle & Coltheart, 1998). Thus, the influence of word identification on passages with a comparable vocabulary difficulty level should be similar. In the current study, the simple- or complex-structure passages varied only in syntactic complexity, not word difficulty level. Therefore, participants were expected to perform similarly in processing syntactically simple and complex passages as a function of word identification. Monolinguals' similar performances for syntactically simple or complex structures as (associated with word identification) yielded similar  $\beta$  values. However, the bilingual results revealed stronger correlations between word identification and first fixation durations for syntactically simple passages than for complex passages. As discussed in the between-group comparisons, the influence of word identification may be restricted in syntactically complex passage reading because of the unfamiliarity of English complex

structures.

Regarding the effects of passage comprehension or auditory working memory within groups, studies have shown that readers' reading ability and working memory capacity are crucial when reading complex texts (Cain et al., 2004; Daneman & Merikle, 1996; Kintsch, 1991; Nation & Snowling, 2000). Therefore, passage comprehension ability and working memory capacity (facilitating readers to carry out comprehension processes) may be more influential in reading passages with more syntactically complex structures. As expected, monolinguals demonstrated stronger correlations between the test scores (i.e., passage comprehension or auditory working memory) and first fixation duration when reading syntactically complex passages. However, bilinguals showed stronger correlations between passage comprehension or auditory working memory and first fixation duration for syntactically simple passages than for complex passages. The more influential effects of test scores on simple-structure texts may again indicate the impact of syntactic structure unfamiliarity. Reiterating the between-group comparisons, syntactically complex passages may have been too difficult for bilinguals to sufficiently apply reading knowledge or cognitive ability for text processing.

### **Limitations**

The reported study was an extension of a larger study and therefore was constrained by the parameters of that project. As noted above, the larger study was designed to examine potential text processing differences between bilinguals and monolinguals via eye-tracking techniques and fNIRS data. Due to the requirements of

fNIRS in data collection and processing, the study was conducted in an experimental block design instead of a self-paced reading design. Different from the more authentic self-paced reading design that allows participants to switch to subsequent task (e.g., answering follow-up questions or reading another passage) displayed at a pace they control by pressing a button, block design reading instructs participants to read and reread a passage until the passage disappeared. Therefore, in this study, because the reading passages varied in length, there were situations in which some participants read the shortest passage (101 words) several times, while some did not complete reading the longest passage (165 words) within 60 s. Consequently, eye-tracking measures such as regressions, fixation durations, or total reading time could not be analyzed in ways that self-paced reading designs can. For example, 27% of the bilingual children did not complete their reading of the Baseball passage, which aligns with the Droop & Verhoeven's (1998) hypothesis that Chinese bilinguals' background knowledge (unfamiliar with Baseball and its rules) influenced reading performance. However, because we did not measure participants' background knowledge on the four topics, the data collected in this study was insufficient to support the above hypothesis.

To compare text processing differences between bilinguals and monolinguals, in this case, the researcher calculated reading speed and fixation duration based on the first reading time. By screening each participant's scan-path manually the first reading time was recorded as the time that each participant initially completed reading the whole passage. However, because participants were asked to read and reread the passage as time allowed, some participants may have actually scanned first and then read. Thus, using



first reading time to calculate eye-tracking measures may have calculated scanning instead of attentional reading. Using directions or instructions that more intentionally elicited effortful reading may have promoted comprehension-based silent reading at more normal rates instead of screen scanning. Furthermore, because some participants (mostly bilinguals) did not complete some passages in their entirety (mostly the hard passages) reading within the timeframe, it was inevitable that some eye-tracking data for the ending part of the passage were missing. Consequently, the choice of eye-tracking measures restricted the means to measure more incremental reading data.

Another limitation of this study is the use of true/false questions, rather than other formats that could test comprehension more discreetly. The true/false questions served as a minimal measure of comprehension and allowed for guessing, with no significant differences found between bilingual and monolingual children's accuracy regardless of reading difficulty level or syntactic complexity. Employment of alternative comprehension measures (e.g., multiple-choice questions, a cloze task, or retell protocol) may have rendered more robust results and a more nuanced look at participants' reading performance. Such measures could have generated more information about the effect of language group (bilingual vs. monolingual), reading difficulty level (easy vs. hard), or syntactic complexity (simple vs. complex).

Thirdly, the lack of offline tests that measured participants' vocabulary size and reading level may be additional limitations. In this study, a significant reading speed difference was found for reading difficulty level (indexed by vocabulary difficulty) between groups, but not for syntactic complexity, which may indicate that instead of

complexity in syntax, participants' vocabulary proficiency influenced reading processes. However, although the difficulty of reading materials was evaluated based on vocabulary difficulty and Flesch-Kincaid grade level (i.e., Grades 4 or 8) to match participant's age (aged 9-14), the participants' reading ability levels were not measured at pretest. Additionally, the Woodcock Johnson word identification test focused on participants' word recognition ability not vocabulary size. Thus, offline tests that measured vocabulary size and reading ability level may have afforded a different moderation effect for the relationship between textual features (i.e., reading difficulty level vs. syntactic complexity) and reading performance.

Finally, this exploratory study was limited by a modest sample size. A larger and wider sample of participants (e.g., bilingual children with older bilinguals) may have afforded more information about possible L1 transfer effect on L2 reading performance from the aspect of developing L2 learners. Additionally, because of the modest sample size, generalizing any significant findings of this study to a larger population should be done with caution.

### **Recommendations for Future Research**

As limitations addressed above suggest, future research could benefit from a larger sample with a wider range of participants, including children of various ages and adults. Future research would also be enlightened by using alternative forms of comprehension questions—other than basic true/false questions—to investigate the effect of language group, reading difficulty level, or syntactic complexity on comprehension.

Additionally, experiment directions that intentionally guide effortful reading and offset the tendency to scan screens first could be used to facilitate comprehension-based reading in future research. Another suggestion for future research is using passages with a comparable length, which could afford the selection of more eye-tracking measures to analyze. Adding offline tests that measure participants' vocabulary size and reading ability level could include more variables functioning as moderators to reveal different performances between bilingual and monolingual groups. Future research could also utilize other types of eye-tracking measures and designs. For example, a self-paced reading design and eye-tracking measures such as regressive fixations, first-time fixations, or total reading time could better investigate the differences between bilinguals and monolinguals when processing texts with various vocabulary difficulty levels or syntactic complexity.

## **Theoretical Implications**

### **Landscape Model**

Reading comprehension is a complex, incremental process and as Kintsch and VanDijk's (1978) construction-integration model highlights, involves different processes (activating word meanings, forming propositions, and producing inferences and elaborations) in search of a coherent representation (Kintsch, 1991). In the present study, as noted above, the outcome variables (i.e., reading speed vs. first fixation duration) corresponded to different reading performance outcomes (i.e., final reading performance vs. immediate identification processing). Therefore, the first fixation duration may relate

to word recognition and meaning activation, whereas, the reading speed may relate to global text processing, including integrating smaller units like words or sentences into a coherent whole. This whole passage comprehension process, according to van den Broek et al.'s (1999) landscape model, is associated with current text processing, immediately preceding cycle activation, earlier preceding cycle activation, and background knowledge integration. Therefore, it was reasonable that reading speeds and first fixation durations revealed different results regarding relationships to language group, reading difficulty level, or syntactic complexity. As expected, results demonstrated different main effect patterns when examining impact of reading difficulty or syntactic complexity on reading performance. One example is the finding of significant differences between easy and hard passages for reading speed, but not for first fixation duration. Additionally, although no significant syntactic complexity effect was found related to reading speed, syntactic complexity was associated with first fixation duration across groups after examining the moderation effects of linguistic, reading, and cognitive tests. However, because of the limitations acknowledged above, the choice of eye-tracking measures was insufficient to examine different processes related to whole text comprehension. For example, activation or reactivation of immediate or earlier preceding cycles could be examined by regressive fixations, first-pass reading fixations, or go-past reading fixations. Future studies could employ other experimental options to examine the differences among immediate text and preceding cycle activation and reactivation processes.

Regarding possible L1 transfer, because Chinese sentences are structured differently from English, Chinese-dominant children may process English differently

from English monolinguals due to the influence of their L1. Shorter and less complex sentences and preferred paratactic structures in Chinese may support successful processing of simple structure, but not complex structures in English. As predicted, results showed that bilinguals demonstrated some different processing patterns from monolinguals. As noted previously, a lack of significant differences between easy and hard passages in reading speed and first fixation duration for bilinguals implies that word-based difficulty may not have influenced bilinguals' reading processes. Additionally, although results revealed insignificant reading speed differences for syntactic complexity for bilinguals, several three-way significant interactions demonstrated the influence of syntactic complexity in first fixation duration as a function of the behavioral test scores. Again, monolinguals' performance aligns with prior research addressing relationships between reading or cognitive capacity and comprehension with different syntactic complexity. However, bilinguals revealed contradictory results, which suggests L1 transfer of simple sentence structure for simpler passages, but not complex syntactic structures.

### **Conclusion**

This study examined passage processing of Chinese-English bilingual and English-monolingual children as they performed an on-screen reading task. Compared to prior studies that mostly addressed the effect of syntactic complexity on reading comprehension at the sentence level, the current study utilized extended texts with simple or complex structures embedded in paragraphs to examine how syntactic complexity

influenced text processing. Additionally, different from presenting the texts sentence by sentence, the current study presented the entire stimulus text simultaneously on a single screen, which followed the natural reading process. However, as noted above, because this study was part of a larger investigation design using fNIRS and eye-tracking techniques, there were challenges and limitations in analyzing data and interpreting results using only the eye-tracking measures only.

To explore the potential processing differences between bilinguals and monolinguals reading syntactically simple or complex passages, myriad behavioral and eye-tracking data were analyzed. Behaviorally, both bilingual and monolingual groups had high probability for correctly answering true/false questions (over 85%), which might indicate successful reading behaviors. However, the results of reading speed and first fixation duration revealed different processing patterns, either between or within groups, depending on respective reading difficulty level or syntactic complexity. Bilinguals read more slowly and fixated longer across all passages, which is consistent with prior research. In addition to these expected results, there were surprising and contradictory findings that challenge and confound interpretations. One of the surprising findings was a lack of significant speed differences for bilinguals when they read easy versus hard passages, suggesting that text difficulty may not have influenced bilinguals' reading and that they applied similar reading speeds regardless of textual differences. Another contradictory finding was the between-group comparisons with greater  $\beta$  values for monolinguals when processing complex-structure passages, but for bilinguals when processing simple-structure passages. The results may indicate possible L1 transfer and

less familiarity with complex syntactic structures for bilinguals during English reading. Moreover, the findings that reading behavioral tests (i.e., word identification or passage comprehension) were more influential than language proficiency (i.e., grammatical judgment) or cognitive capacity (i.e., auditory working memory) on reading performance (regardless of reading difficulty or syntactic complexity) suggest that reading measures informed the analysis of online reading behaviors more than the other proficiencies.

Essentially, in this study of online reading processing, word-reading competency was more strongly related to passage reading outcomes than were language proficiency measures. Thus, any understanding of reading performances among monolingual and bilingual readers should carefully account for the word-level competencies (e.g., word recognition and vocabulary) that underlie more holistic reading tasks. Consideration of other variables, including language proficiency or L1-L2 structural comparisons, can and likely should augment analyses of these fundamental reading skills to elucidate the complexity of reading comprehension. Moreover, the analyses of eye-tracking measures were based on times that participants initially completed whole passage reading, which was likely associated with screen scanning rather than more authentic reading. Therefore, the influence of reading difficulty and syntactic complexity on authentic reading performance across bilingual and monolingual groups merits additional investigation.

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APPENDIX

## Lion Simple

Twelve girls were playing a game at a party. A picture of a lion hung on the wall before them. He had a fierce look in his eyes. First, the girls put large paper bags over their heads. They couldn't see. The clock ticked off one minute after another. Each of the girls tried to pin a ribbon on the lion's tail. They put ribbons on the lion's paws, head, and body. That gave the lion a friendly look. Everyone missed the tail, so nobody won the prize. The game was finished. After that, everyone had cake and ice cream.



## Lion Complex

A game at a party was played by twelve girls. On the wall before them hung a picture of a lion with a fierce look in his eyes. The girls first put large paper bags over their heads so they couldn't see. As one minute after another was ticked off the clock, each of the girls tried to pin a ribbon on the lion's tail. They put ribbons on the lion's paws, head, and body, which gave the lion a friendly look. The tail was missed by everyone, so nobody won the prize. After the game was finished, everyone had cake and ice cream.



## Marco Polo Simple

In the thirteenth century the people of Europe were ignorant about many remote areas of the world. European maps of Asian territory did not include the vast and powerful country of China. Marco Polo was one of the first European travelers to visit this distant region. He learned several languages spoken in China. He also served its great rulers for many years. He explored the corners of the kingdom as the emperor's agent. He kept a notebook filled with fascinating accounts of his experiences. He also completed economic and political reports for the emperor's use. Marco Polo then returned home from the Far East. He brought back marvelous treasures. He also brought a wealth of new geographical information. His narratives revealed a world that Europeans scarcely knew existed.



## Marco Polo Complex

In the thirteenth century the people of Europe were ignorant about many remote areas of the world. China, a vast and powerful country in Asia, was uncharted territory on the Europeans' map. One of the first European travelers to visit this distant region was Marco Polo. He learned several languages spoken in China and served its great rulers for many years. As the emperor's agent, he explored the far corners of the kingdom. He kept a notebook filled with fascinating accounts of his experiences as well as economic and political reports for the emperor's use. When Marco Polo returned home from the Far East, he brought back marvelous treasures and a wealth of new geographical information. His narratives revealed a world that Europeans scarcely knew existed.



## Baseball Simple

The applauding spectators fell silent. They had cheered the dauntless Warriors through eight hard-fought innings against their fiercest rivals, the Pythons. The Warriors needed one run to defeat them. The Pythons had an unbeaten record. They also had a reputation as formidable opponents. The Pythons would cinch their title as champions. They could earn the previous trophy if they won one more game. Pedro took his position at the plate. He sensed tension in the stands. He knew the fans viewed him as a novice. They were perhaps thinking about his errors in the previous competitions. Pedro forced himself to concentrate on those times when the coach had congratulated him on skillful play. The coach assured him that with practice and determination he would develop into an outstanding athlete. Pedro knew he had talent. But, he wondered whether he had the spunk to perform well in a pinch. Pedro glimpsed the coach's steady gaze on him. Then, he felt a quick surge of confidence.



## Baseball Complex

The applauding spectators fell silent. They had cheered the dauntless Warriors who had played eight hard-fought innings against their fiercest rivals. Only one run was required to defeat the Pythons, whose unbeaten record had given them a reputation as formidable opponents. Their title as champions would be cinched, earning them the previous trophy, if they won one more game. As Pedro took his position at the plate, he sensed tension in the stands. He knew the fans, thinking about his errors in the previous competitions, perhaps regarded him as a novice. He forced himself to concentrate on those times when he had been congratulated by the coach after a skillful play, assuring him that with practice and determination he would develop into an outstanding athlete. Pedro knew he had talent, but what about the spunk to perform well in a pinch? Then he glimpsed the coach's steady gaze up on him and felt a quick surge of confidence.



## Pet Day Simple

It was pet day at the fair. The children were under the big pink tent waiting for the parade of animals to begin. They had trained their pets to do many different tricks in front of the judges. One girl trained her bunny to climb a ladder. Another girl had a talking bird. A tall, red-headed boy was among the youngsters. His goat made trouble for him. He had trained it to dance, but it kicked and tried hard to break away. But, the goat became still when it heard the band. Then it danced very well during the parade. It won the blue ribbon prize for first place.



## Pet Day Complex

It was pet day at the fair. Under the big pink tent the children were waiting for the parade of animals to begin. The pets that had been trained by the children could do many different tricks in front of the judges. One girl had a bunny that could climb a ladder, and another had a bird that could talk. Among the youngsters was a tall, red-headed boy whose goat made trouble for him. Even though the goat had been trained to dance, it kicked and tried hard to break away. When it heard the band though, it became still. During the parade, it danced so well it won a prize – a blue ribbon for first place.



## CURRICULUM VITAE

GUOQIN DING

435-512-4213  
dgq@outlook.com**AREAS OF SPECIALIZATION**

Language comprehension of English monolinguals and Chinese bilinguals using Eye-tracking equipment and functional Near-infrared Spectroscopy (fNIRS) neuroimaging technique to provide instructional recommendations for teachers of English Language Learners (ELLs) and weak readers.

**EDUCATION & ACADEMIC BACKGROUND****Doctor of Philosophy, 2022**

Utah State University  
Presidential Doctoral Research Fellowship (PDRF)  
Curriculum & Instruction Specialization, Literacy Emphasis

**Bachelor of Science, 2013**

Harbin University of Science and Technology, Harbin, China  
Major in Finance

**Master of Art, 2008**

Southwest University, Chongqing, China  
English Language and Literature, General Linguistics

**Bachelor of Art, 2005**

Harbin University of Science and Technology, Harbin, China  
Major in English

**PROFESSIONAL WORK EXPERIENCE****Literacy Clinic Supervisor (2018 Fall, 2019 Spring)**

Utah State University  
EEJ CEHS (Emma Eccles Jones College of Education and Human Services)  
Literacy Clinic  
Responsibilities included observation of 36 tutors and giving them feedback on their tutoring sessions.



**Teaching Assistant****ELED 5105** Motivation and Classroom Management (2019 Fall, 2020 Spring)

Utah State University

Responsibilities included grading assignments, tracking attendance, and substitute teaching while the professor was gone.

**SCED 5210** Learning Theory, Curriculum Design & Assessment (2019 Fall, 2020 Spring)

Utah State University

Responsibilities included grading assignments, tracking attendance, and answering questions.

**PSY/EDUC 6600** Research Design and Analysis I (2018 Fall)

Utah State University

Responsibilities included reviewing material with students, answering questions on statistical methods, grading assignments, and tracking attendance.

**ELED 4040** Assessment and Instruction for Struggling Readers (2018 Fall, 2019 Spring)

Utah State University

Responsibilities included tracking attendance and supervision of preservice students in literacy clinic

**Research Assistant (2016 Fall-2020 Spring)**

Utah State University

LEAP (Language, Education, and Auditory Processing) NIRS Brain Imaging Lab

Responsibilities included work on SPARC project with Dr. Ron Gilliam using SMI eye tracker and fNIRS and research of English monolinguals and Chinese bilingual children and adults on tasks including English Agent Selection, Chinese Agent Selection, English Reading, Continuous N-back and Attention Switch.

**Service (2018 Spring)**

Student representative of the searching committee for an ESL lecturer position in the School of Teacher Education and Leadership

**Guest Teaching****ELED 4040** Assessment and Instruction for Struggling Readers (2018 Fall)

Utah State University

Presentation on the topic of Classroom Management in China: The Influence of Chinese Culture

**PSY/EDUC 6600** Research Design and Analysis I (2018 Fall)

Utah State University

Presentation on the topic of Reliability and Validity

**ELED 4030 Teaching Language Arts (2017 Spring)**

Utah State University

Presentation on the topic of Writing Conference

**TEAL 6785 Instructional Practices for English Learners (2017 Spring)**

Utah State University

Teaching 15-20 minutes each week for 14 weeks on Technology Tools for ELLs Instruction

**Lecturer (2008-2015)****050103 Extensive Reading (2013 Fall-2015 Spring)**

Department of Foreign Languages, Cambridge College, Heilongjiang University, Harbin, China

The purpose of this course is to provide instruction to English major students that can enhance their general reading skills, including reading speed and global comprehension, as well as improve word recognition automaticity.

**050201 College English (2010 Fall-2012 Spring; 2012 Fall-2014 Spring)**

Department of Foreign Languages, Cambridge College, Heilongjiang University, Harbin, China

This is a course provided to first- and second-year non-English major college students (e.g., students from Computer Science, Business Management, Japanese, and Early Childhood Education, etc.). The purpose of this course is to enable students to read, analyze, and write expository, descriptive, and argumentative essays so they can successfully read and write text in the level of College English Test 4 (CET-4) or even 6 (CET-6).

**050202 English Listening Comprehension (2010 Fall-2012 Spring)**

Department of Foreign Languages, Cambridge College, Heilongjiang University, Harbin, China

This is a course provided to first- and second-year non-English major college students (e.g., students from Computer Science, Business Management, Japanese, and Early Childhood Education, etc.). The purpose of this course is to develop students' language pronunciation and listening skills, improve their social communication skills, and prepare them to communicate in both public and academic environments.

**050102 Intensive Reading (2008 Fall-2010 Spring)**

Department of Foreign Languages, Cambridge College, Heilongjiang University, Harbin, China

The purpose of this course is to provide instruction to English major students that enables them to accelerate the development of reading and writing skills and to strengthen those skills so they can successfully read and write text in the level of

Test for English Major 4 (TEM-4) or even 8 (TEM-8).

### PUBLICATIONS

- Orellana, C. I., Schwartz, S., Juth, S., **Ding, G.**, Wada, R., Hancock, A., & Gillam, R. B. (under review). Working memory and syntactic processing in bilingual and monolingual children. *Bilingualism: Language and Cognition*.
- Ding, G.**, Mohr, K. A., Orellana, C. I., Hancock, A., Juth, S., Wada, R., & Gillam, R. B. (2021). Use of functional near infrared spectroscopy to assess syntactic processing by monolingual and bilingual adults and children. *Frontiers in Human Neuroscience*.  
<https://www.frontiersin.org/articles/10.3389/fnhum.2021.621025/full>
- Jones, C. D., Priestley, K., & **Ding, G.** (2018). An overview of four challenges for English learners experiencing learning difficulties. *Teachers College Record*,  
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- Mohr, K. A., **Ding, G.**, Priestley, K., Strong, A., Branum, L., Watson, N., Juth, S., Carpenter, N., & Lundstrom, K. (2017). Reading the past to inform the future: 25 years of *The Reading Teacher*. *The Reading Teacher*, 71(3), 251-264.
- Ding, G.** (2007). Exploring the use of ‘ziji’ (-self) in Chinese. *Foreign Language of Literature Studies*, 24(4), 229-233.

### CONFERENCE PRESENTATION

- Ding, G.**, Mohr, K. A., Gillam, S. Juth, R., Orellana, C., Hancock, A., & Wada, R. (2021 July). *Syntactic comprehension in reading comprehension among bilinguals and monolinguals*. Paper session presented at the meeting of Society for the Scientific Study of Reading (SSSR) Annual Conference (*Virtual*).
- Ding, G.**, Mohr, K. A. (2020 December). Text processing of science passages among Chinese-English bilinguals and English monolinguals: Insights from an eye-tracking study. In Marla Robertson (chair), *Literacy Research and Science: Disciplinary Literacy Coaching in Biology, Reading Strategies Intervention in Biology with LD Students, and Cognitive Processing Patterns of Science Text Reading*. Symposia/Alternative Sessions conducted at the meeting of Literacy Research Association (LRA) Annual Conference (*Virtual*), Houston, TX.
- Ding, G.**, Mohr, K. A., Gillam, R., Orellana, C., & Hancock, A. (2020 May). *Sentence Listening Comprehension Among Chinese Bilinguals and English Monolinguals: An fNIRS Study*. Visual poster session presented at the meeting of Cognitive Neuroscience Society (CNS) Annual Conference, Boston, MA.

- Hancock, A.S., Jones, S., Warren, C.M., Orellana, C.I., C., Cutler, A., **Ding, G.** & Gillam, R.B. (2020, May). *Brain Region Importance for the Auditory N-back Task via Machine Learning*. Virtual poster presentation at Cognitive Neuroscience Society (CNS), Boston, MA.
- Ding, G.**, Mohr, K. A., Chou, P. (2020 February). *The Role of Connectives in Reading Comprehension Across Languages*. Paper session presented at the meeting of National Association for Bilingual Education (NABE) Annual Conference, Las Vegas, NV.
- Ding, G.**, Mohr, K. A., Gillam, R. B., Orellana, C. I., & Hancock, A. (2019 October). *Cortical activation during sentence processing among Chinese-English bilinguals and English monolinguals: An fNIRS study*. Poster session presented at the meeting of Society for Neuroscience (SfN) Annual Conference, Chicago, IL.
- Ding, G.**, Mohr, K. A., Gillam, R. B., Juth, S., Orellana, C. I., Hancock, A., & Wada, R. (2019 July). *Effects of sentence types on reading in bilinguals and monolinguals: Evidence from eye tracking*. Paper session presented at the meeting of Society for the Scientific Study of Reading (SSSR) Annual Conference, Toronto, Canada.
- Ding, G.**, Mohr, K. A., Gillam, R. B., Orellana, C. I., & Hancock, A. (2019 March). *Syntactic Processing in Bilinguals and Monolinguals: Evidence from functional Near-infrared Spectroscopy (fNIRS)*. Poster session presented at the meeting of Cognitive Neuroscience Society (CNS) Annual Conference, San Francisco, CA.
- Ding, G.**, Mohr, K. A., Gillam, R. B., Orellana, C. I., & Hancock, A. (2018 October). *An fNIRS study of sentence processing of Chinese bilinguals in first and second languages*. Paper session presented at the meeting of Northern Mountain Educational Research Association (NRMERA) Annual Conference, Salt Lake City, UT.
- Orellana, C. I., Juth, S., **Ding, G.**, & Gillam, R. B. (2018 June). *Sentence Comprehension in children developing typically, children with language impairment, and Spanish-English bilingual children: Multilevel modeling of behavioral and eye-tracking evidence*. Poster session presented at the 39<sup>th</sup> annual Symposium on Research in Child Language Disorders (SCRLD), Madison, WI.
- Ding, G.** (2017 November). A content analysis of the *Reading Teacher* 2001-2016: Articles targeting English Learners (ELs). In Kathleen A. J. Mohr (chair), *Exploring 25 years of the Reading Teacher: Analyzing past content to inform future instruction*. Symposium conducted at the meeting of Association of Literacy Educators and Researchers (ALER) Annual Conference, St. Petersburg, FL.

**Ding, G.** (2007 November). *The application of semantic-mapping on setting illustrations in bilingual dictionaries*. Paper session presented at the meeting of Chinalex Bilingual Committee Annual Conference, Chongqing, China.

### PROFESSIONAL ASSOCIATIONS

Literacy Research Association (LRA) membership, Oct. 2020 – Oct. 2021  
 Association of Literacy Educators and Researchers (ALER) membership, Nov. 2017-Nov. 2018.  
 Cognitive Neuroscience Society (CNS) membership, Dec. 2018-Dec. 2021.  
 Society for the Scientific Study of Reading (SSSR) membership, Dec. 2018-Dec. 2020.  
 Society for Neuroscience (SfN) membership, Jan. 2019-Jan. 2021.

### PROFESSIONAL CERTIFICATES

The Certificate in Advanced Research Method and Analysis, Utah State University  
 Mandarin Proficiency Test Certificate, National Language Work Committee of PRC  
 Teachers Qualification Certificate, Ministry of Education of PRC  
 Lecturer Certificate, Heilongjiang Human Resources and Security Hall, PRC

### LANGUAGES

Chinese (Native Proficiency)  
 English (Full Professional Proficiency)  
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### SOFTWARE AND PROGRAMMING EXPERIENCES

**SPSS:** Expert (4 years of weekly use)

Database Management

Data Analytics

**R and RMarkdown:** Moderate Experience (1 year of weekly use)

Database Queries, Creation and Management

Data Analytics

**Mplus:** Moderate Experience (1 year of weekly use)

Psychometric Models Test

Data Analytics

**MATLAB:** Some Experience (4 years of occasional use)  
Signal Processing  
Database Management  
Data Analytics

## **HONORS**

**Presidential Doctoral Research Fellowship**, 2016-2020, School of Teacher Education and Leadership, Utah State University

This award is presented to recognize students with a 3.5 or above cumulative GPA and GRE scores at the 70<sup>th</sup> percentile or higher. The fellowship includes a minimum of \$20,000/year for a duration of 4 years, plus a tuition award for either in-state or nonresident students. Ten students from Ph.D. applicants are selected yearly as recipients of this award.