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Word Reading, Reading Comprehension, and Eye Movements During Reading in Chinese Persons with Aphasia

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WORD READING, READING COMPREHENSION, AND EYE MOVEMENTS DURING READING IN CHINESE PERSONS WITH APHASIA

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LIST OF ABBREVIATIONS

AOS	Apraxia of Speech
CRRCAE	China Rehabilitation Research Center Aphasia Examination
DRC	Dual Route Cascaded
IWA	Individual with Aphasia
LARC	Legitimate Alternative Reading of Components
NLCA	Non-language Cognitive Assessment
SD	Semantic Dementia
svPPA	Semantic-variant Primary Progressive Aphasia
VWFA	Visual Word Form Area

ABSTRACT

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Individuals with aphasia (IWA) often exhibit challenges in single word reading as well as in reading comprehension. Recently, eye-tracking technology has become instrumental in delving deeper into reading behaviors. Specifically, it has illuminated the differences in word reading and comprehension abilities among aphasic English speakers. However, there is a noticeable scarcity of research focusing on these aspects among Chinese IWA. The current study aimed to contrast the abilities of Chinese IWA and neurotypical controls in reading single words, with an emphasis on types like regular, irregular, and pseudowords, and reading comprehension abilities. Further, this study investigated the patterns of eye movements during paragraph reading, paying special attention to measures such as fixation durations and saccades. This study also examined the association of these eye-tracking measures with reading comprehension across both cohorts.

The results indicate that the control group read more accurately across all word types compared to the IWA. The results also indicated that the IWA group exhibited longer fixation durations, more frequent fixations, and shorter saccade amplitudes when compared to the control group. Moreover, the control group consistently demonstrated

superior reading comprehension accuracy across both language assessment and eye-tracking tasks. Notably, among the IWA, there were significant correlations between reading comprehension and both regular and irregular word reading. This association persisted even after rigorous statistical corrections. However, such correlations were absent in the control group. Further multiple regression analysis revealed that, even after controlling for education level and months post-stroke, a composite of regular and irregular word reading accounted for 60% and 58.5% of the variance in reading comprehension for the IWA and controls, respectively. The pronounced influence of regular and irregular word reading on comprehension in IWA suggests potential avenues for targeted reading strategies or interventions. In conclusion, this research highlights the complexity of reading comprehension, suggesting a need for a holistic approach in future studies to explore various factors influencing reading in Chinese IWA and neurotypical individuals.

CHAPTER I

INTRODUCTION

Humans use the complex ability of reading to obtain knowledge. Word recognition and making form, sound, and meaning connections are the cornerstones of reading instruction for new readers (Yang et al., 2011). As individuals move along their stages of growth, their skill to precisely recognize words is enhanced. Reading instruction goes from a focus on individual words and phrases to an emphasis on reading and understanding complete sentences, paragraphs, and chapters (Guo et al., 2022).

Reading is a complicated task that necessitates letter-to-sound transfer, letter-to-sound recognition, a connection to meaning, and nearly automatic visual processing of letters. The Dual Route Cascaded (DRC) model, put forth by (Coltheart et al., 2001), is currently one accepted theoretical framework of the reading process. Another one is a connectionist model. The Dual Route Cascaded model (DRC) has two routes that, when combined, explain how we are able to understand new words, non-words, words that adhere to conventional spelling-to-sound norms, such as cave, time, and cat, as well as irregular words (e.g., have). When it comes to non-lexical reading, the grapheme-phoneme conversion method explains how humans are able to read new vocabulary, non-words like bos, dar, and jow, and words that follow common pronunciation norms (e.g., cave, time, cat). The connectionist model (Patterson et al., 1996), also known as the

Parallel Distributed Processing model, is a neural network model that attempts to simulate the way information is processed in the human brain. This model emphasizes the connection between a substantial amount of elementary unit-of -processing and the parallel computation between them. In reading, the connectionist model is particularly concerned with how spelling-related, sound-related, and meaning-related information is represented and processed by these connections. In particular, connectionist models have attempted to explain surface dyslexia, a specific cognition and learning impairment characterized by difficulties in accurately and fluently reading irregular words or unusual words. Research suggests that surface dyslexia can occur when the connections in neural networks that process the relationship between meaning and phonemes are damaged (Yin & Butterworth, 1992). This impairment causes patients to have difficulty in trying to translate the meaning of words into their corresponding sounds. Overall, the connectionist model provides us with a framework to understand how the brain processes and represents linguistic information through neural networks, and the dyslexia that can arise when these networks are damaged.

Numerous cerebral regions facilitate the cognitive process of reading. Several brain mapping studies on grown-up readers have demonstrated that the back region of the superior temporal lobe and the VWFA are involved in supporting reading. (Baker et al., 2007; Dehaene et al., 2015; Stevens et al., 2017). Other studies have shown that activation pathways for reading across languages are similar. For example, Feng and colleagues (Feng et al., 2020) found a reading circuit composed primarily of the cingulate gyri of left hemisphere, superior area of the temporal gyri/sulci, precentral gyri, along with intermediate area of the frontal gyri with striking similarities across languages.

The basic logic of reading in different language scripts, including Chinese and English, is essentially similar in all writing systems, except for the superficial differences in font. They are assembled of a small set of visual symbols, the combination of which allows visual access to the spoken language network. All Chinese languages use scripts that are not letters. Non-alphabetic scripts are less transparent than alphabetic in their connection with spelling and pronunciation. All Chinese characters are made up of parts that are constituted of strokes that are written in a square. To become literate, a modern reader only needs to know the 3000 most common characters. In Chinese, each character stands for a morpheme (Yin & Butterworth, 1992). This makes sense from a morphological point of view because a single syllable is the smallest unit that can be read in a character. This also indicates that there is a corresponding morpheme in the spoken language for each written form. The letters of the alphabet, on the other hand, do not have any meaning. In Chinese, oral reading can be conducted by a minimum of two distinct pathways. The process of reading for semantics is facilitated by the lexical-semantic pathway, which connects the meaning of words and their associated concepts. On the other hand, the non-semantic pathway establishes connections between orthographic representations, such as strokes, character root, and script symbols with phonological representations like phonetic units, vowel-consonant combinations, and pitch levels (Yin et al., 2005). These pathways parallel those proposed in the DRC model.

As described, the reading process is complex and relies on many neural regions. Therefore, any disruption in neurological functioning in the visual or language processes that support reading may lead to an acquired reading impairment commonly identified as acquired dyslexia or adult-onset dyslexia. Aphasia is a multimodal language issue that can interfere with any modality of language, understanding, expressing, writing, and reading, and is usually caused by stroke. Aphasia often is associated with acquired dyslexia (Darley et al., 1975). Aphasia and acquired dyslexia can significantly impact an individual's quality of life and safety. For instance, acquired dyslexia in those with aphasia may prohibit them from going back to work, enjoying leisure reading, correctly reading medication labels, or reading the instruction booklet for any piece of equipment or home appliance.

Word reading and comprehension are essential components of linguistic processing, which is frequently interrupted in aphasia and affects both understanding texts and word recognition. Research into the oral reading abilities of IWA and the effectiveness of therapies (Friedman, 1996; Fuchs et al., 2001; Webster et al., 2013) to improve reading skills has been extensive, with a particular focus on single word reading to discover distinct neuropsychological breakdown patterns. Notably, there has been a strong focus on examining single word reading as a means of identifying distinct patterns of neuropsychological impairment. Recent research (Smith & Ryan, 2020) has investigated the intricacies of understanding written texts at many levels, including single word, sentence, and text comprehension. These studies (Friedman, 1996; Fuchs et al., 2001; Smith & Ryan, 2020; Webster et al., 2013) have uncovered a notable positive association among these dimensions. However, it is worth noting that no meaningful relationship was observed between the capacity to comprehend single words and the comprehension of texts. The studies taken together highlight the intricate skill of comprehending text in IWA, emphasizing the need for a comprehensive evaluation strategy to effectively address the reading challenges experienced by this population.

However, little research is available to suggest that acquired dyslexia in Chinese individuals could stem from a disruption in linking orthographic, semantic, and phonological processing, as discussed by Yin and Butterworth (1992) and Yin and Weekes (2003), aligning Chinese reading models with the Dual Route Cascaded (DRC) like in English. Contrarily, other studies (Han & Bi, 2009; Law et al., 2009) lean towards a connectionist model for reading in Chinese, emphasizing semantic mediation in transitioning from orthography to phonology, with clinical cases illustrating these theories through patients with dementia or brain injury reading aloud (Han & Bi, 2009; Law et al., 2005). Specifically, how accurately Chinese people read phonetic compound characters was affected by how well they could guess the pronunciation and how familiar they were with the character. This shows that both the lexical and 'non-lexical' systems play a part in these reading patterns. Despite these findings, mostly from Cantonese-speaking regions with traditional script, there is a research gap concerning acquired dyslexia in mainland China using Mandarin, warranting further investigation for both theoretical and clinical insights.

One tool used to examine reading in IWA and without aphasia and acquired dyslexia, particularly in English speakers, is eye tracking (Akhavan et al., 2022; Bai et al., 2008; Bonhage et al., 2015; Chen et al., 2017; DeDe & Kelleher, 2021; Li et al., 2011; Li et al., 2009; Niehorster et al., 2020; Nilsson Benfatto et al., 2016; Oralova & Kuperman, 2021; Rayner, 1998). It has shown to be a useful tool because it can record cognitive and linguistic activities online (Bonhage et al., 2015; Chen et al., 2022; Eekhof et al., 2021; Parola & Bosco, 2022; Wendt et al., 2014) and has informed our understanding of reading and reading comprehension in both neurotypical and clinical populations like IWA. Studies have even been conducted to examine differences in reading English and Chinese texts in neurotypical adults (Rayner et al., 2007; Yan et al., 2006) indicating the average fixation period and regression rate were equivalent; however, significant differences were discovered in the average saccade length, which was shorter for Chinese readers with fewer than two to three characters (Yan et al., 2006).

Numerous studies utilizing eye-tracking technology have been undertaken to investigate the task of the reading process in English speakers with acquired dyslexia (Ablinger et al., 2014; Akhavan et al., 2022; DeDe & Kelleher, 2021; Knilans & DeDe, 2015; Marshall & Newcombe, 1973; Smith et al., 2018; van Scherpenberg et al., 2021). However, no studies were found examining eye movements during reading of Chinese speakers with acquired dyslexia. This gap in the research is notable as it is unclear how the eye movements of Chinese speakers with acquired dyslexia differ from individuals without acquired dyslexia. Furthermore, it is unclear what implications can be drawn from eye movements about reading and reading comprehension in Chinese speakers with acquired dyslexia. Additionally, limited knowledge exists regarding word reading and comprehending text abilities among IWA who are native speakers of Chinese, and how their reading abilities compare to neurotypical readers.

In conclusion, eye-tracking serves as an important evaluation tool to reveal language processing behaviors and to predict and observe eye-movement measures in persons with acquired dyslexia. A growing body of research (Smith et al., 2018) has demonstrated the sensitivity of eye-tracking measurements for the functional assessment of dyslexia following aphasia. By observing eye tracking indicators, it is anticipated there may be significant differences in eye tracking measures among Chinese IWA and a neurotypical group. Furthermore, there is a significant gap in knowledge regarding word reading and comprehension abilities of Chinese IWA which is critical to understanding and managing acquired dyslexia.

Therefore, the overall intention of the current investigation was to characterize word reading and reading comprehension abilities, and to examine eye movements during reading of Chinese IWA and acquired dyslexia. Specifically, the aim of the proposed investigation was to determine if there are differences in word reading, reading comprehension, and eye tracking patterns during reading between Chinese IWA and control participants. An additional goal was to gain insight into the associations between eye tracking measures including total fixation duration, average of fixation duration, number of fixations, time to first fixations, first fixation duration, number saccades, mean amplitude of saccades, total saccades amplitude, time to first saccades, amplitude of first saccade of Chinese IWA and comprehension. Lastly, the association between single word and reading comprehension abilities was also examined. Overall, this study provides insight into the reading abilities and eye movement characteristics in IWA who are native Chinese speakers; thus, providing insights into the potential predictors of reading comprehension in this population when compared to neurotypical individuals.

CHAPTER II

LITERATURE REVIEW

2.1 Reading, A Universal Process

Understanding how to read is crucial for many facets of daily life. A person's daily life can be affected by their inability to read. The underlying logic of reading is the same across all writing systems, despite the fact that different writing systems use different languages. Each writing system uses a restricted collection of visual elements, as well as the combinations of these symbols provide visual connection to the network grammatical and lexical languages.

The Dual Route Cascaded (DRC) reading mode is currently the greatest amount widely accepted theoretical framework of the reading process (Coltheart et al., 2001). The DRC model proposes two routes that, when combined, explain how we are able to understand new words, non-words, words that adhere to conventional spelling-to-sound norms, such as cave, time, and cat, as well as irregular words (e.g., have). The grapheme-phoneme conversion approach to non-lexical reading explains how we are able to read aloud new vocabulary, unusual, arranged words (e.g., bos, dar, jow), and words that adhere to standard written language to phonemic representation conventions (e.g., cave, time, cat). Both regular words like “cave” and irregular words like “have” can have pronunciations produced using the lexical reading approach.

The connectionist model (Seidenberg & McClelland, 1989) is a neural network model mimicking human brain's information processing. The model delineates two primary paths for word reading: the direct phonological channel, which involves the transfer of information from orthography (spelling) to sound, and the semantic pathway, which establishes connections across of orthography to pronunciation, as well as meaning representations. The assumption is made that there exists a collaborative distribution of labor among the orthographic components, semantic components, and phonological components, thereby demonstrating the interconnectedness and interdependence of these aspects in the process of reading. In research (Hutzler et al., 2004) on the English language, various facets of reading such as the process of adolescents acquiring reading capabilities, proficient reading, and dyslexia-related reading impairments have been investigated using connectionist models. With its adaptations for both English and German, the connectionist model has significantly enriched the understanding of computational principles in quasi-regular domains concerning word reading, thereby offering valuable insights into both typical and atypical word reading scenarios. In Chinese language research, connectionist models have been applied in various capacities to study the complex processing involved in reading and understanding Chinese characters and structures. Wu (2022) introduced a connectionist model aimed at the recognition and identifying of Chinese vocabulary, showcasing its utility in deciphering the linguistic analysis and manipulation of the Chinese language. In another study, a connectionist reading model was used to examine the system of Chinese language learning such as characters or words reading (Dang et al., 2019). The model aimed to simulate the impacts of uniformity and coherence, together with the relationship to frequency, on the reading abilities of normal adult individuals. The researchers discovered noteworthy and statistically significant results in relation to the aforementioned factors within the given context of reading Chinese characters. Research indicates that by integrating the connectionist model and functional magnetic resonance technology, two neural pathways are identified in the brain during Chinese character recognition (Wang et al., 2016). One pathway, managed by the angular gyrus and the left middle temporal gyri, is in charge of the orthographic to semantic processing. The other, overseen by the inferior frontal gyri and insula, is accountable for orthographic-phonological workflow. Together, these pathways construct a system of neural networks to process genuine and pseudo-word, elucidating the underlying brain mechanisms participating in the handling and deciphering of diverse character kinds. The outcomes are in accordance with the research on English script languages, in step with the reading model's predictions, this model suggests that Chinese and English share the same universal architecture. These studies and applications highlight the potential and effectiveness of connectionist models in investigating the intricate mechanisms involved in Chinese language processing and reading. This model and its variants have been instrumental in the ongoing exploration and discussion concerning the cognitive and neurological underpinnings of reading, and their implications in both educational and clinical settings.

2.2 Neural Correlates of Reading

Acquired knowledge by reading is a natural process that relies on multiple neural structures for successful completion such as back region of the superior temporal lobe and the visual word form area, as supported by multiple neuroimaging research on readers of adulthood (Baker et al., 2007; Dehaene et al., 2015; Stevens et al., 2017). Other research indicates that the activation pathways involved in reading across languages are analogous. For example, Feng and colleagues (2020) discovered a reading circuit composed of the superior temporal sulci/gyri, the left fusiform gyri, precentral and middle frontal gyrus that was similar across languages. Reading challenges influenced activity in multiple regions previously associated with developmental dyslexia, including the middle frontal gyrus, in readers of both Chinese and French.

According to Feng and colleagues (2020), the neural underpinnings of reading development and reading difficulties exhibit a significant certain level of linguistic consistency. To investigate brain activity of syntactic processing in reading logographic Chinese, Wang and colleagues (Wang et al., 2008) conducted event-related functional magnetic resonance imaging to look at grammatical processing mechanisms in the brain. In conjunction with the findings from alphabetic scripts (Bulut et al., 2017), these findings show that common brain foundations underpin syntactic processing in writing systems as diverse as logographic Chinese and alphabetic English. Converging data (Bulut et al., 2017; Guo et al., 2022; Zou et al., 2022) reveals that the left middle frontal gyrus serves as a particular hub location that connects the ventral with the dorsal pathways for Chinese reading. According to a study conducted on Chinese reading (Siok et al., 2020), the network responsible for processing Chinese reading consists of the fusiform gyri, the left middle area of frontal gyri, and the premotor area.

In short, the visual word form area, the left frontal gyri, the superior temporal brain region, and the fusiform gyri are essential components of reading. Reading problems affected activity in more than one area that was previously linked to developmental reading impairment. This was true for both Chinese and French readers. Syntactic processing in writing systems as different as logographic Chinese and alphabetic English is based on the same parts of the brain. The left temporo-occipital-ventral junction, specifically the middle and posterior left fusiform gyrus, is crucial for word shape processing, whereas the left temporo-parietal area, left superior temporal gyri, left hemisphere of anterior temporal gyri, and left side of brain's inferior frontal gyri may be held accountable for allowing access to word shape information to speech and semantic representation, thereby achieving correct reading and comprehension (Bulut et al., 2017). This is important to note, as acquired injuries to the brain such as stroke, that impact reading abilities may result in similar deficits among readers of different languages.

2.3 Reading Chinese

The mechanism of Chinese reading has been well studied. Chinese, unlike other languages, employs a logographic writing system that uses strokes and radicals to represent characters and words. At its most basic level, orthographic processing serves as a prelude to word recognition by extracting from words' surface structure that can then be used in later processing steps such as phonological processing and semantic comprehension. The surface structures of Chinese characters and alphabetic characters are distinct. Chinese characters have their own graphics, single character structure like '我' (means 'I'), left and right compound structures '眼' (means 'eye'), up and down compound structures '否' (means 'no'), and so forth. However, alphabetic language like English is made up of letters as a single word configuration (e.g., E-n-g-l-i-s-h). Additionally, Chinese characters are a type of morpheme character, whose fundamental unit is the union of shape, sound, and meaning, whereas alphabet characters record phonemes and the separated letters themselves have no meaning. The analysis of the general characteristics of Chinese written characters (Yin et al., 2005) reveals that the ratio of effective pronunciation of phonetic cues is approximately 77%, and the ratio of effective representation of semantics is up to 83%. This demonstrates both the ability of pronouncing Chinese vocabular to represent phonology combined with that contemporary Chinese letters are able to express meaning.

Additionally, there are phonological rules for the alphabet and characters, and proficient adult readers can directly access the semantic and phonetic elements. The same character can have different shapes without affecting its meaning, for example, the first letter of the Latin alphabet can be written as /a/ or /ɑ/, and the Chinese characters "強/强" (e.g., means strong) and "户／户／戸" （e.g., means family). Chinese children can gradually master the orthography and employ phonetic and morphological information, but both children and adults learn each word, one sound, and one meaning one at a time. Based on these traits, it might be surmised that reading Chinese characters may include a particular cerebral process for converting form, sound, and meaning (Fiorina, 2017).

2.4 Acquired Dyslexia and Chinese Individuals with Aphasia Reading and Reading Comprehension

Aphasia is a multifaceted language disorder that may impact any and/or all modes of communication, including comprehending, expressing, writing, as well as reading. Aphasia also is distinguished by a lack of function in the capacity to comprehend spoken communication and interact to the others. It is typically brought on by stroke (Darley et al., 1975). Aphasia frequently co-occurs with alexia (also referred to as acquired dyslexia), an acquired reading impairment. Of the 99 participants in a study by Brookshire and colleagues, 68% who had aphasia satisfied the study's criteria for acquired dyslexia (Brookshire et al., 2014). Aphasia and acquired dyslexia can significantly impact a sufferers' quality of life and safety. For instance, acquired dyslexia in those with aphasia may prohibit them from going back to work, enjoying leisure reading, or correctly reading medication labels.

The capacity for reading aloud single words and understanding the meaning of text can be significantly impaired, leading to challenges in both reading comprehension and single word reading. A considerable body of research (e.g., Friedman, 1996; Fuchs et al., 2001) has been dedicated to examining the oral reading proficiency of IWA and evaluating the effectiveness of therapies (Webster et al., 2013) aimed at improving reading skills, particularly in English speaking IWA. The investigation of one-word reading served a vital role in evaluating distinct patterns of impairment linked to neuropsychological frameworks of reading, such as the DRC model (Coltheart et al., 2001) and connectionist model (Patterson et al., 1996). It has established connections between certain characteristics of words (e.g., age of acquisition, frequency) together with the rate of reading (Webster et al., 2018), effectiveness, and various classifications of errors (e.g., semantic, phonetic errors, and visual errors) displayed by IWA while on oral reading of single words. A recent study by Webster and colleagues explored the relationship about how the typical evaluations understanding of reading difficulties at only one word, sentences, and text levels in IWA (Webster et al., 2023). The findings indicated a statistically significant positive association among the variables. Smith and Ryan's findings (Smith & Ryan, 2020) revealed a substantial correlation between single word reading and textual accuracy. However, there was no discernible correlation found between an individual's word reading capacity and their reading comprehension abilities. These studies collectively hint at the complex nature of text comprehension in IWA and suggest a multilevel approach to better understand and address the reading challenges faced by this population.

Based on the linguistic attributes of Chinese written script and the modern cognitive neuropsychological approach, researchers (Yin & Butterworth, 1992; Yin & Weekes, 2003) believe that acquired dyslexia in Chinese individuals can be caused by a disruption in the normal connection between orthographic, semantic, and phonological processing, resulting in graphic-phonetic and graphic-semantic reading deficit. Yin and others propose that the reading model of Chinese is the same as that of English, both grounded on the DRC system, encompassing lexical and sub-lexical pathways (Yin & Butterworth, 1992; Yin & Weekes, 2003). However, there are different studies indicating that the reading model of Chinese tends to lean towards a connectionist model (Han & Bi, 2009; Law et al., 2009), where the process of transitioning from orthography to phonology requires semantic mediation. Han and Bi (2009) reported a case of a native Mandarin speaker diagnosed with dementia and examines the patient's reading proficiency in relation to phonetic compound characters, which exhibit varied degrees of regular and coherence pattern. Reading was found to be influenced by two factors, the anticipated pronunciation accuracy based on the sound radical, and familiarity with the target item. This patient could accurately read characters they comprehended, as proven by the definitions given, with one exception. For characters they did not understand, higher reading accuracy was noted for consistent characters over disparities. The authors suggested that this consistent effect observed can be equally effectively elucidated by both lexical and 'sub-lexical' systems, as per existing models. They hypothesized that a sub-lexical reading manner of the Chinese language may involve using rules linking the subtype system, notably pronouncing cue, to phonological elements. Furthermore, these regulations are not only derived from the independent articulation of the phonetic component but highlight the orthographic structure's effectiveness as a phonetic indicator. Another single case (Law et al., 2005) reported that an individual with brain injury and acquired dyslexia in the Cantonese language, underwent an assessment to evaluate his proficiency in reading aloud and comprehending disyllabic phrases that consist of homographic heterophonies characters. These characters have several pronunciations, which can only be clarified based on the surrounding word context. A notable link was identified between reading proficiency and comprehension skills, indicating a higher level of performance in the former. The aforementioned studies about single word reading and reading comprehension come from regions where Cantonese is spoken, which is quite different from the Mandarin used in mainland China. In these studies, expressions are made in Cantonese and the script system employed is traditional characters. Importantly, there is little research in Chinese IWA with acquired dyslexia in mainland China.

There are few studies with Chinese IWA and acquired dyslexia, but some studies of developmental reading difficulties (Peng et al., 2017; Shu et al., 2006) and aging older adult reading difficulty (Zhang et al., 2022) have been reported. Weekes and Chen (1999) described their findings of eleven Chinese adults who suffered brain-damaged and subsequently had reading difficulties. They found that brain injury can selectively disrupt each route of reading, leading to various types of reading difficulty. These findings support the two-route model's generality for reading scripts in both alphabetic and non-alphabetic forms, as well as the independent brain organization of each route. Additionally, Yin and Butterworth (1992) also reported findings from a Chinese patient with acquired dyslexia suggesting lexical-semantic impairment occurs in Chinese along with other foreign languages. A review related to subtypes of acquired dyslexia (Yin & Weekes, 2003) concluded that the language context, and particularly the kind of script used for reading and writing, will affect how acquired dyslexia manifests itself in Chinese. Lastly, a case study from Yin and Butterworth (1992) concluded that persons with Chinese surface dyslexia demonstrated homophone misunderstanding in reading comprehension.

2.5 Eye Movements during Reading

Eye tracking technology is a method employed to investigate online reading behavior in a non-intrusive manner, providing real-time data. Studies vary from the recording of neurotypical persons' reading habits to the investigation of acquired dyslexia patterns. A few common eye movement behavior measurements include fixation, saccade, and regression. The movement of the human eye when reading a line of text actually consists of two primary movement phenomena, the eyes' natural movement called a saccade and a fixation when the eyes are relatively immobile (Rayner, 2009). Fixations typically last about 200–300 milliseconds. The fovea area, which is the 2° field of vision in the center of vision, the parafovea area, which is the area between 2° and 5° in the center of vision, and the peripheral area are the three portions of a line of text that the reader sees when reading. Visual sensitivity is highest in middle of the fovea, second highest at the parafovea, and lowest in the peripheral area. To see new reading content in the fovea visual area when reading, the reader must move the eyes. People mostly gain information when reading through their fixation. Saccades in normal fluent reading is the movement of the eyes from a known area to an unknown area. Eye movements during reading that moves in the opposite direction of saccades is referred to as regression. Ten to fifteen percent of the time is spent in regression by skilled readers. The metric of regression is directed to previous words in the opposite direction of the text; particularly when comprehension is insufficient, or the text is too complex, longer and more frequent regressions occur (Rayner, 1998).

Eye movements during reading have been studied greatly in neurotypical English and Chinese readers. When reading in Chinese and English, there are some differences in the eye movements (Rayner et al., 2005), although, average fixation times are rather close, between 225 and 250 milliseconds. Average saccades are substantially shorter in Chinese (2.6 characters) than in English (7-8 letters) and the rate of regression appears to be somewhat higher among Chinese readers (about 15%), compared to the rate seen among English readers (approximately 10%). Additionally, compared to English, Chinese readers have a larger tendency to skip words (42% vs. 20% respectively).

Variations that are distinctive to a language have been discovered to be associated to strategies for reading Chinese and English texts that are different from one another. It is claimed that Chinese readers are taken more on the context than on the information contained by unique characters or words, whereas English readers focus closely on the precise syntactic as well as semantic information that is embedded within words (Weekes & Chen, 1999). Chinese readers prefer to use word units rather than character units when reading sentences or paragraphs (Bai et al., 2008). Several investigations have revealed that the word traits (e.g., predictable effect and word frequency effect) impact time of fixations and skipping of word in Chinese more than character properties. The investigation was undertaken by Zhao et al. (2019) revealed that older Chinese readers experienced more pronounced impacts of word prediction on their reading time, which encompassed both lexical recognition (gaze time) and understanding based on context (regression route reading times). Therefore, elderly Chinese readers utilize the predictability of words to assist in the identification of lexical items and the incorporation of sentence context (Zhao et al., 2019).

Liu et al. (2019) conducted a study on Chinese reading where the participants were required to scan continuous sequences of Landolt-Cs in search of target circles. The aims of the research were to investigate the visual and oculomotor limitations that may influence the direction of eye movements during a task that encompasses various motor and perceptual processes associated with Chinese reading, while excluding the processing of lexical or linguistic information (Liu et al., 2019). Their research indicated that Chinese readers adjust their gaze length based on processing difficulty rather than simply choosing a default scanning target, such as at the start location or in center site of a forthcoming word. With regard to word skipping, Ma and colleagues (Ma et al., 2019) established stringent controls for word frequency effects and other words effect to examine skipping rate. The findings showed that longer words were much less likely to be skipped and were gazed at more often than shorter words. Shorter words took less time to read overall than longer words did, and words with one character took longer to read than words with two characters. Over these findings indicated the impact of length of word on the control of eyes movement is subtly different when reading Chinese than it is when reading English.

Yu and colleagues (2021) looked at participant eye movements by employing both corpus-based data sets and a more conventional analysis of the target words. The findings were used to clarify how the uninterrupted sequences of characters are divided for words recognition and eye guidance while reading. Chinese words can vary from one to two more characters, and there are no definite word limits (e.g., inter-word gap). In agreement with the generally accepted default selection hypothesis (Rayner & McConkie, 1976), Chinese readers focus their attention on a select few favored-viewing sites, such as the beginning or middle of incoming words. However, the results from Xia and colleagues (2022) experiments concluded that the preferred-viewing location did not exist in Chinese reading. A collection of ocular movement measurements of characters when reading sentences was published by Zhang and colleagues (2022). They were able to utilize databases and leverage extensive lexical tests to examine eye-tracking measures during the reading process of Chinese sentences. The results demonstrated the complexity of dealing with Chinese language during text reading, thereby providing eye movement measures for controlling or manipulating the level of challenge exhibited in Chinese writings. The measures used for eye movement measurements in this database included first fixation duration, total duration of fixation, saccades, and number of fixations. However, these eye-tracking indicators are for typical Chinese readers, and there is limited research regarding how Chinese acquired dyslexia affects eye-movement control and language processing.

2.6 Summary and Purpose of the Investigation

There are few studies investigating reading abilities or utilizing eye-tracking to infer linguistic processes in IWA and concomitant acquired dyslexia who are native Chinese speakers. However, the current literature indicates that the involvement of brain regions during reading is similar in different writing systems. Furthermore, eye-tracking is an important evaluation tool to reveal language processing behavior and, combined with theoretical models, can likely distinguish between the reading of IWA and acquired dyslexia after stroke and neurotypical persons. Based on prior research that has shown differences in the ability to read words, comprehend text and in eye-tracking measures in English speakers with aphasia relative to neurotypical control participants (McWilliams, 2022; Smith et al., 2018), it is hypothesized that there may be significant differences in word reading, reading comprehension, and eye movement measures between Chinese IWA and acquired dyslexia and control participants.

Thus, the present investigation focused on the assessment of individual word reading proficiency, how readers with Chinese aphasia move their eyes during reading, and how they comprehend what they are reading. The primary objectives of this study revolve around investigating various aspects of reading abilities and eye movement measures in Chinese IWA compared to a neurotypical controls. Specifically, the current study aims to: 1) explore whether single word reading abilities, specifically reading precision of regular words, irregular words, and pseudowords, differ between Chinese IWA and a neurotypical control group; 2) examine the differences in eye movement measures during paragraph reading, focusing on factors such as fixation time, fixation count, saccades, and saccade amplitudes, between Chinese IWA and a neurotypical control group; 3) examine whether reading comprehension abilities between Chinese IWA and a neurotypical control group differ; 4) explore the predictive potential of eye movement measures with respect to reading understanding among Chinese IWA and the neurotypical control group; 5) examine whether the ability to read aloud single words, including regular words, irregular words, and pseudowords, can predict reading comprehension in Chinese IWA and the neurotypical controls. Overall, this study aimed to shed light on the reading skills and eye movement characteristic in IWA who are native Chinese speakers; thus, providing insights into potential predictors of reading comprehension in this population when compared to neurotypical individuals.

2.7 Research Questions and Hypotheses

Based there on, the following research questions for the investigation were as follows:

1. Are there differences in the single word reading abilities, specifically regular, irregular word, and pseudo-word reading between Chinese IWA and a neurotypical control group?

   Hypothesis: Based on Law et al. (2009) and Law et al. (2005), it was hypothesized that IWA would read regular, irregular, and pseudowords with significantly lower accuracy than the control group.

2. Are there differences in the eye movement measures (time of fixations, number of fixations, saccades, amplitude of saccades) during paragraph reading between Chinese IWA and a neurotypical control group?

   Hypothesis: Based on Smith et al. (2018), it was hypothesized that there would be significant differences in each eye movement measure between the groups. The IWA would have longer first fixation, longer time to first fixations, longer total fixation duration, longer average of fixation duration, larger number of fixation, larger number of saccades, shorter average amplitude of saccades, shorter total amplitude of saccade amplitude, longer time to first saccades, and shorter amplitude of first saccade than the control group.

3. Are there differences in the reading comprehension abilities between Chinese IWA and a neurotypical control group?

   Hypothesis: Based on Coltheart et al. (2001) and Webster et al. (2013), it was hypothesized there would be significant differences in reading comprehension during eye tracking and reading comprehension from the China Rehabilitation

Research Center Aphasia Examination (CRRCAE) language assessment between groups. The IWA will have lower accuracy than the control group.

4. What is the association between eye-tracking measures and reading comprehension during eye-tracking in Chinese IWA and neurotypical control group?

   Hypothesis: Based on McWilliams (2022), it was hypothesized that eye movements would be associated with reading comprehension in Chinese IWA and neurotypical control groups.

5. What is the relationship between word reading, specifically regular, irregular, and pseudo word reading, and reading comprehension （CRRCAE) in Chinese IWA and neurotypical control groups?

   Hypothesis: Given the results by Bi et al. (2007) and Law et al. (2009), it was hypothesized that accuracy of single word reading on regular word, irregular word and pseudowords would be associated with reading comprehension in Chinese IWA and neurotypical controls.

CHAPTER III

METHOD

Figure 1 shows the overall method and procedure for study participation.

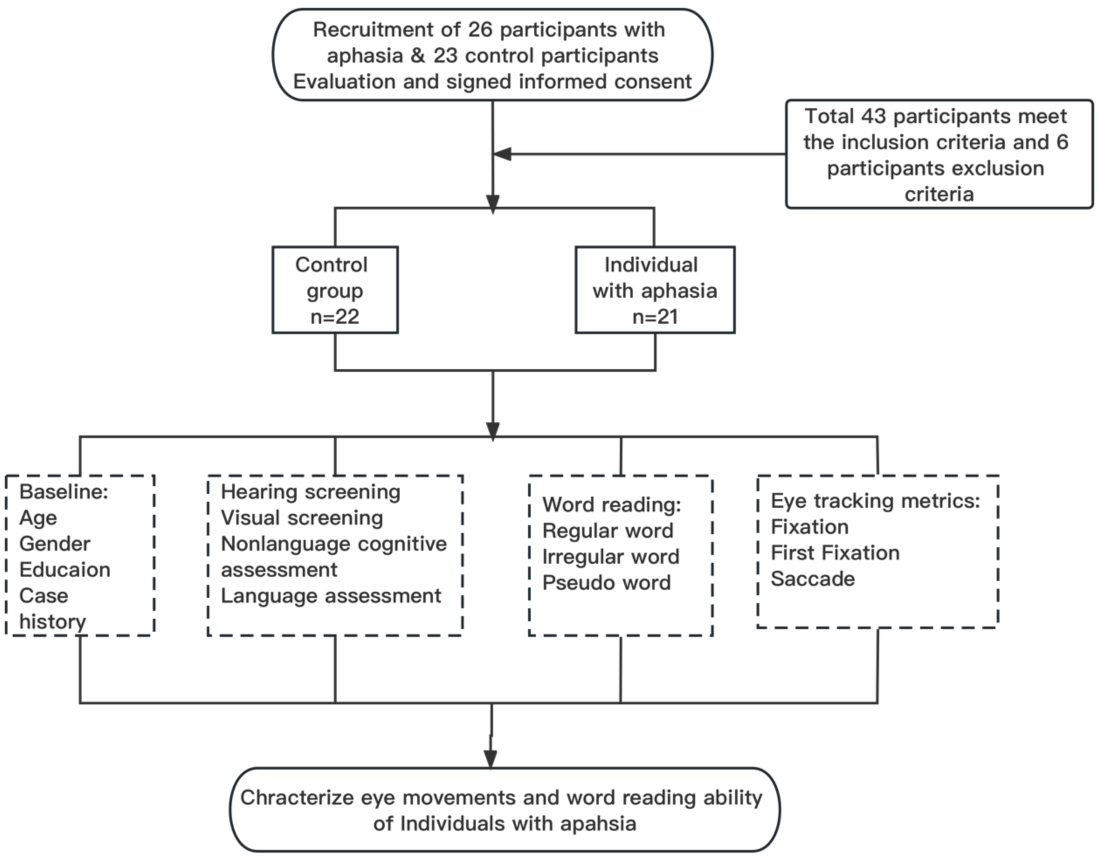

Figure 1. Reading and Eye Movements Experiment Procedure Overview

3.1 Participants

Individuals with aphasia had a diagnosis of left hemisphere stroke confirmed by CT or MRI examination, had at least primary education level, were no less than 6 months post-onset of aphasia and acquired dyslexia, from 18 to 80 years of age, right-handed, and native Mandarin speakers. Aphasia in recruited participants was confirmed through language assessment using the China Rehabilitation Research Center Aphasia Examination (CRRCAE) (Mahmoud et al., 2023). Control participants were native Mandarin speakers, between the ages of 18 and 80 years old, right-handed, with normal cognition, vision (or corrected to normal), and hearing, and the ability to read aloud. The standards for inclusion and exclusion were ascertained by administering a research questionnaire (Appendix B), by self-reporting, as well as through hearing, vision, and cognitive screening measures.

IWA were recruited from the Fujian University of Traditional Chinese Medicine's affiliated hospital system. The control group was recruited from various Fuzhou City communities via flyers, posters, or online resources like WeChat. This study screened 26 IWA and 23 control participants. In the aphasia group, 5 participants were excluded for various reasons, including severe cognitive impairments, severe apraxia of speech, hearing and vision disabilities, and calibration failures. The control group was matched with the aphasia group based on age and educational background, with one participant excluded due to retinal issues. After the initial screening of this study, a total of 22 IWA, who were matched in terms of age and education with 22 control subjects were included in the study. However, during the eye movement calibration phase, one IWA failed multiple attempts and was therefore excluded. Ultimately, the age and years of education of the remaining 21 IWA and 22 control participants were matched, but the sample sizes were unequal (age (t (41) = -.22, p = .83, years of education (t (41) = -.22, p = .83). Table 1 shows demographic information and language assessment (CRRCAE) information for participants.

Table 1. Demographic and Language Assessment (CRRCAE) Information for Participants

Individuals with Aphasia													
Pt	**Age**	**Gender**	**Ed Level (yrs)**	**Handedness**	**Mos Post-Onset**	**Stroke Type**	**AOS**	**NC**	**C %**	**R %**	**NS %**	**RA %**	**R %**
P1	51	M	15	R	10	I	9	77	95	100	96	100	97
P2	55	M	15	R	9	I	9	71	90	100	76	100	87
P3	74	M	14	R	48	I	10	64.5	95	100	100	100	100
P4	61	M	11	R	6	I	10	70	72	100	73	96	77
P5	80	M	14	R	7	I	6	45.5	25	86	43	93	25
P6	49	M	15	R	11	I	10	74	100	100	60	90	85
P7	56	M	14	R	10	H	10	69	65	86	66	56	75
P8	53	M	15	R	14	H	9	55	37	83	26	73	50
P9	42	M	14	R	7	H	8	75	87	66	43	100	90
P10	42	M	15	R	7	H	9	68	90	93	56	100	90
P11	72	F	11	R	15	I	6	61	85	86	90	93	87
P12	53	M	5	R	15	H	9	74	87	100	76	100	95
P13	24	M	14	R	7	H	8	79	55	73	43	100	92
P14	55	M	8	R	10	H	9	52.5	27	76	23	76	45
P15	46	M	15	R	10	H	8	64	55	66	5	20	20
P16	33	M	11	R	19	H	10	74	57	76	73	93	82
P17	38	M	8	R	6	H	10	69	90	93	80	93	87
P18	34	M	14	R	6	H	9	57.5	2	80	16	36	27
P19	74	M	5	R	6	H	7	55.5	20	70	3	50	10
P20	40	M	8	R	66	I	7	77	90	76	93	100	95
P21	39	M	14	R	6	H	8	77	47	63	10	80	60

Table 1, cont.

M	*51.0*	*12.14*	*14.05*	*8.62*	*67.12*	65.29	*84.43*	*54.81*	*83.29*	*70.29*
(SD)	*14.95*	*3.39*	*15.00*	*1.64*	*9.43*	29.45	*12.88*	*31.40*	*23.54*	*28.78*

Control Group

Pt	Age	Gender	Ed Level (yrs)	Handedness	NC	C %	REP %	NS %	RA %	R %
C1	49	M	8	R	80	100	100	100	100	100
C2	40	M	14	R	80	100	100	100	100	100
C3	42	F	15	R	78	100	100	100	100	100
C4	52	F	15	R	78	100	100	100	100	100
C5	72	M	5	R	70	80	100	93	100	85
C6	45	F	8	R	78	90	100	96	100	97
C7	20	F	14	R	80	100	100	100	100	100
C8	42	M	15	R	71	95	100	93	100	97
C9	43	F	14	R	77	100	100	100	100	97
C10	34	M	14	R	76	97	100	100	100	97
C11	46	F	15	R	78	100	100	100	100	100
C12	68	M	11	R	78	97	100	100	100	97
C13	63	F	14	R	72	92	93	100	93	100
C14	46	F	5	R	75	100	100	100	100	100
C15	56	F	5	R	70	97	100	100	100	100
C16	35	F	13	R	80	100	100	100	100	100
C17	51	M	14	R	78	100	100	100	100	100
C18	40	F	8	R	75	97	96	100	100	100
C19	69	F	14	R	78	97	100	100	100	100
C20	72	M	15	R	73	97	100	100	100	95

Table 1, cont.

C21	69	F	11	R	77	100	100	100	100	100
C22	47	F	15	R	80	100	100	100	100	100
M	*50.05*		*11.91*		*76.45*	*97.23*	*99.50*	*99.18*	*98.68*	*98.41*
(SD)	*13.88*		*3.65*		*3.30*	*4.75*	*1.68*	*2.17*	*1.49*	*3.37*

Note. Pt = participant; Ed level = education level; mos post-onset = months post-stroke; AOS = apraxia of speech; NC = non-language cognitive assessment; C = auditory comprehension; REP = repetition; NS = naming speaking; RA = reading aloud; R = reading comprehension.

3.2 Assessments

Aphasia and AOS severity. The China Rehabilitation Research Center Aphasia Examination (CRRCAE) (Mahmoud et al., 2023) was used to assess language function including listening comprehension, repetition, naming, reading aloud, reading comprehension, transcription, dictation, and calculation of nouns, verbs, and sentences for the IWA and neurotypical group. However, this study only extracted language assessment results pertaining to auditory comprehension, naming speaking, repetition, oral reading, and reading comprehension. The CRRCAE was also administered to solicit a speech sample to evaluate the occurrence and extent of AOS. The Apraxia of Speech (AOS) Scale of evaluation was applied to the speech sample to quantify severity on a scale of 0 -10, with scores of 6 -10 indicating mild and normal apraxia of speech and 1- 4 indicating severe apraxia of speech. One participant from the aphasia group was excluded from the study due to AOS test score belong to 1- 4.

Cognition. The Non-Language Cognitive Assessment (NLCA; Wu et al., 2017) was used to screen for cognitive dysfunction for participants in both groups. The NLCA is comprised of five nonverbal tests designed to assess non-language cognitive domains in IWA, including visuospatial processes, focus, recall, logic, and executive skills. These tests have been adapted from existing nonverbal assessments, with some adjustments made to align them with features of Chinese culture. The total score on the NLCA is 80, with 70 points as the cutoff value; individuals with scores below 70 may be considered to have cognitive impairment (Wu et al., 2017). In this study, IWA with NLCA examination scores below 50 were considered to have severe cognitive impairment and were excluded from the research. Participants in the control group with NLCA scores below 70 were excluded from this study. One participant from the aphasia group was excluded from the study due to this cognitive function test score below 50 points.

Hearing Screening. A pure-tone hearing screening was conducted for frequencies between 125Hz and 8,000 Hz at 30 dB HL in a quiet room using a portable audiometer. During the screening, the participants sat comfortably, and then the researcher placed the headphones or ear inserts on the participant. The device automatically played a series of tones at different frequencies and volumes. After the hearing test for each ear was completed, the audiometer screen displayed either "Passed" or "Referral". The criteria for participation in the study was that all participants must have at least one ear that passed the hearing test at frequencies of 500, 1000, 2000, and 4000 Hz on the audiometer screen. One IWA was excluded from the study because the hearing test results for both ears indicated a "Referral".

Vision Screening. All participants underwent vision screening at the ophthalmology outpatient clinic of Fujian Rehabilitation Hospital. The main screening items included distance vision, near vision, eye alignment/motility, ocular function, and the fundus for optic nerve disease and macular disease. Corrected binocular vision was evaluated. The visual acuity chart 5.0 and 1.0 were measures of visual acuity and can be converted to each other. Visual acuity 1.0 indicates decimal recording and visual acuity 5.0 indicates logarithmic recording. If the individual displayed 0.8 -1.0 binocular vision, both corrected distance and near vision were regarded as adequate for study participation. One participant in the control group was excluded from the study because of retinal dysfunction, and another participant from the aphasia group was excluded after examination revealed damage to the optic nerve in the right eye.

Word Reading Aloud Test. A total of 180 characters were sourced from Lau et al. (2014). This test primarily targeted individuals in the Hong Kong region, utilizing traditional Chinese characters. To facilitate the participation of subjects from mainland China, the traditional characters were converted into equivalent simplified characters with no change in word meaning before the commencement of the research. During this conversion process, 28 characters that could not be effectively transformed for mainland practicality were excluded. Ultimately, a total of 153 Chinese characters were selected for a word reading aloud test, and these were categorized into three types: regular words, irregular words, and pseudowords. There were 54 regular characters, 40 irregular characters, and 59 pseudo characters (Appendix A). Both the IWA and the controls underwent single word reading tests.

The experimental stimuli were created using Psychopy software, with all the characters presented in image format. The images featured white backgrounds with black characters, rendered in Microsoft YaHei font at 28-point size. The presentation of all characters was randomized. The stimulus screen was positioned approximately 50-70 centimeters in front of the participants. The participants were positioned in an upright posture facing the computer screen during the testing session. Before each character was presented, participants were instructed to read it aloud. Next, to ensure focused attention, participants were instructed to fixate at the cross on the screen for a continuous 5 seconds. In the case of pseudo characters, participants were required to identify whether the character display in front of them was a real word. If the participant judged it as a pseudo character or indicated that they did not recognize it and could not read it, the researcher considered it a correct response. That is, the individual correctly identified that it was a pseudo character. However, if the participant judged it as a real word and read it with phonetic radical, the researcher considered it an incorrect response. For regular and irregular characters, participants read the words aloud. Figure 2 shows the word reading task procedure.

Figure 2. Word Reading Task

3.3 Eye Tracking Equipment for Sentence Reading

The Tobii pro spectrum eye-tracker infrared, laptop-mounted eye-tracking system was applied to monitor eye movement motions during the experiment. Using Tobii's proprietary software, connected-text stimuli was presented to participants and to track their right eye movements at a sampling rate of 1200 Hz (accuracy 0.3° at optimal conditions). At the bottom of the laptop monitor, there was an infrared illuminator bar that patients sat 55–70 cm away from. During the calibration process of the Tobii pro spectrum, the screen was automatically displaying nine calibration points, which can be followed directly by the participant.

3.4 Connected-Text Experimental Stimuli

The sentence reading and comprehension tasks used for the eye-tracking were sourced from the Chinese Reading Eye Movement Measurement Database (Zhang et al., 2022). The experiment included 20 trials presented sequentially. Each trial presented a short narrative and consisted of characters and punctuation marks, with word counts ranging from 18-26 words. A list of the stimuli is in Appendix C. After reading each narrative, the researcher posed a corresponding comprehension question along with four multiple choice answer options. The stimuli remained on the screen while the participant answered the question. The sentences were shown against a white backdrop, utilizing a 28-point black Times New Roman typeface. Figure 3 shows an example of the stimuli and reading comprehension question along with the English translation.

句子 1: 悦容和学诚喜欢吃剁椒鱼头，昨天聚餐悦容点了这道菜。

问题 1: 悦容和学诚喜欢吃什么？

A. 剁椒鱼头

B. 清蒸鱼

C. 红烧鱼

D. 水煮鱼

Sentence 1: Yuelong and Xuecheng like to eat fish head with chopped pepper, Yuerong ordered this dish for dinner yesterday.

Comprehension Question 1: What do Yuerong and Xuecheng like to eat?

A. Fish head with chopped pepper

B. Steamed fish

C. Braised fish

D. Boiled fish

Figure 3. An Example of Stimuli Sentence and Following Comprehension Question and Answers during Eye Tracking

3.5 Procedures

The study was approved by the Institutional Review Board at the University of South Alabama and Fujian Province of Rehabilitation Hospital. All individuals involved in the study provided their informed consent prior to their participation. Following informed consent procedures, IWA completed the CRRCAE (i.e., aphasia and AOS assessment), the non-language cognitive assessment, vision, and hearing screenings. Following assessment and screening procedures, all participants completed the eye-tracking protocol. The assessments were administered in quiet, well-lit rooms. Study participation was completed in one 2–3-hour session, however, some participants attended 2 sessions because of fatigue or limited time.

For the eye-tracking protocol, the task instructions were reviewed before the practice sentence was presented. Prior to advancing to the practice sentence, participants had the chance to seek clarification by asking questions and to demonstrate their comprehension of the instructions. Subsequently, participants underwent a calibration procedure, which followed these steps: 1）Ensured proper positioning of the participant in front of the eye-tracking device to enable unobstructed observation of the subject's eyes by the eye-tracking device; 2) Instructed the participant to track the object appearing on the screen by gazing at it after the calibration had commenced; 3) The calibration procedure was initiated by the subject by clicking the "start calibration" button on their screen; 4) After collecting the calibration data, the calibration results were graphically displayed on the subject's screen, showing the accuracy and precision of the gaze points; 5) A table was displayed on the right-hand side of the window, presenting an estimation of the mean overall outcomes for all calibration points. Calibration was repeated as necessary. All participants successfully underwent eye movement calibration. However, one participant from the aphasia group was excluded from the study after failing to pass the calibration despite multiple attempts.

Following calibration, the screen display turned to the practice sentence, followed by the comprehension questions for the practice sentence. After confirming the participant's comprehension of the task, the presentation of the first experimental sentence commenced. Participants were encouraged to read silently to avoid motor speech challenges and given as much time as they need to read each paragraph. Participants indicated completion verbally or through gestures. Subsequently, comprehension questions related to the sentences were verbally presented by the researcher. After posing the questions, the relevant answer choices were provided for the participant to select the correct response, which was then recorded by the operator. Participants answered the multiple-choice questions either verbally or by pointing to the answer. The sentence stimuli remained on the screen while the participant answered the corresponding question. Participants were allowed to rest between the trials as needed.

3.6 Eye Tracking Measures and Data Preparation

Eye movement data preparation was done using the Tobii Pro Lab application which allowed for extraction and calculation of eye movement measures (Sharma et al., 2021). The area of interest was marked as the entire connected-text passage. Table 2 shows the eye movement variables of interest that were examined in the current study. Although there were several eye movement measures to select from, these were selected as an initial characterization of eye movements during reading for Chinese IWA and the neurotypical control group. Utilizing Tobii software to draw a quadrilateral, the entire sentence was delineated as the area of interest, and eye movement measures within this area were extracted (see Table 2 for details).

Table 2. Eye Tracking Measures for Analysis

Measure	*Definition*	*Unit of Measurement*
Fixation	Fixations refer to moments when the eyes remain relatively stationary, stabilizing the central foveal vision, allowing the visual system to gather detailed information about the observed object.	
Total duration of fixations (TDF)	The cumulative length of time that fixations occur inside a specified Area of Interest (AOI) over a certain interval.	milliseconds
Average of fixation duration (AFD)	The mean duration of fixations within an Area of Interest (AOI) for a certain time span.	milliseconds
Number of fixations (NF)	The frequency of fixations taking place inside an Area of Interest (AOI) throughout a certain time frame.	counts
First fixations	Refers to the initial instance when a person's gaze lands on a specific Area of Interest (AOI) during eye-tracking	
Time to first fixations (TFF)	The duration until the initial fixation occurs inside an Area of Interest (AOI) within a certain time interval.	milliseconds
Duration of First fixation (DFF)	The temporal extent of the initial fixation on a particular word during the initial reading of a text, specifically eliminating fixations that occur subsequent to regressions.	milliseconds
Saccades	Saccades represent a category of eye movements employed to swiftly shift the fovea's focus from one location to another. This motion initiates with a rapid acceleration, culminating in the eye reaching its maximum velocity.	
Number of saccades (NS)	The frequency of saccades seen within a certain time interval.	counts
Average amplitude of saccades (AAS)	The saccades' mean amplitude within this time interval.	velocity
Total amplitude of saccades (TAS)	The total amplitude of all saccades in this interval	velocity
Time to first saccade (TFS)	The duration until the initiation of the initial saccadic eye movements during a given time interval.	milliseconds

Table 2, cont.

Amplitude of first saccade (AFS)	The magnitude of the initial saccadic eye movement within the given time frame.	velocity

Accuracy of word reading data was expressed as a percentage calculated by the percentage of correctly pronounced (i.e., regular, and irregular words) or identified (i.e., pseudowords) words in each group divided by the total word count in each group. It is worth noting that the total word count varies with regularity level, comprised of 54 regular words, 40 irregular words, and 59 pseudowords. The CRRCAE subtests including auditory comprehension, repetition, naming speaking, reading aloud, reading comprehension were scored according to the manual and expressed as percentage of accuracy as well. During the eye-tracking test, there were a total of 20 reading comprehension questions. Each participant's final score was represented as a percentage of the questions answered correctly.

3.7 Reliability

For reliability, a second Chinese-speaking rater scored the word reading task and language assessment for 10% (i.e., two participants) from each group of participants who were randomly selected based on recordings of the assessments. An acceptable reliability criterion of 85% agreement was established prior to the commencement of this study. The results revealed a high inter-rater reliability, with a 99.2% agreement for the word reading task and a 95% agreement for the language assessment. Intra-rater reliability was also high for the language assessment (99.4%), the word reading task (98.7%), the eye tracking task reading comprehension questions (100%), and the cognitive assessment (99%).

3.8 Data Analysis

For research question 1, descriptive statistics were used to characterize the single word reading accuracy including means and standard deviation among groups. Average accuracy scores for each set of words with different regularity (i.e., regular words, irregular words) were examined descriptively for the IWA group and the control group. Due to nonnormal distributions (see Appendix E) that violated the assumptions of parametric tests, nonparametric tests were employed. The Mann-Whitney U test was used to compare the group of IWA and the control group for the accuracy on each regularity level (i.e., regular, irregular, pseudo).

For research question 2, descriptive statistics were used to characterize each eye tracking measure including mean, standard deviation for each participant group. The Mann-Whitney U test was conducted to see the difference between the group of IWA and the controls for each eye tracking measures that did not meet normality (see Appendix E) and homogeneity of variances. However, multivariate ANOVA was employed to compare the group of IWA and the control group for eye tracking measures that met normality and homogeneity of variances.

For research question 3, descriptive statistics were reported for reading comprehension scores of each group. The Mann-Whitney U test was used to assess the reading comprehension performance between the IWA and control group, as the data exhibited nonnormal distributions (see Appendix E) that contradicted the assumptions of parametric testing.

For research question 4, separate Spearman correlations were utilized to explore the associations between eye tracking measures and comprehension of texts for both the IWA group and controls.

For research question 5, separate Spearman correlations and multiple regressions were executed to explore the relationships between word reading abilities (i.e., regular, irregular, and pseudo word) and reading comprehension for the IWA and control group. Given the three tests conducted, a Bonferroni correction was applied, setting the significance level at $p < .05/3$ (i.e., $p < .017$) to correct for multiple comparisons. Additionally, another multiple regression was performed to determine whether regular, irregular, and pseudowords have predictive validity for reading comprehension. In the IWA group, the multiple regression analysis included educational level and months post onset as control variables, while in the control group, the multiple regression analysis included only the educational level as a control variable.

CHAPTER IV

RESULTS

4.1 Research Question 1

The control group read with significantly higher accuracy for regular, irregular, and pseudowords (all $p < .05$) compared to IWA. Table 3 summarizes the Mann-Whitney U results for each comparison.

Table 3. Research Question 1 Mann-Whitney U Results

	Group Median		Mann Whitney *U*	Mann Whitney *Z*	*p*	^{d}*Cohen*
	Controls	IWA				
Regular	96.30	75.90	41.50	-4.62	<.001**	0.49
Irregular	85.00	57.50	61.00	-4.15	<.001**	0.40
Pseudo	94.90	76.60	89.50	-3.45	.001**	0.28

* $p<0.05$ ** $p<0.01$

4.2 Research Question 2

Table 4 shows the descriptive statistics for each eye movement measure and participant group. The IWA demonstrated significantly longer total and average fixation duration, a higher frequency of fixations, an extended time to initiate their first fixation, shorter saccade amplitude, and a delayed onset of the first saccades in comparison to the control group. No differences emerged between the groups for number of saccades, total amplitude of saccades, amplitude to first saccade, first fixation duration. Table 5 summarizes the results of the eye movement measures analyzed using multivariate analysis of variance, and Table 6 show the results of the eye movement measures analyzed using Mann-Whitney U due to non-normality.

Table 4. Descriptive Statistics of Eye Movement Measures

Eye Movement Measure	Group	*M*	*SD*
Total Duration Fixation	Control	7848.50	4570.55
	Aphasia	16288.88	8656.08
Average Fixation Duration	Control	209.60	37.17
	Aphasia	251.58	74.47
Number Fixation	Control	36.82	19.71
	Aphasia	60.89	26.15
Time to First Fixation	Control	210296.54	55794.42
	Aphasia	496712.73	132132.77
Duration of First Fixation	Control	166.82	34.41
	Aphasia	180.20	43.32
Number of Saccades	Control	564.41	346.52
	Aphasia	813.91	488.69
Average Amplitude of Saccades	Control	6.10	1.86
	Aphasia	4.70	2.00
Total Amplitude of Saccades	Control	3337.32	1680.78
	Aphasia	4292.65	3581.22
Time to First Saccade	Control	677.22	660.66
	Aphasia	2801.39	4574.33
Amplitude of First Saccade	Control	6.70	2.41
	Aphasia	5.66	3.14

Table 5. Multivariate ANOVA Results for Research Question 2

Group (Means ± SD)	Average Fixation Duration	Duration of First Fixation	Average Amplitude of Saccades	Amplitude of First Saccade
Control	209.60 ± 37.17	166.82 ± 34.41	6.10 ± 1.86	6.70 ± 2.41
IWA	251.58 ± 74.47	180.20 ± 43.31	4.70 ± 2.00	5.66 ± 3.14
df	1	1	1	1
F	5.55	1.26	5.61	1.49
p	0.02	0.27	0.02	0.23
^{d}*Cohen*	0.72	0.34	-0.73	-0.37

* *p*<0.05 ** *p*<0.01

Table 6. Mann-Whitney U Results for Research Question 2

	Group Median		Mann Whitney *U*	Mann Whitney *Z*	*p*	^{d}*Cohen*
	Control group	Aphasia group				
Total Duration Fixation	7665.25	17890.45	359.00	-3.11	0.002**	0.23
Number of Fixations	32.95	62.80	353.50	-2.98	0.003**	0.21
Time to First Fixation	200786.48	463387	459.00	-5.54	0.000**	0.71
Number of Saccades	516.50	903.000	159.50	-1.74	0.08	0.55
Total Amplitude of Saccades	3606.45	2504.39	222.00	-0.22	0.83	0.07
Time to First Saccade	361.17	832.79	333.00	-2.48	0.01*	0.14

* *p*<0.05 ** *p*<0.01

4.3 Research Question 3

The control group read with significantly higher reading comprehension accuracy when compared to IWA for both the language assessment subtest and the eye tracking task reading comprehension questions. Table 7 summarizes these results.

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4.4 Research Question 4

No associations between eye movement measures and the eye tracking reading comprehension scores for IWA or the control group reached statistical significance. Table 8 and Table 9 summarizes the correlation results for both groups.

Table 8. Spearman Correlation Result for Research Question 4 for Controls

		Eye Tracking Reading Comprehension
Total Duration Fixation	r_s	-0.33
	p	0.14
Average Fixation Duration	r_s	0.29
	p	0.19
Number of Fixation	r_s	-0.33
	p	0.14
Time to First Fixation	r_s	-0.33
	p	0.14
Duration of First Fixation	r_s	0.33
	p	0.14
Number of Saccades	r_s	-0.33
	p	0.14
Average Amplitude of Saccades	r_s	0.33
	p	0.14
Total Amplitude of Saccades	r_s	0.05
	p	0.82
Time to First Saccade	r_s	-0.22
	p	0.32
Amplitude of First Saccade	r_s	0.29
	p	0.19

* $p<0.05$ ** $p<0.01$

Table 9. Spearman Correlation Result for Research Question 4 for IWA

		Eye Tracking Reading Comprehension
Total Duration Fixation	r_s	-0.05
	p	0.85
Average Fixation Duration	r_s	0.11
	p	0.63
Number of Fixation	r_s	-0.11
	p	0.64
Time to First Fixation	r_s	-0.40
	p	0.08
Duration of First Fixation	r_s	0.12
	p	0.62
Number of Saccades	r_s	0.02
	p	0.94
Average Amplitude of Saccades	r_s	0.18
	p	0.43
Total Amplitude of Saccades	r_s	0.05
	p	0.82
Time to First Saccade	r_s	-0.24
	p	0.29
Amplitude of First Saccade	r_s	0.21
	p	0.36

* $p<0.05$ ** $p<0.01$

4.5 Research Question 5

Significant associations between reading comprehension assessed by the CRRCAE and regular ($r_s = .79$, $p < .001$) as well as irregular word reading ($r_s = .79$, $p < .001$) emerged for IWA. However, there was no correlation between reading comprehension and pseudoword reading (r_s = -.12, p = .59) for IWA. Figure 6 shows a scatterplot of reading comprehension and single word reading. For the control group, regular (r_s = .09, p = .70), irregular (r_s = .19, p = .39), and pseudoword reading (r_s = .18, p = .42) were not significantly associated with reading comprehension.

Given the high correlation between regular word reading and irregular word reading (r_s = .85) in IWA, a regularity composite variable was created to aggregate regular word reading and irregular word reading. A multiple regression analysis was also employed to investigate the association between reading comprehension as the dependent variable and single word reading ability as independent variable in IWA along with education level and months post-stroke included as covariates. The model automatically identified by the stepwise regression analysis accounted for 59.7% of the variance in reading comprehension (R^2 = 0.60). The F-test for the model indicated statistical significance (F = 28.10, p < 0.001), suggesting that regular and irregular word reading indeed has a significant impact on reading comprehension for IWA.

Similar to IWA, a high correlation between regular word reading and irregular word reading was present in controls (r_s = .72), so a regularity composite variable was created to aggregate regular word reading and irregular word reading. Another regression model was created with reading comprehension as the dependent variable and the regularity composite variable as the independent variable. Education level was included as a covariate. The model automatically identified by the stepwise regression analysis that the final model solely included the regularity composite variable, education level as the control factor, which accounted for 58.5% of the variance in reading comprehension (R^2 = 0.59). The F-test for the model indicated statistical significance (F = 28.22, p <

0.001), suggesting that regular and irregular word reading indeed has a significant impact on reading comprehension for the controls. The results from the multiple regression show a significant relation between single word reading and reading comprehension, even though there is no significant correlation based on the Spearman's correlation in controls.

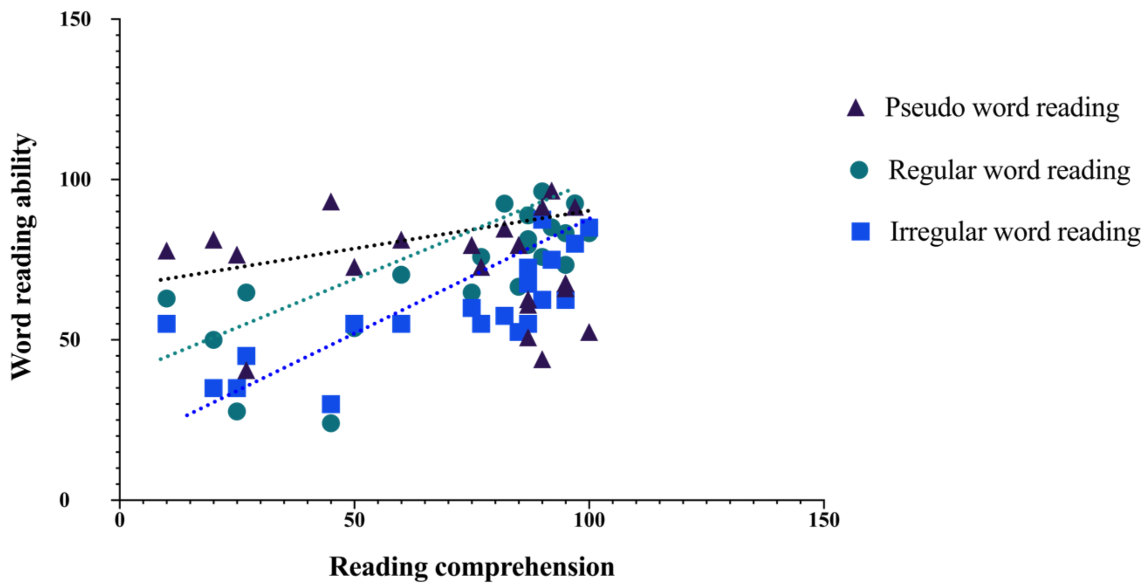


Figure 4. Relationship of Comprehension and Word Reading for IWA

4.6 Post Hoc Analysis

Considering that both IWA and control participants' education levels and months post-onset stroke (IWA only) varied significantly in this study and that there is the possibility of these factors influencing reading results, post hoc analyses were conducted to examine whether education level and months post-onset impacted participants' word reading and comprehension abilities. Separate Spearman correlations were conducted to examine the association between education level and months post onset and word reading and comprehension abilities.

For all participants, the Spearman correlation indicated no significant association between education level and word reading (regular r_s=.22, p = .16, irregular r_s = .25, p = .10; pseudo word r_s = .23, p =.14) or reading comprehension scores (CRRCAE r_s = .02, p = .89; eye tracking task reading comprehension r_s = .11, p = .49). For IWA, there was also no association between months post onset and word reading (regular r_s = .19, p = .42, irregular r_s = .29, p = .21; pseudo word r_s = .03, p = .91) or reading comprehension abilities (CRRCAE r_s = .42, p = .06; eye tracking task reading comprehension r_s = .40, p = .08).

Additionally, statistical power is a crucial measure as it indicates the probability of correctly rejecting the null hypothesis when the alternative hypothesis is true. Therefore, post hoc power analyses were conducted to evaluate whether the sample size in this study was adequate to detect the expected effects for research questions 1, 2, and 3 and whether the results should be interpreted with caution due to low power. Table 10 indicates the power calculated for each research question. Using power of .80 as an indicator of an adequate sample size for detecting differences among participant groups for each measure, the results of the power analyses indicate the sample size may be inadequate for most of the comparisons between groups with the exception of time to first fixation under research question 2.

Table 10. Power Calculations for Research Question 1, Research Question 2, and Research Question 3

	Power
Research Question 1	
Regular	0.50
Irregular	0.35
Pseudo	0.19
Research Question 2	
Average fixation duration	0.63
Average amplitude of saccades	0.64
Duration of first fixation	0.20
Amplitude of first saccade	0.22
Total duration of fixation	0.14
Number of fixations	0.13
Time to first fixation	0.81
Time to first saccades	0.09
Number of saccades	0.58
Total amplitude of saccades	0.06
Research Question 3	
Reading Comprehension (CRRCAE)	0.60
Eye Tracking Task Reading Comprehension	0.57

CHAPTER V

DISCUSSION

5.1 Research Question 1

Acquired reading difficulties, also known as acquired dyslexia, are common among IWA. When aphasia occurs, chronic acquired dyslexia can hinder an individual's reintegration into societal functions, impacting their ability to work, communicate, and undertake learning tasks (Knollman-Porter et al., 2022). Extensive research has been conducted on the abilities of one-word reading aloud of English IWA, encompassing words of varying frequencies and categories including verbs, nouns, content words, and function words (Alyahya et al., 2018; Berndt et al., 1997). However, research addressing the word reading abilities of Chinese IWA, particularly from the perspective of different regularities (i.e., regular words, irregular words, and pseudowords), remains relatively scarce. The conclusions reached of the current investigation validate the proposed thought that Chinese IWA have lower accuracy across all regularity levels (i.e., regular, irregular, and pseudo word reading) compared to the neurotypical control group. While all three categories showed a significant difference, the effect size decreased from regular to pseudowords. This suggests that while the accuracy difference is statistically significant across all categories, the clinical implications might differ. Regular and irregular word reading abilities are moderately affected, whereas pseudoword reading abilities show a smaller difference. Research has found that when reading Chinese characters aloud, individuals automatically recognize the phonetic and semantic radicals within the characters (Bi et al., 2007; Law et al., 2009). Specifically, the phonetic radicals are associated with phonological representation, while the semantic radicals are linked to semantic representation, assisting in pronouncing the character and understanding its meaning. Additionally, the frequency effect and position effect of the semantic radical and phonetic radical serves vital function in this mechanism. Based on the findings of the current study, IWA face significant challenges when processing regular characters, irregular characters, and pseudo-characters. This might be due to their difficulties in phonological representation, semantic representation, or in simultaneously extracting both semantic and phonetic information, compared to the control group. The findings by Borghesani and colleagues (2020) suggests that while both control group and persons with semantic-variant primary progressive aphasia (svPPA) exhibit different patterns in reading regular, irregular, and pseudowords, the svPPA patients display a distinct pattern indicative of surface dyslexia. The smaller effect size in the current study somewhat aligns with this finding. Although the primary emphasis of the Borghesani et al. research (2020) was on svPPA, the characteristics as well as manifestations of the reading impairment observed align closely with those associated with aphasia. Given the significant differences observed in this research, future studies should delve deeper into the specific challenges experienced by IWA in Chinese word reading and explore potential therapeutic approaches.

According to early research by Yin and Butterworth (1992), they tested 11 brain-injured patients on reading regular words, irregular words, and pseudowords. Among them, patients diagnosed with "surface dyslexia" performed relatively accurately when reading regular words. However, those diagnosed with "deep dyslexia" had an accuracy rate of less than 60% when reading regular words. This aligns with some of my research findings, where aphasia patients have a lower accuracy rate when reading regular words compared to neurotypical individuals. Nevertheless, the current study did not differentiate between types of dyslexia and provided no conclusive evidence for the existence of an orthography-to-phonology conversion route in Chinese. Other research suggests that pseudoword reading of Chinese characters also occurs through the lexical route (Law et al., 2009). Additionally, they found that two acquired dyslexia patients responded to pseudo characters as reasonably as neurotypical individuals. This is similar to my findings. The smaller effect size for pseudoword reading in the current study somewhat aligns with this perspective, although pseudoword reading was significantly poorer than IWA. One may think this could be due to regaining of language functions after treatment over time or education level prior to their stroke, however, my ad hoc analyses examining months post onset and education level do not indicate these two factors as an explanation.

5.2 Research Question 2

The present study aimed to examine the disparities in eye-tracking during the process of reading sentences between Chinese IWA and control participants. It is widely recognized that considerations such as the influence of word frequency, length effects, and predictable effects can contribute to gaze duration and saccade amplitude. For instance, high-frequency words tend to reduce fixation duration, while longer words increase the likelihood of prolonged gaze and re-fixations. Additionally, in a contextual setting, the recognition of semantically ambiguous words can extend fixation duration. The current study was conducted without specific conditions, focusing solely on observing the eye movement indicators of IWA and controls, all of whom had at least a primary school level of education. While the findings regarding the total fixation duration, average of fixation duration, number of fixations, time to first fixation, mean amplitude of saccades, and time to first saccades were consistent with my hypothesis, the results related to the duration of first fixation, amplitude of first saccade, the number of saccades, and total amplitude of saccades were non-significant. The non-significant findings could potentially indicate that these are less affected in IWA, or that there might be compensatory strategies that these individuals adopt during reading Chinese sentences.

The relationship between language processing and eye movement patterns has long been a subject of interest in the realm of cognitive neuroscience. The study under discussion delves deep into this relationship, particularly focusing on Chinese IWA and their eye movement patterns during sentence reading. Aphasia, a linguistic-level disorder resulting from brain damage, often impacts the individual's capacity to comprehend written and spoken material as well as produce language. The findings of this study unveiled subtle disparities in reading patterns between individuals with acquired impairments and neurotypical control participants, as well as delineated characteristics of eye movement indicators across diverse populations of native Chinese speakers. Consistent with the hypothesis, and aligning with previous research (Smith et al., 2018), IWA exhibited several distinct eye movement patterns in comparison to the control group. Specifically, prolonged total fixation durations and an increased frequency of fixations were noted for IWA. This prolonged duration and increased frequency may be attributed to the cognitive and linguistic challenges IWA face during reading, which necessitate a slower and more meticulous examination of the text (Smith et al., 2018). It is notable to highlight that the patterns observed in Smith et al (2018) study are not isolated but align with broader research trends. This consistency underscores the reliability of the observed patterns and their potential generalizability across different populations of IWA.

The control group did not have these language impairments, so their eye movement patterns were likely to be more fluid and natural. Because aphasia is a neurological condition characterized by impaired language abilities, which can manifest as difficulties in reading comprehension, the heightened cognitive load experienced by IWA during the processing of reading material may lead to alterations in their patterns of eye movement. IWA may experience delays in the cognitive processing and comprehension of written material, resulting in an extended time of fixation on the text. The aforementioned observations align with the outcomes of the current investigation pertaining to the aggregate fixation duration and the mean duration of fixation.

Regarding the current study, it was observed a notable distinction in the total number of fixations between these groups, aligning with my expectations. Typically, those without aphasia exhibit a streamlined pattern of fixations, swiftly focusing on essential information areas. In contrast, IWA's language processing challenges mean these individuals often need more fixations to understand equivalent content. When considering the time to first fixation, individuals without aphasia tend to quickly zero in on pertinent information. However, IWA, due to their processing delays, often take longer to register their initial fixation. This trend extends to the time to first saccades;

while the unaffected group swiftly initiates their first saccadic movement thanks to efficient cognitive processing, those with aphasia experience delays. Lastly, the amplitude of saccades in the typical group remains consistent, reflecting their steady cognitive processing. But for those with aphasia, the amplitude varies. Overall, the saccades of IWA are smaller than controls. It implies that IWA might be bypassing confusing segments, with a heightened focus on specific areas. IWA often face a heightened cognitive load, especially when processing written stimuli. When compared to the group that did not have this additional strain, those individuals' patterns of eye movements can be noticeably different. To cope, they may adopt compensatory eye movement strategies, further differentiating their eye tracking measures. Moreover, the brain areas impacted by aphasia, especially those central to language processing may influence both visual processing and eye movement control. Disruptions in these brain regions are likely contributors to the observed eye tracking disparities. In essence, the pronounced eye tracking differences between the aphasia and control groups stem from the unique linguistic challenges, cognitive demands, adaptive strategies, and neural considerations faced by those with aphasia.

While no statistically significant difference in the first fixation duration was seen in this study, it is important to take into account the fact that the mean duration of the first fixation for IWA was a little larger compared to the control group. This is incongruous with what was expected. First fixation duration is usually focused on individual word processing, and word processing time is captured by reporting this measure. In most cases, the length of time spent fixating a word for the first time is unaffected by the number of times that the word is examined. Even though the t-tests did not show significant differences between the participant groups, the medium effect size and low power suggests that there might still be a meaningful difference between the groups in terms of these eye movement measures. Nonetheless, no difference in the groups in this study may also be because some readers ignore the first word of the sentence and read straight ahead. This phenomenon could be attributed to the fact that the duration of first fixation is subject to the influence of various elements, extending beyond mere language processing capabilities. Huck and colleagues (2017) analyzed the impact of frequency of words and situational prediction on understanding sentences in IWA as well as control participants. Huck and colleagues (2017) measured gaze duration, probability of first fixation, and initial regressions. The results indicated that the frequency and predictability of words substantially influenced the eye movements of both IWA and a control group. However, DeDe (2012) found that IWA were more sensitive with the first fixation duration than the control group with lexical variables like frequency and word length. Given the absence of established lexical variables, such as word frequency or imageability, for assessing first fixation duration in the current study, it is unsurprising that the comparison between the two groups lacks substantial significance. Examination of specific lexical variables, like word frequency, on eye movement measures in IWA is warranted in future research.

It is widely accepted that optimal reading and comprehension require many factors, including focused visual attention, coordinated eye movements, cognitive processing (Henderson et al., 2018), and linguistic systems. Additionally, the complexity of the reading material, the frequency of vocabulary, and the surrounding context can significantly influence the reading process. Eye-tracking measurements, employed as a tool to assess reading comprehension, predominantly focus on measures such as fixations, saccades, and regressions. Should any disruptions arise in the reading process, be it cognitive challenges, linguistic processing difficulties, or increased complexity of the material, typical manifestations include prolonged fixation durations, shortened saccadic intervals, and increased regression frequencies. However, in this study, I observed significant disparities in fixation measures between the control group and those with aphasia. Intriguingly, saccadic measures, including the first saccade amplitude, the number of saccades, and the total saccadic amplitude, revealed no statistically significant variations. This is inconsistent with my hypothesis. Interestingly, while the present study observed no statistically significant differences in those saccadic measures between the two groups, it is essential to consider the broader context. However, to fully grasp the implications of these findings, it is crucial to consider the effect sizes. For the number of saccades, the effect size suggests a large effect. This implies that, despite the lack of statistical significance, there is a practical difference between the groups in terms of the number of saccades. This could be indicative of underlying differences in reading strategies or cognitive processes between the groups, even if these differences are not pronounced enough to reach statistical significance in this particular analysis. Conversely, the total amplitude of saccades had a small effect. This suggests that the practical difference between the groups concerning the total amplitude of saccades is minimal. In this context, the contrasting effect sizes for the two measures emphasizes the need to consider both statistical and practical significance. While the number of saccades might warrant further investigation due to its large effect size, the total amplitude of saccades, given its small effect size, might be less of a concern in terms of practical implications. Calabrese and colleagues (2016) have asserted that lack of regularity in fixations has a significant role in determining reading speed, regardless of the amplitude of saccades. However, observing the raw data, the total saccadic amplitude for the IWA is still shorter than controls. This suggests that, compared to the control group, the IWA may have certain limitations in their language processing abilities during reading, indicating that while certain eye-tracking measures might not show differences, they still offer valuable insights into the underlying reading challenges faced by IWA. Furthermore, the lack of significant differences in saccadic measures, such as the initial saccade amplitude and the total saccadic amplitude, might be indicative of other underlying factors not directly related to aphasia. It is possible that other cognitive or linguistic processes, not captured by the current study, play a role in these observations or that processes involved in saccades may be more intact in IWA than previously thought. Future research should delve deeper into these aspects, considering the multifactorial nature of reading and comprehension, to provide a more comprehensive understanding of the challenges faced by IWA.

5.3 Research Question 3

Within this current study, I sought to examine the deviation in reading comprehension abilities for Chinese IWA relative to a control group. Participants' reading comprehension abilities were assessed using the CRRCAE and through comprehension questions associated with the eye-tracking task. Consistent with my hypothesis, I saw a substantial difference in reading comprehension scores. Unsurprisingly, the control group demonstrated markedly superior reading comprehension skills compared to IWA. This finding aligns with the presumption that aphasia, which affects the language processes necessary for successful reading comprehension. It is also noteworthy that the present study is among the first to focus on the Chinese-speaking population with aphasia, adding to the limited literature available on this demographic. The differences observed for reading comprehension during the eye-tracking task further elucidate the disparity in understanding of the reading abilities between groups. The controls' superior performance over IWA during this assessment is likely indicative of the IWA challenges in processing linguistic information in real-time during reading. There could be several reasons for the observed differences. Aphasia is known to affect various linguistic processes, which could impact reading comprehension directly. DeDe (2012) emphasized that IWA exhibit altered sentence comprehension, subject to the influence of word frequency and delivery paradigms. This could suggest that the materials used in reading comprehension tasks for IWA should be carefully selected, considering the frequency of words and how they are presented. Additionally, cognitive deficits frequently associated with aphasia, such as reduced working memory or attentional difficulties, could also play a vital role in the compromised reading abilities of IWA. To obtain a more thorough knowledge of the fundamental mechanisms that contribute to these disparities, more research is necessary.

5.4 Research Question 4

The main goal of research question 4 was to ascertain the connection between eye movement measurements and comprehension in Chinese IWA and the control group. The foundation of the hypothesis was anchored in prior studies suggesting a probable link between eye-tracking measures and reading comprehension in skilled readers (e.g., Copeland & Gedeon, 2013; Krieber et al., 2016). However, the findings of the current research provide a fresh perspective by challenging these pre-existing notions. Within the control group, there was no evidence to indicate a statistically significant relationship between the eye-tracking measures and reading comprehension. For IWA, none of the eye movement measures demonstrated a significant correlation with either reading comprehension measure. These findings depart from my initial hypothesis, which posited that increased number of fixations and longer total duration of fixation, among the other measures, would predict poorer reading comprehension in both groups. My findings are partially consistent with a previous study (McWilliams, 2022) that also found no association between first fixation duration and average of amplitude saccade and reading comprehension.

Contrary to expectation, my results suggest that, at least within the parameters of this study, eye movement measures may not be viable predictive markers for reading comprehension. There are several potential explanations for this. First, it is plausible that reading comprehension, especially in a logographic script like Chinese, is influenced by myriad factors beyond eye movements. Variables such as semantic processing, syntactic structures, prior knowledge, and the reader's experience with the text may play more dominant roles in determining comprehension. This complexity in the reading process, especially in Chinese, may dilute the effectiveness of eye movements on predicting comprehension. For instance, Krieber and colleagues (2016) discovered that there is a correlation between reading skills and eye movement patterns, regardless of the language being read. However, it should be noted that the nature of this correlation may differ depending on the level of orthographic coherence in the language. This suggests that while there might be a general relationship between reading skills and eye movements, the specifics of this relationship could differ based on the script or language in question. White and colleagues (2012) discovered that visual characteristics of Japanese words, another logographic script, significantly influence eye movement behavior during reading. This aligns with the idea that logographic scripts might poses distinct and specific difficulties or considerations when it relates to reading comprehension and eye-tracking. Li and Pollatsek (2020) developed a model that simulated the relationship between word processing and eye moving motion during reading in Chinese. Their model suggests that Chinese readers might process information differently, especially when it comes to segmenting words with ambiguous boundaries or utilizing parafoveal vision. Furthermore, Li and colleagues (2014) argued that reading in Chinese might be fundamentally akin to reading in linguistic contexts involving diverse writing systems, proposing that the nature of reading might remain consistent across languages. This raises the question of whether the absence of predictive capability of eye movements in the present study is due to other dominant factors influencing comprehension. In conclusion, while the present study suggests that the predictive value of eye movement measurements in relation to comprehension for reading in Chinese may not be robust, the broader literature indicates a complex interplay between eye movements, script type, and reading comprehension. Further research is necessary to tease apart these relationships and understand the nuances of the task of comprehending written text across different languages and scripts.

Additionally, aphasia is a multifaceted condition. The heterogeneity of its presentations means that while some individuals may exhibit disruptions in reading due to linguistic processing difficulties, others might primarily face challenges due to motoric or perceptual aspects of reading. Consequently, generalizing eye movement patterns for all IWA can be challenging. In the present study, the results indicate that eye movement measures may not serve as reliable predictive markers for reading comprehension in IWA. This finding is intriguing, especially when juxtaposed with other research in the field. For instance, Heuer and Hallowell (2015) validated an innovative eye-tracking technique proposed to evaluate how attention is distributed in individuals both with and without aphasia, suggesting that eye movements may indeed provide valuable insights into the processing cognition of these individuals. However, it is essential to note that their focus was on attention allocation rather than directly on reading comprehension. Furthermore, Webster and colleagues (2021) emphasized the individual variability in reading among IWA, emphasizing the significance of incorporating individual perspectives in conjunction with standardized reading comprehension evaluations. This aligns with the presented study's assertion about the multifaceted nature of aphasia and the challenges in generalizing eye movement patterns for all individuals with the condition. Another study by DeDe (2012) found that IWA might employ reading tactics that vary from controls, especially when faced with infrequency and complex sentence structures. This could potentially explain why eye movement measures may not consistently predict reading comprehension across all IWA.

Based on previous research, for native Chinese speakers in the general population, there is indeed a certain correlation between eye movement indicators and reading comprehension (Liu et al., 2021). However, our findings deviate from this consensus. Additionally, studies (Bonhage et al., 2015; McWilliams, 2022; Sharma et al., 2021; Smith et al., 2018) have delved into the potential relationship between eye-tracking measures (e.g., skipping rate, regression) and understanding of text reading in IWA whose native language is English, be it direct or indirect. The current research is an attempt to look into the relationship between indicators of eye-tracking and reading comprehension in Chinese speaking IWA. Although the results do not align with my expectations, future research is warranted to explore reasons for the inconsistent findings, and to examine eye movements under specific variables, such as passive sentences, contextual relevance, and linguistic characteristics such as word frequency.

5.5 Research Question 5

Research question 5 examined the associations between word reading abilities (regular word, irregular word, pseudo word) and reading comprehension in Chinese IWA and controls. The findings unearthed various implications for the understanding of reading processes in IWA and how these may differ from those of neurotypical individuals. A primary finding of this research is the significant association between reading comprehension and both regular and irregular word reading in the IWA group. These findings align with my hypothesis that the accuracy of single-word reading can serve as a predictive factor for reading comprehension in Chinese IWA. Specifically, IWA who showed higher proficiency in reading regular and irregular words were also those who demonstrated better reading comprehension abilities. Although the overall study is not solely focused on individual word reading, this study confirms a positive relationship between the two. However, some research findings are to the contrary. DeDe further stated that in IWA, frequency of use effects of words impacted performance on assessments of phrase comprehension (DeDe, 2012). This suggests that beyond the regularity or irregularity of words, the frequency of word occurrence can also play a pivotal role in reading comprehension for IWA. Furthermore, DeDe (2012) has discovered that when reading, IWA may be responsive to both complexity of structure and word frequency. This insight provides a broader context to the current study, suggesting that while single word reading abilities are crucial, other factors like sentence structure can also influence reading comprehension in aphasia. In conclusion, the current study's findings highlight the importance of single word reading abilities in predicting reading comprehension in Chinese IWA.

The findings from an additional regression analysis underscore the intricate relationship between regular and irregular word reading and reading comprehension in IWA. A notably high correlation between regular and irregular word reading was observed, leading to the creation of a composite variable that amalgamates both reading types. This approach was not only methodologically sound but also provided a more holistic view of reading abilities in IWA. The regression model, which took into account factors like education level and months post-stroke, revealed that this composite variable of regularity was a dominant factor, accounting for nearly 60% of the variance in reading comprehension. This is a significant finding, emphasizing the pivotal role that word reading, both regular and irregular, plays in overall comprehension for IWA. The model's statistical significance further reinforces the robustness of these findings. Interestingly, while initial correlations were based on Spearman's rho, the multiple regression results highlighted partial correlations after accounting for other potential influencers. Even when adding control factors like education level or months post stroke onset, word reading ability—both regular and irregular—still stands out as the most crucial factor in reading comprehension for this group. In conclusion, interventions aimed at improving reading comprehension in IWA might benefit from a focus on enhancing both regular and irregular word reading skills, given their significant contribution to overall comprehension. Future studies might delve deeper into understanding the nuances of these reading types and devising targeted strategies for improvement.

The specific prominence of irregular and regular word reading suggests that the ability to correctly read aloud words that are not consistent to typical phonological or morphological patterns is crucial for understanding complex texts in IWA. Individuals with aphasia may experience more challenges in the cognitive-linguistic processing of both the semantic and phonemic aspects of irregular words. Madden and colleagues' (2018) study indicated that semantic reading exhibits the highest level of predictability for irregular words, but phoneme reading demonstrates the highest level of predictability for pseudo-homophones and non-words. This result suggests that IWA may need to depend on semantic and phonemic cues to comprehend irregular words, thus impacting their reading comprehension abilities. In other words, there may be a positive correlation between the capacity to easily read irregular words and the level of reading comprehension ability. Conversely, a negative correlation might be observed as well. This observation aligns with the outcomes of our research. Linking to the connectionist model of single word reading in Parallel Distributed Processing (PDP) (Plaut, 1996), the connections between phonology, semantics, and orthography form parallel triangular connections. This is evident when reading irregular words, as semantic patterns are activated, while nonword reading relies more on phonological pattern. Smith and Ryan (2020) have discovered a link between word reading accuracy in IWA and achievement on comprehension tasks, meaning that competence on read comprehension assessments is predictive of comprehension abilities. Irregular words, because they do not conform to conventional phonological or morphological patterns, may require more cognitive resources for IWA to process, thus affecting their reading comprehension.

Harciarek and Kertesz (2009) revealed that deficits specific to individual word comprehension are prevalent among patients with different forms of progressive aphasia and the intensity of these shortcomings correlates with the aphasia's severity (Harciarek & Kertesz, 2009). Category-specific deficits refer to challenges in understanding within a particular domain, such as patients possibly having more difficulty comprehending nouns than verbs. A study case found that a patient with semantic dementia (SD) struggled more with processing low-frequency and irregular words than they do with high-frequency regular words (Cipolotti & Warrington, 1995). That is to say frequency effect can facilitate comprehension but not word reading with SD. However, this study is inconsistent with my study's emphasis on the importance of single word reading in influencing overall reading comprehension. It might be due to the differences in the participants studied. Language processing issues like semantic challenges and naming difficulties are present in both post-stroke aphasia and degenerative dementia, but semantics and phonological processing might differ.

In summary, the strong association between irregular words and reading comprehension in IWA may stem from the semantic and non-orthographic language processing difficulties they face in processing irregular words, as well as the impact these difficulties have on their ability to read and comprehend connected texts. Through multiple regression analysis, it can be seen that irregular word reading is of special importance with the reading comprehension of IWA, which may provide important implications for future reading intervention for IWA.

However, it is noteworthy that the pseudoword reading did not show a significant association with reading comprehension in the IWA group. This suggests that, for this population, the ability to decode unfamiliar or non-existent words (pseudoword) may not be a reliable indicator of overall reading comprehension. One possible interpretation could be the distinct nature of Chinese pseudowords and their role in reading comprehension. Unlike alphabetic languages, where pseudowords can provide insights into phonological decoding skills, Chinese pseudowords might not serve the same purpose due to the logographic nature of the language. Comparatively, other studies have also explored the relationship between individual word reading abilities and reading comprehension in IWA. Two such studies, albeit not specifically within the Chinese context, observed the relationship between individual word reading, reading related text, and comprehension in IWA (Law et al., 2009; Smith & Ryan, 2020). These studies could potentially align with the provided study's findings regarding the importance of single word reading abilities in reading comprehension among IWA. Another research study (Law et al., 2009) focused on two individuals with acquired dyslexia which may share some characteristics with aphasia reading aloud pseudo-characters in Chinese, hinted at lexically mediated processes in reading Chinese, which could be a different mechanism compared to alphabetic languages. The results indicate that the pseudoword reading in these two cases of acquired dyslexia is affected by semantic impairment to varying degrees. Moreover, a neuroimaging study (Brambati et al., 2009) noted that in primary progressive aphasia, pseudoword reading accuracy correlated with certain brain regions, hinting at a neurological basis for this reading ability, which may or may not translate to reading comprehension. These diverse findings demonstrate that the connection between pseudoword production and reading comprehension in IWA, particularly in a logographic language like Chinese, may be complex and potentially divergent from patterns observed in alphabetic languages. The lack of association found in the present study between pseudoword reading and reading comprehension in IWA could be aligned with the distinct nature of Chinese pseudowords and the logographic characteristics of the language. These comparisons suggest that the role and impact of pseudoword reading on reading comprehension may vary significantly across different languages and populations, and further cross-linguistic research could provide more insights into these relationships. Contrary to the concluding statement in the results, it is imperative to note that while regular and irregular word readings were indicated to have significant positive associations with reading comprehension in IWA, pseudoword reading did not. Hence, it would be more accurate to say that while regular and irregular word reading abilities play a crucial position in predicting understanding of reading among IWA, the significance of pseudoword reading ability remains ambiguous.

A multiple regression analysis for the control group revealed the significant relationship between regular and irregular word reading and their collective influence on reading comprehension. Even when accounting for control factors like education level, word reading ability—both regular and irregular—emerges as the predominant factor in reading comprehension among the controls. The formation of a composite variable, given the significant correlation between these two types of word reading, offers a holistic view of their combined effects. This composite variable, in the regression model, accounted for a substantial 58.5% of the variance in reading comprehension. This finding is not only statistically significant but also underscores the central role of word reading abilities in determining reading comprehension. Interestingly, while the Spearman's rho correlation did not indicate a significant relationship in the control group, the multiple regression results highlighted a significant association between the composite single word reading and reading comprehension scores. This suggests that the combined effects of regular and irregular word reading are pivotal in influencing reading comprehension, even if individual correlations might not always be evident. Furthermore, the ability to read both regular and irregular words stands out as the primary determinant of reading comprehension in the control group, even when other factors, like education level, are considered. This insight emphasizes the importance of both types of word reading in reading comprehension assessments and strategies. Future studies might delve deeper into these relationships and their broader implications.

The analyses between the IWA and control groups, while primarily focused on word reading abilities and their influence on reading comprehension, might hint at deeper, underlying implications. The consistent prominence of word reading ability across both groups suggests that foundational reading skills are universally crucial, regardless of cognitive or linguistic challenges. In the group of IWA, reading comprehension may be impacted by lexical and syntactic difficulties, which could affect their processing abilities at the level of individual words, phrases, and sentences, thereby influencing knowledge of reading (Webster et al., 2023). However, the nuanced differences in correlations might indicate that the process of reading comprehension is multifaceted and influenced by a myriad of factors, both intrinsic and extrinsic. Additionally, the divergence in results based on different statistical methods hints at the complex interplay of variables and the potential for varied interpretations.

In conclusion, our results shed significant light on the intricate bond extending from the ability to read individual words to understanding texts in Chinese IWA and controls. While further research is warranted to delve deeper into these findings, the present study underscores the significance of understanding individual word reading skills when assessing and potentially intervening in reading comprehension challenges in different populations.

5.6 Limitations and Future Directions

Nevertheless, there are numerous limitations to the current study. The sample size could be a potential limitation. In light of the conducted post hoc power analyses, it becomes evident that the sample size in this study might not be sufficiently robust for many of the group comparisons, potentially affecting the reliability of the findings. While the power of .80 is typically considered a benchmark for adequate sample size, our study only met this threshold for the 'time to first fixation' under research question 2. Consequently, the results for research questions 1, 2 (excluding time to first fixation), and 3 should be interpreted with caution. Future studies in this domain should consider larger sample sizes or alternative methodologies to ensure more definitive conclusions. Relatedly, there was limited variability in the reading abilities of the control participants which may have contributed to the weaker correlations in the results. Methodologically, there are some limitations. The experimental design of eye movement tracking measured the entire sentence without delineating word boundaries to observe more areas of interest regarding different frequency effects and predictability effects. Word boundaries are also important for calculating more refined eye tracking measures such as word skipping and regressions. Moreover, the eye movement stimuli did not provide indications of whether the words were of high or low frequency. Additionally, while a broad range of measures was considered, there might be other subtle eye movement characteristics or patterns specific to the reading process in Chinese that were not captured in this research. Also, as the sentence stimuli remained on the eye tracking screen while the participants were answering the comprehension questions, the reported eye tracking data included both reading eye movements and any eye movements during the comprehension question portion of the protocol. Lastly, the single characters used in the experiment were converted from traditional characters. Although these converted characters are recognizable to the mainland population, there was no assessment on the daily usage frequency of these characters among the simplified character-using mainland population, which might affect the universality of the experimental results. These limitations suggest that future research should consider more refined experimental design and larger sample sizes, as well as evaluate the impact of different dialects and script systems on reading comprehension. Additionally, the diversity within the aphasia group with regard to the severity of aphasia was not detailed, which could have implications for the generalizability of the results. Moreover, the thresholds for statistical significance could potentially be re-evaluated in larger samples or using other methodological approaches.

Given the limitations mentioned in this study, there is fertile ground for future research to evolve in a more detailed and comprehensive manner, aiming for more precise and widely applicable conclusions. Enhancements in experimental design are pivotal, which include delineation of word boundaries in eye movement tracking experiments to enable a meticulous observation of different interest areas during varying frequency and predictability effects. This can foster a better understanding of reading processes at the lexical level. Moreover, assessing and controlling the frequency effects of the stimuli could unravel its impact on reading comprehension and eye movement patterns. Technological and equipment advancements are essential to capture finer indicators of sentence reading comprehension like regressive eye movements and skip counts as well as setting the experiment to stop eye movement analysis during question portions of the protocol; therefore, enabling a deeper insight into eye movement patterns and cognitive processes during reading. It is imperative to increase the sample size and diversify the sample to include different dialects and script users, thereby evaluating the impact of these variables on reading comprehension and enhancing the generalizability of the findings. Since the characters used in this study were converted from traditional script, future research should assess the daily usage frequency of these characters among simplified writing users in mainland China and explore the impact of different scripts on reading comprehension. A comparative analysis of different reading routes like the DRC model and connectionist model could elucidate which model aptly describes and explains Chinese reading process, especially under varying dialect and script conditions. Moreover, embarking on clinical evaluations and interventions for reading comprehension difficulties, based on the findings of future research, could foster clinical applications in this domain. Through these multifaceted research directions, future investigations can delve deeper into understanding the eye movement patterns and cognitive mechanisms in Chinese reading processes, and how different factors like frequency effects, predictability effects, dialects, and scripts affect reading comprehension. This comprehensive approach will subsequently provide more effective theoretical and empirical bases for enhancing reading education and clinical interventions.

5.7 Conclusions

In conclusion, this study underscores the intricate nature of reading comprehension, emphasizing that it is likely an interplay of various factors, with eye movement measures being just one piece of the puzzle. These findings can be instrumental in shaping future research, urging scholars to adopt a multifaceted approach to understand reading in both clinical and neurotypical populations. Further studies are indeed warranted, not only to reaffirm these findings but also to discover other potential markers or predictors of reading comprehension abilities in Chinese IWA.

REFERENCES

Ablinger, I., Huber, W., & Radach, R. (2014). Eye movement analyses indicate the underlying reading strategy in the recovery of lexical readers. *Aphasiology*, *28*(6), 640-657. https://doi.org/10.1080/02687038.2014.894960

Akhavan, N., Sen, C., Baker, C., Abbott, N., Gravier, M., & Love, T. (2022). Effect of Lexical-Semantic Cues during Real-Time Sentence Processing in Aphasia. *Brain Sci*, *12*(3). https://doi.org/10.3390/brainsci12030312

Alyahya, R. S., Halai, A. D., Conroy, P., & Ralph, M. A. L. (2018). The behavioural patterns and neural correlates of concrete and abstract verb processing in aphasia: A novel verb semantic battery. *NeuroImage: Clinical*, *17*, 811-825.

Bai, X., Yan, G., Liversedge, S. P., Zang, C., & Rayner, K. (2008). Reading spaced and unspaced Chinese text: evidence from eye movements. *J Exp Psychol Hum Percept Perform*, *34*(5), 1277-1287. https://doi.org/10.1037/0096-1523.34.5.1277

Baker, C. I., Liu, J., Wald, L. L., Kwong, K. K., Benner, T., & Kanwisher, N. (2007). Visual word processing and experiential origins of functional selectivity in human extrastriate cortex. *Proc Natl Acad Sci U S A*, *104*(21), 9087-9092. https://doi.org/10.1073/pnas.0703300104

Berndt, R. S., Mitchum, C. C., Haendiges, A. N., & Sandson, J. (1997). Verb retrieval in aphasia. 1. Characterizing single word impairments. *Brain and language, 56*(1), 68-106.

Bi, Y., Han, Z., Weekes, B., & Shu, H. (2007). The interaction between semantic and the nonsemantic systems in reading: Evidence from Chinese. *Neuropsychologia, 45*(12), 2660-2673.

Bonhage, C. E., Mueller, J. L., Friederici, A. D., & Fiebach, C. J. (2015). Combined eye tracking and fMRI reveals neural basis of linguistic predictions during sentence comprehension. *Cortex, 68*, 33-47. https://doi.org/10.1016/j.cortex.2015.04.011

Borghesani, V., Hinkley, L. B., Ranasinghe, K. G., Thompson, M. M., Shwe, W., Mizuiri, D., Lauricella, M., Europa, E., Honma, S., & Miller, Z. (2020). Taking the sublexical route: brain dynamics of reading in the semantic variant of primary progressive aphasia. *Brain*, *143*(8), 2545-2560.

Brambati, S., Ogar, J., Neuhaus, J., Miller, B., & Gorno-Tempini, M. L. (2009). Reading disorders in primary progressive aphasia: a behavioral and neuroimaging study. *Neuropsychologia*, *47*(8-9), 1893-1900.

Brookshire, C. E., Wilson, J. P., Nadeau, S. E., Gonzalez Rothi, L. J., & Kendall, D. L. (2014). Frequency, nature, and predictors of alexia in a convenience sample of individuals with chronic aphasia. *Aphasiology*, *28*(12), 1464-1480. https://doi.org/10.1080/02687038.2014.945389

Bulut, T., Hung, Y. H., Tzeng, O., & Wu, D. H. (2017). Neural correlates of processing sentences and compound words in Chinese. *PLoS One*, *12*(12), e0188526. https://doi.org/10.1371/journal.pone.0188526

Calabrese, A., Bernard, J.-B., Faure, G., Hoffart, L., & Castet, E. (2016). Clustering of eye fixations: A new oculomotor determinant of reading speed in maculopathy. *Investigative ophthalmology & visual science*, *57*(7), 3192-3202.

Chen, Q., Huang, X., Bai, L., Xu, X., Yang, Y., & Tanenhaus, M. K. (2017). The effect of contextual diversity on eye movements in Chinese sentence reading. *Psychon Bull Rev*, *24*(2), 510-518. https://doi.org/10.3758/s13423-016-1119-1

Chen, X., Ren, H., & Yan, X. (2022). Metonymy Processing in Chinese: A Linguistic Context-Sensitive Eye-Tracking Preliminary Study. *Front Psychol*, *13*, 916854. https://doi.org/10.3389/fpsyg.2022.916854

Cipolotti, L., & Warrington, E. K. (1995). Semantic memory and reading abilities: A case report. *Journal of the International Neuropsychological Society*, *1*(1), 104-110.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: a dual route cascaded model of visual word recognition and reading aloud. *Psychological review*, *108*(1), 204.

Copeland, L., & Gedeon, T. (2013). Measuring reading comprehension using eye movements. 2013 IEEE 4th International Conference on Cognitive Infocommunications (CogInfoCom),

Dang, M., Zhang, R., Wang, X., & Yang, J. (2019). The interaction between phonological and semantic processing in reading Chinese characters. *Frontiers in Psychology*, *9*, 2748.

Darley, F. L., Aronson, A. E., & Brown, J. R. (1975). *Motor speech disorders*. WB Saunders Company.

DeDe, G. (2012). Effects of word frequency and modality on sentence comprehension impairments in people with aphasia.

DeDe, G. (2020). Perceptual span in individuals with aphasia. *Aphasiology*, *34*(2), 235-253.

DeDe, G., & Kelleher, D. (2021). Effects of animacy and sentence type on silent reading comprehension in aphasia: An eye-tracking study. *J Neurolinguistics*, *57*. https://doi.org/10.1016/j.jneuroling.2020.100950

Dehaene, S., Cohen, L., Morais, J., & Kolinsky, R. (2015). Illiterate to literate: behavioural and cerebral changes induced by reading acquisition. *Nat Rev Neurosci*, *16*(4), 234-244. https://doi.org/10.1038/nrn3924

Eekhof, L. S., van Krieken, K., Sanders, J., & Willems, R. M. (2021). Reading Minds, Reading Stories: Social-Cognitive Abilities Affect the Linguistic Processing of Narrative Viewpoint. *Front Psychol*, *12*, 698986. https://doi.org/10.3389/fpsyg.2021.698986

Feng, X., Altarelli, I., Monzalvo, K., Ding, G., Ramus, F., Shu, H., Dehaene, S., Meng, X., & Dehaene-Lambertz, G. (2020). A universal reading network and its modulation by writing system and reading ability in French and Chinese children. *Elife*, *9*. https://doi.org/10.7554/eLife.54591

Fiorina, G. (2017). Designing Typographic Images.

Friedman, R. B. (1996). Phonological text alexia: Poor pseudoword reading plus difficulty reading functors and affixes in text. *Cognitive Neuropsychology*, *13*(6), 869-885.

Fuchs, L. S., Fuchs, D., Hosp, M. K., & Jenkins, J. R. (2001). Oral reading fluency as an indicator of reading competence: A theoretical, empirical, and historical analysis. *Scientific studies of reading*, *5*(3), 239-256.

Guo, W., Geng, S., Cao, M., & Feng, J. (2022). The Brain Connectome for Chinese Reading. *Neurosci Bull*, *38*(9), 1097-1113. https://doi.org/10.1007/s12264-022-00864-3

Han, Z., & Bi, Y. (2009). Reading comprehension without phonological mediation: Further evidence from a Chinese aphasic individual. *Science in China Series C: Life Sciences*, *52*(5), 492-499.

Harciarek, M., & Kertesz, A. (2009). Longitudinal study of single-word comprehension in semantic dementia: A comparison with primary progressive aphasia and Alzheimer's disease. *Aphasiology*, *23*(5), 606-626.

Henderson, J. M., Choi, W., Luke, S. G., & Schmidt, J. (2018). Neural correlates of individual differences in fixation duration during natural reading. *Quarterly Journal of Experimental Psychology*, *71*(1), 314-323.

Heuer, S., & Hallowell, B. (2015). A novel eye-tracking method to assess attention allocation in individuals with and without aphasia using a dual-task paradigm. *Journal of communication disorders*, *55*, 15-30.

Huck, A., Thompson, R. L., Cruice, M., & Marshall, J. (2017). Effects of word frequency and contextual predictability on sentence reading in aphasia: an eye movement analysis. *Aphasiology*, *31*(11), 1307-1332. https://doi.org/10.1080/02687038.2017.1278741

Hutzler, F., Ziegler, J. C., Perry, C., Wimmer, H., & Zorzi, M. (2004). Do current connectionist learning models account for reading development in different languages? *Cognition*, *91*(3), 273-296.

Knilans, J., & DeDe, G. (2015). Online Sentence Reading in People With Aphasia: Evidence From Eye Tracking. *Am J Speech Lang Pathol*, *24*(4), S961-973. https://doi.org/10.1044/2015_ajslp-14-0140

Knollman-Porter, K., Hux, K., Wallace, S. E., Pruitt, M., Hughes, M. R., & Brown, J. A. (2022). Comprehension, Processing Time, and Modality Preferences When People With Aphasia and Neurotypical Healthy Adults Read Books: A Pilot Study. *American journal of speech-language pathology*, *31*(6), 2569-2590.

Krieber, M., Bartl-Pokorny, K. D., Pokorny, F. B., Einspieler, C., Langmann, A., Körner, C., Falck-Ytter, T., & Marschik, P. B. (2016). The relation between reading skills and eye movement patterns in adolescent readers: evidence from a regular orthography. *PLoS One*, *11*(1), e0145934.

Lau, D. K. Y., Kong, A. P. H., & Wilson, M. (2014). Regular-, irregular-, and pseudo-character processing in Chinese: The regularity effect in normal adult readers. *Frontiers in Psychology*, *5*.

Law, S.-P., Weekes, B. S., Wong, W., & Chiu, K. (2009). Reading aloud pseudo-characters by individuals with acquired dyslexia: Evidence for lexically mediated processes in reading Chinese. *Language and cognitive processes*, *24*(7-8), 983-1008.

Law, S. P., Wong, W., & Chiu, K. M. (2005). Whole-word phonological representations of disyllabic words in the Chinese lexicon: data from acquired dyslexia. *Behav Neurol*, *16*(2-3), 169-177. https://doi.org/10.1155/2005/597581

Li, X., Bicknell, K., Liu, P., Wei, W., & Rayner, K. (2014). Reading is fundamentally similar across disparate writing systems: a systematic characterization of how words and characters influence eye movements in Chinese reading. *Journal of Experimental Psychology: General*, *143*(2), 895.

Li, X., Liu, P., & Rayner, K. (2011). Eye movement guidance in Chinese reading: is there a preferred viewing location? *Vision Res*, *51*(10), 1146-1156. https://doi.org/10.1016/j.visres.2011.03.004

Li, X., & Pollatsek, A. (2020). An integrated model of word processing and eye-movement control during Chinese reading. *Psychological Review*, *127*(6), 1139.

Li, X., Rayner, K., & Cave, K. R. (2009). On the segmentation of Chinese words during reading. *Cogn Psychol*, *58*(4), 525-552. https://doi.org/10.1016/j.cogpsych.2009.02.003

Liu, N., Wang, X., Yan, G., Paterson, K. B., & Pagán, A. (2021). Eye movements of developing Chinese readers: Effects of word frequency and predictability. *Scientific studies of reading*, *25*(3), 234-250.

Liu, Y., Yu, L., & Reichle, E. D. (2019). The dynamic adjustment of saccades during Chinese reading: Evidence from eye movements and simulations. *J Exp Psychol Learn Mem Cogn*, *45*(3), 535-543. https://doi.org/10.1037/xlm0000595

Ma, G., Li, Z., Xu, F., & Li, X. (2019). The modulation of eye movement control by word length in reading Chinese. *Q J Exp Psychol (Hove)*, *72*(7), 1620-1631. https://doi.org/10.1177/1747021818799994

Madden, E. B., Conway, T., Henry, M. L., Spencer, K. A., Yorkston, K. M., & Kendall, D. L. (2018). The relationship between non-orthographic language abilities and reading performance in chronic aphasia: An exploration of the primary systems hypothesis. *Journal of speech, language, and hearing research*, *61*(12), 3038-3054.

Mahmoud, S. S., Pallaud, R. F., Kumar, A., Faisal, S., Wang, Y., & Fang, Q. (2023). A Comparative Investigation of Automatic Speech Recognition Platforms for Aphasia Assessment Batteries. *Sensors*, *23*(2), 857.

Marshall, J. C., & Newcombe, F. (1973). Patterns of paralexia: a psycholinguistic approach. *J Psycholinguist Res*, *2*(3), 175-199. https://doi.org/10.1007/BF01067101

McWilliams, S. C. (2022). *Relationship Between Eye Movements During Reading and Severity of Language Impairment in Persons with Aphasia* (Thesis, University of South Alabama).

Niehorster, D. C., Andersson, R., & Nystrom, M. (2020). Titta: A toolbox for creating PsychToolbox and Psychopy experiments with Tobii eye trackers. *Behav Res Methods*, *52*(5), 1970-1979. https://doi.org/10.3758/s13428-020-01358-8

Nilsson Benfatto, M., Oqvist Seimyr, G., Ygge, J., Pansell, T., Rydberg, A., & Jacobson, C. (2016). Screening for Dyslexia Using Eye Tracking during Reading. *PLoS One*, *11*(12), e0165508. https://doi.org/10.1371/journal.pone.0165508

Oralova, G., & Kuperman, V. (2021). Effects of Spacing on Sentence Reading in Chinese. *Front Psychol*, *12*, 765335. https://doi.org/10.3389/fpsyg.2021.765335

Parola, A., & Bosco, F. M. (2022). An eye-tracking investigation of the cognitive processes involved in the comprehension of simple and complex communicative acts. *Q J Exp Psychol (Hove)*, *75*(10), 1976-1995. https://doi.org/10.1177/17470218221079629

Patterson, K., Plaut, D. C., Mcclelland, J. L., Seidenberg, M. S., Behrmann, M., & Hodges, J. R. (1996). Connections and disconnections: A connectionist account of surface dyslexia. In *Neural modeling of brain and cognitive disorders* (pp. 177-199). World Scientific.

Peng, P., Wang, C., Tao, S., & Sun, C. (2017). The deficit profiles of Chinese children with reading difficulties: A meta-analysis. *Educational Psychology Review*, *29*, 513-564.

Plaut, D. C. (1996). Relearning after damage in connectionist networks: Toward a theory of rehabilitation. *Brain and language, 52*(1), 25-82.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychol Bull, 124*(3), 372-422. https://doi.org/10.1037/0033-2909.124.3.372

Rayner, K. (2009). Eye movements in reading: Models and data. *Journal of eye movement research, 2*(5), 1. https://doi.org/10.1017/s0140525x03520106

Rayner, K., Li, X., Juhasz, B. J., & Yan, G. (2005). The effect of word predictability on the eye movements of Chinese readers. *Psychonomic Bulletin & Review*, *12*, 1089-1093. https://doi.org/10.3758/bf03206448

Rayner, K., Li, X., & Pollatsek, A. (2007). Extending the e-z reader model of eye movement control to chinese readers. *Cogn Sci, 31*(6), 1021-1033. https://doi.org/10.1080/03640210701703824

Rayner, K., & McConkie, G. W. (1976). What guides a reader's eye movements? *Vision Research*, *16*(8), 829-837. https://doi.org/https://doi.org/10.1016/0042-6989(76)90143-7

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review*, *96*(4), 523.

Sharma, S., Kim, H., Harris, H., Haberstroh, A., Wright, H. H., & Rothermich, K. (2021). Eye Tracking Measures for Studying Language Comprehension Deficits in Aphasia: A Systematic Search and Scoping Review. *J Speech Lang Hear Res*, *64*(3), 1008-1022. https://doi.org/10.1044/2020_JSLHR-20-00287

Shu, H., McBride-Chang, C., Wu, S., & Liu, H. (2006). Understanding Chinese developmental dyslexia: morphological awareness as a core cognitive construct. *Journal of educational psychology*, *98*(1), 122.

Siok, W. T., Jia, F., Liu, C. Y., Perfetti, C. A., & Tan, L. H. (2020). A lifespan fMRI study of neurodevelopment associated with reading Chinese. *Cerebral Cortex*, *30*(7), 4140-4157.

Smith, K. G., & Ryan, A. E. (2020). Relationship Between Single Word Reading, Connected Text Reading, and Reading Comprehension in Persons With Aphasia. *Am J Speech Lang Pathol*, *29*(4), 2039-2048. https://doi.org/10.1044/2020_AJSLP-19-00135

Smith, K. G., Schmidt, J., Wang, B., Henderson, J. M., & Fridriksson, J. (2018). Task-Related Differences in Eye Movements in Individuals With Aphasia. *Front Psychol*, *9*, 2430. https://doi.org/10.3389/fpsyg.2018.02430

Stevens, W. D., Kravitz, D. J., Peng, C. S., Tessler, M. H., & Martin, A. (2017). Privileged Functional Connectivity between the Visual Word Form Area and the Language System. *J Neurosci*, *37*(21), 5288-5297. https://doi.org/10.1523/jneurosci.0138-17.2017

van Scherpenberg, C., Abdel Rahman, R., Regenbrecht, F., & Obrig, H. (2021). Semantic Interference through Multiple Distractors in Picture Naming in People with Aphasia. *J Cogn Neurosci*, *33*(8), 1612-1633. https://doi.org/10.1162/jocn_a_01731

Wang, S., Zhu, Z., Zhang, J. X., Wang, Z., Xiao, Z., Xiang, H., & Chen, H.-C. (2008). Broca's area plays a role in syntactic processing during Chinese reading comprehension. *Neuropsychologia*, *46*(5), 1371-1378.

Wang, X., Zhao, R., Zevin, J. D., & Yang, J. (2016). The neural correlates of the interaction between semantic and phonological processing for Chinese character reading. *Frontiers in Psychology*, 947.

Webster, J., Morris, J., Connor, C., Horner, R., McCormac, C., & Potts, A. (2013). Text level reading comprehension in aphasia: What do we know about therapy and what do we need to know? *Aphasiology*, *27*(11), 1362-1380.

Webster, J., Morris, J., & Howard, D. (2023). Reading comprehension in aphasia: the relationship between linguistic performance, personal perspective, and preferences. *Aphasiology*, *37*(5), 785-801.

Webster, J., Morris, J., Howard, D., & Garraffa, M. (2018). Reading for meaning: What influences paragraph understanding in aphasia? *American journal of speech-language pathology*, *27*(1S), 423-437.

Webster, J., Morris, J., Malone, J., & Howard, D. (2021). Reading comprehension difficulties in people with aphasia: Investigating personal perception of reading ability, practice, and difficulties. *Aphasiology*, *35*(6), 805-823.

Weekes, B., & Chen, H. Q. (1999). Surface dyslexia in Chinese. *Neurocase*, *5*(2), 161-172.

Wendt, D., Brand, T., & Kollmeier, B. (2014). An eye-tracking paradigm for analyzing the processing time of sentences with different linguistic complexities. *PLoS One*, *9*(6), e100186. https://doi.org/10.1371/journal.pone.0100186

White, S. J., Hirotani, M., & Liversedge, S. P. (2012). Eye movement behaviour during reading of Japanese sentences: Effects of word length and visual complexity. *Reading and Writing*, *25*, 981-1006.

Wu, J. (2022). Neurocognition in the reading of Chinese characters. *Journal of Chinese Writing Systems*, *6*(3), 167-183.

Wu, J.-B., Lyu, Z.-H., Liu, X.-J., Li, H.-P., & Wang, Q. (2017). Development and standardization of a new cognitive assessment test battery for Chinese aphasic patients: a preliminary study. *Chinese Medical Journal*, *130*(19), 2283-2290.

Xia, X., Liu, Y., Yu, L., & Reichle, E. D. (2022). Are there preferred viewing locations in Chinese reading? Evidence from eye-tracking and computer simulations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, No Pagination Specified-No Pagination Specified. https://doi.org/10.1037/xlm0001142

Yan, G., Tian, H., Bai, X., & Rayner, K. (2006). The effect of word and character frequency on the eye movements of Chinese readers. *Br J Psychol*, *97*(Pt 2), 259-268. https://doi.org/10.1348/000712605x70066

Yang, J., Wang, X., Shu, H., & Zevin, J. D. (2011). Brain networks associated with sublexical properties of Chinese characters. *Brain Lang*, *119*(2), 68-79. https://doi.org/10.1016/j.bandl.2011.03.004

Yin, W., & Butterworth, B. (1992). Deep and Surface Dyslexia in Chinese. In *Language Processing in Chinese* (pp. 349-366). https://doi.org/10.1016/s0166-4115(08)61897-x

Yin, W., He, S., & Weekes, B. S. (2005). Acquired dyslexia and dysgraphia in Chinese. *Behav Neurol*, *16*(2-3), 159-167. https://doi.org/10.1155/2005/323205

Yin, W. G., & Weekes, B. S. (2003). Dyslexia in Chinese-Clues from cognitive neuropsychology. *Annals of Dyslexia*, *53*(1), 255-279. https://doi.org/https://doi.org/10.1007/s11881-003-0012-6

Yu, L., Liu, Y., & Reichle, E. D. (2021). A corpus-based versus experimental examination of word- and character-frequency effects in Chinese reading: Theoretical implications for models of reading. *Journal of Experimental Psychology: General*, *150*, 1612-1641. https://doi.org/10.1037/xge0001014

Zhang, G., Yao, P., Ma, G., Wang, J., Zhou, J., Huang, L., Xu, P., Chen, L., Chen, S., Gu, J., Wei, W., Cheng, X., Hua, H., Liu, P., Lou, Y., Shen, W., Bao, Y., Liu, J., Lin, N., & Li, X. (2022). The database of eye-movement measures on words in Chinese reading. *Sci Data*, *9*(1), 411. https://doi.org/10.1038/s41597-022-01464-6

Zhang, J., Warrington, K. L., Li, L., Pagan, A., Paterson, K. B., White, S. J., & McGowan, V. A. (2022). Are older adults more risky readers? Evidence from meta-analysis. *Psychol Aging*, *37*(2), 239-259. https://doi.org/10.1037/pag0000522

Zhao, S., Li, L., Chang, M., Xu, Q., Zhang, K., Wang, J., & Paterson, K. B. (2019). Older adults make greater use of word predictability in Chinese reading. *Psychol Aging*, *34*(6), 780-790. https://doi.org/10.1037/pag0000382

Zou, L., Xia, Z., Zhang, W., Zhang, X., & Shu, H. (2022). Brain responses during auditory word recognition vary with reading ability in Chinese school-age children. *Developmental Science*, *25*(3), e13216.

APPENDICES

Appendix A. Single Word Read Aloud – Regular, Irregular, Pseudo

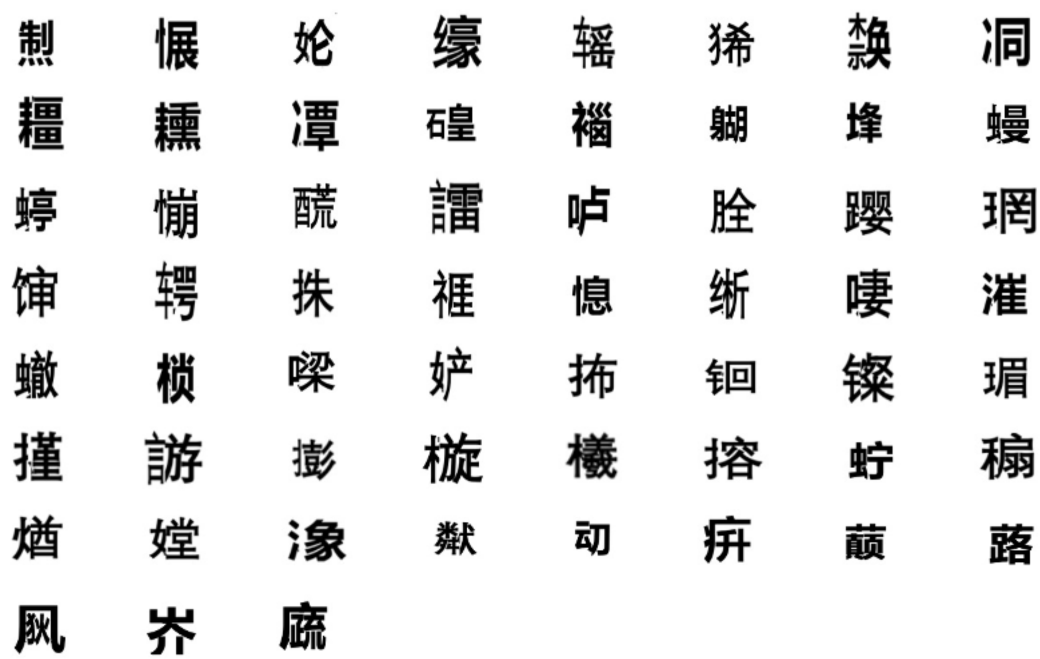
Regular

铲	礴	脓	凰	茱	仕	溶	璇
媳	耘	摧	蹦	凄	凄	揶	璐
稀	媚	嘭	濠	谎	焕	辗	擂
躬	浦	蜥	癫	煽	酮	惘	芥
蝴	骥	橡	遨	烬	缨	膛	遑
诠	颀	柠	锤	柄	醇	遁	蚁
曦	潭	栖	蔓	嵌	褥		

Irregular

弼	忒	栩	屉	岩	赦	讹	晾
楔	冀	穗	菅	霎	嗜	驯	狐
疼	侈	荡	亩	屙	窟	煎	懈
剃	诟	摺	皱	坎	涕	绽	砍
砾	闽	唉	蹲	挨	仑	升	徊

Pseudo



Appendix B. Research Questionnaires

An Analysis of Oral Reading in Individuals with Aphasia

Research Questionnaire for Participants with Aphasia

Participant Number: __________ Date of Birth: ______/ ______/ _________

Gender: M F Race: __________ Ethnicity: _______________

Highest level of education: _________________________________

Occupation: ____

Home Phone Number: (_________) __________-_____________

Alternate/Cell Phone Number: (__________) _________-____________

Is English your first language? Yes No

How many strokes have you had? _______

Date(s) of stroke(s)

1st: ______/ ______/______ 2nd: ______/______/_______

3rd: ______/______/______

Type of stroke: Ischemic Hemorrhagic Unknown

Dominant hand *before* your stroke: Left Right

Dominant hand *after* your stroke: Left Right

Are you currently receiving speech therapy? Yes No

If yes, how many hours per week: _____________

Did you have a history of reading disabilities *before* your stroke? Yes No

If yes, please describe:

____

____

Did you have a history of speech, language, or cognitive difficulties *before* your stroke? Yes No

If yes, please describe:

____

____

____

Have you ever had brain surgery or brain injury besides your stroke?

Yes No

If yes, please describe:

____

____

Have you ever experienced a seizure? Yes No

If yes, what was the date of your most recent seizure:

_______/_______/__________

Do you have a history of chronic pain? Yes No

How many headaches do you have per month: _________

Do you have allergies? Yes No

If yes, please explain:

____

____

Do you have a history of depression?   Yes   No

Have you been diagnosed with any neurological disorder (for example- MS, ALS, Parkinson's)?   Yes   No

If yes, please list:

____

Have you been diagnosed with diabetes?   Yes   No

If yes, how is your diabetes managed: Medications   Insulin

Other:

____

List any other medical information you would like us to be aware of:

____

____

____

Please list all current medications:

____

____

____

____

Visual History

Did you have a history of vision problems *before* your stroke? Yes No

If yes, please explain:

____

____

____

Has your vision changed since your stroke? Yes No

If yes, please explain:

____

____

Have you had a vision evaluation since your stroke? Yes No

Is your vision normal or corrected to normal with glasses or contact lenses?

Yes No

Were any additional tests or treatments recommended or completed pertaining to your vision?

Yes No

If yes, please explain:

____

____

____

Do you wear glasses or contact lenses? Yes No

If yes, why do you wear glasses/contact lenses (reading, distance)?

____

____

If yes, how often do you wear glasses/contact lenses?

____

____

Please list any other concerns or changes you have noticed in your vision or reading since your stroke.

____

____

____

____

____

Appendix C. Eye Tracking Stimuli and Following Comprehension Questions and Answers

句子 1: 悦容和学诚喜欢吃剁椒鱼头，昨天聚餐悦容点了这道菜。

问题 1：悦容和学诚喜欢吃什么？

A. 剁椒鱼头

B. 清蒸鱼

C. 红烧鱼

D. 水煮鱼

Sentence 2: 雪琴和季升天天加班闷坏了，所以周末雪琴出去散心了。

Question 2: 周末谁去散心了？

A. 季升

B. 雪琴

C. 小红

D. 小王

Sentence 3: 伟朋和安如要参加上司的婚礼，晚上伟朋准备了贺礼。

Question 3: 伟朋和安如参加谁的婚礼？

A. 朋友

B. 同学

C. 上司

D. 亲戚

Sentence4: 明辉和美平要出差，所以昨天明辉订了车票。

Question4: 明辉订了什么票？

A. 机票

B. 车票

C. 火车票

D. 轮船票

Sentence5: 静芬和富元在学游泳，最近只有静芬不去打球。

Question5: 静芬和富元在学什么？

A. 唱歌

B. 跳舞

C. 跑步

D. 游泳

Sentence6：家锐和丽纯在学下棋，最近家锐常来棋牌室玩。

Question 6：最近家锐常去哪里玩？

A. 棋牌室

B. 录音棚

C. 游泳馆

D. 球馆

Sentence7: 艺芳和晓枫喜欢花花草草，所以考大学时艺芳报了园艺系。

Question7: 艺芳大学报考了什么专业？

A. 园艺系

B. 建筑系

C. 中文系

D. 外语系

Sentence8: 巧盈和伯兴讲得一口标准普通话，所以开学后巧盈加入了广播社。

Question8: 巧盈开学后加入什么社团？

A. 舞蹈社

B. 广播社

C. 话剧社

D. 体育社

Sentence9: 晓策和宝妍要参加游泳比赛，今天晓策去买了泳衣。

Question9: 晓策今天买了什么衣服？

A. 运动装

B. 睡衣

C. 泳衣

D. 毛衣

Sentence10: 碟香和守义喜欢喝茶，昨天碟香买了一包茶叶。

Question10: 昨天碟香买了什么东西？

A. 一包花茶

B. 一包花生

C. 一包瓜子

D. 一包茶叶

Sentence11: 香岚和毅松想当服装设计师，今年只有香岚开始学服装设计。

Question11: 今年香岚开始学习什么？

A. 服装设计

B. 广告设计

C. 室内设计

D. 园艺设计

Sentence12: 熙默和琼芳没有多少积蓄，失业后只有熙默感到压力。

Question12: 熙默失业后感受到什么？

A. 开心

B. 沮丧

C. 压力

D. 欢喜

Sentence13: 秀莹和仁丰想从图书馆借书，最近秀莹办了借书证？

Question : 秀莹最近办了什么证？

A. 暂住证

B. 身份证

C. 借书证

D. 离婚证

Sentence14: 安琪和德超晚上加班没时间出来吃饭，后来只有安琪叫了外卖。

Question14: 后来安琪叫了什么？

A. 外卖

B. 水果

C. 炒饭

D. 牛肉

Sentence15: 明涛和素芹快付不起房租了，这几天明涛申请了房租补贴。

Question15: 这几天明涛申请了什么补贴？

A. 买房补贴

B. 买车补贴

C. 房租补贴

D. 助学补贴

Sentence16: 贤亮和香虹喜欢上海，毕业后只有贤亮留在了上海。

Question16: 毕业后贤亮留在哪个城市？

A. 广州

B. 上海

C. 北京

D. 福州

Sentence17: 浩波和美菱搬到西郊了，所以这一阵浩波常去西郊公园散步。

Question17 : 最近浩波经常去哪里散步？

A. 东郊公园

B. 西湖公园

C. 西郊公园

D. 南郊公园

Sentence18: 曼洁和以轩想了解行业最新动态，昨天曼洁去听了那个报告。

Question18 : 昨天曼洁去听了什么？

A. 报告

B. 音乐会

C. 答辩

D. 发布会

Sentence19: 文帆和冬娜通过了考试，所以晚上文帆去喝酒庆祝了。

Question19: 晚上文帆去干嘛了？

A. 唱歌

B. 跳广场舞

C. 划船

D. 喝酒庆祝

Sentence20: 丽莎和博晖没学过编剧，刚开始丽莎干的很吃力。

Question20: 刚开始丽莎觉得干什么很吃力?

A. 编舞

B. 编程

C. 编剧

D. 写作

Appendix D. Institutional Review Board Approval

irb@southalabama.edu

UNIVERSITY OF SOUTH ALABAMA

TELEPHONE: (251) 460-6308
AD 240 · MOBILE, AL. 36688-0002

INSTITUTIONAL REVIEW BOARD
May 1, 2023

Principal Investigator:	XIAOBIN WANG		
IRB # and Title:	IRB PROTOCOL: 23-117 [2038518-2] Characterizing eye movements during reading in Chinese persons with aphasia		
Status:	APPROVED	Review Type:	Full Committee Review
Approval Date:	April 26, 2023	Submission Type:	New Project
Initial Approval:	April 26, 2023	Next Report Due:	April 26, 2024
Review Category:	Category: 45 CFR 46.110 (4): Collection of data through noninvasive procedures (not involving general anesthesia or sedation)		

This panel, operating under the authority of the DHHS Office for Human Research and Protection, assurance number FWA 00001602, and IRB #00000286 or #00011574, has reviewed the submitted materials for the following:

1. *Protection of the rights and the welfare of human subjects involved.*
2. *The methods used to secure and the appropriateness of informed consent.*
3. *The risk and potential benefits to the subject.*

The regulations require that the investigator not initiate any changes in the research without prior IRB approval, except where necessary to eliminate immediate hazards to the human subjects, and that **all problems involving risks and adverse events be reported to the IRB immediately!**

Subsequent supporting documents that have been approved will be stamped with an IRB approval and expiration date (if applicable) on every page. Copies of the supporting documents must be utilized with the current IRB approval stamp unless consent has been waived.

Notes:

EBR full board review was conducted and has determined that this study is minimal risk:

45 CFR 46.110 (4): Collection of data through noninvasive procedures (not involving general anesthesia or sedation)

Institutional Review Board

Approval Number	2023KY-008-02		
Project Title	Characterizing Eye Movements During Reading and Reading Comprehension in Chinese Persons with Aphasia		
Project Source	Research project of Rehabilitation Technology Collaborative Innovation Center		
Research Unit	Rehabilitation Hospital Affiliated to Fujian University of Traditional Chinese Medicine		
Principal Investigators	Wang Xiaobin		
Review Type	Recheck	Review Method	Rapid Review
Review Date	March 33, 2023	Review Location	Rehabilitation Hospital Affiliated to Fujian University of Traditional Chinese Medicine
Committee Members	Xin Wang, Liyu Xie, Jianping Xiao, Songqing Wei, Shangwang Yang, Weihong Zhong, Sai'e Huang, Xiaowen Lian, Di Zhang		
Approval Documents	Clinical Study Protocol Version No: 2.0 Date: March 33, 2023 Informed Consent Version No: 2.0 Date: March 33, 2023 Subjects Recruitment Revelation Version No: 2.0 Date: March 33, 2023		

Review Opinions

According to the National Health Commission "Measures for the Ethical Review of Life Science and Medical Research Involving Human", the National Traditional Chinese Medicine Administration of Traditional Chinese Medicine Clinical Research Ethical Review management Code ", State Food and Drug Administration "Drug Clinical trial quality management code" and "Medical device clinical trial quality management code", World Medical Association "Helsinki Official Words", international According to the ethical principles of the International Ethical Guidelines for Human Biomedical Research of the Medical Science Organization Committee, the Ethics Committee agreed to carry out this study according to the approved clinical study protocol, informed consent and recruitment materials. Please conduct clinical studies in accordance with the principles of GCP and the protocols approved by the Ethics Committee to protect the health and rights of the subjects. Applicants are requested to complete clinical trial registration prior to study commencement. If the principal investigator is changed during the study, any changes to the clinical study protocol, informed consent, recruitment materials, etc., the applicant is requested to submit an amendment vehicle review application. In case of serious adverse events, the applicant is requested to submit the serious adverse event report in time. Please submit the progress report one month before the deadline in accordance with the annual/periodic follow-up review frequency set by the Ethics Committee; The sponsor shall submit a summary report of the research progress of each center to the Ethics Committee of the Group leader: The applicant shall submit a written report to the Ethics Committee in a timely manner in case of any situation which may significantly affect the conduct of the study or increase the risk of subjects. Subjects who did not meet the inclusion or exclusion criteria were enrolled in the study; subjects who did not withdraw from the study when the trial was discontinued; the wrong treatment or dose was given; combinations of drugs prohibited by the protocol were given; Or may cause adverse effects on subjects' rights/health, as well as the scientific nature of the study and other circumstances contrary to the principles of GCP, the sponsor/supervisor/researcher is requested to submit the violation plan report. If the applicant suspends or prematurely terminates the clinical study, please submit the study suspension/termination report in time. To complete a clinical study, the applicant is requested to submit a study completion report.

Annual/periodic follow-up review frequency	To submit a progress report one month before March 22, 2024
Validity period	12 Months
Contact person and contact number	Zufen Guan 0591-88529126
Signature of the Chairman/Vice Chairman	[signature]
Institutional review board	IRB of Rehabilitation Hospital Affiliated to Fujian University of Traditional Chinese Medicine (stamp)
Date	March 22, 2023

伦理委员会

Appendix E. Tests of Normality

Table 11. Tests of Normality

		Shapiro-Wilk		
	Group	Statistic	df	Sig.
Regular word reading	Control	.502	22	<.001
	Aphasia	.902	21	.039
Irregular word reading	Control	.724	22	<.001
	Aphasia	.958	21	.481
Pseudo word reading	Control	.659	22	<.001
	Aphasia	.953	21	.385
Total duration fixation	Control	.861	22	.005
	Aphasia	.952	21	.371
Average fixation duration	Control	.959	22	.479
	Aphasia	,970	21	.732
Number fixations	Control	.842	22	.002
	Aphasia	.977	21	.878
Time to first fixation	Control	.851	22	.004
	Aphasia	.913	21	.063
Duration of first fixation	Control	.953	22	.355
	Aphasia	.941	21	.233
Number of saccades	Control	.889	22	.018
	Aphasia	.953	21	.386
Average saccade amplitude	Control	.949	22	.297
	Aphasia	.938	21	.196
Total saccade amplitude	Control	.970	22	.717
	Aphasia	.895	21	.029
Time to first saccade	Control	.724	22	<.001
	Aphasia	.595	21	<.001
First saccade amplitude	Control	.919	22	.071
	Aphasia	.942	21	.242
Reading comprehension	Control	.523	22	<.001
	Aphasia	.831	21	.002
Reading comprehension of eye movement	Control	.221	22	<.001
	Aphasia	.898	21	.032

BIOGRAPHICAL SKETCH

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Duquesne University, Pittsburg, Pennsylvania
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Doctor of Philosophy in Communication Sciences and Disorders, 2023, Mobile, Alabama
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Zhou H., Wang X., Hu J., Weng M., & Chen J. (2021). Bibliometric analysis of Peplau interpersonal relationship theory in domestic nursing field. *Chinese Journal of Contemporary Medicine, 28*(9), 178-181. [Chinese]